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RICE: BIOLOGICAL PRINCIPLES OF BREEDING AND FARMING PRACTICES

Monograph

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RICE: BIOLOGICAL PRINCIPLES OF BREEDING AND FARMING PRACTICES

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The monograph examines the morphological features and biological traits of rice to be considered during breeding of new rice varieties and development of farming practices to obtain maximum yield with excellent quality of grain. The monograph contains description of rice varieties for different growing conditions.

The book is intended for researchers and professionals involved in rice breeding and growing, as well as for post graduates and students of Agronomy.

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DEDICATED

To 90th anniversary of Department of Genetics, Plant Breeding and Seed Production, Kuban State Agrarian University

INTRODUCTION

Among the huge diversity of crops the most common food plabnts are wheat and rice.

Rice is a wonderful plant, the oldest cultural crop in the world. As the herb producing valuable grain, rice is known for more than 10 thousand years. The name of genus *Oryza* comes from the Chinese word meaning "good grain for food, benefactor of the human race" [79].

Indeed, rice is the staple food for more than half of the population in the world. For the other half of it rice is a valuable dietary product. In Tokyo, there is a monument in homage to rice as a staple food of the population. The Japanese hieroglyph describing it is present in the brand name “Toyota” and means "fertile rice field." In several Asian countries, there is a custom to eat a rice cake during holidays as a symbol of longevity, happiness and wealth. In the oriental kitchen salt and spices are almost never added to rice and strong smelling spices are used reluctantly not to drown out its natural flavor.

Formed in a monsoon climate, this plant is widely spread throughout the world, due to its exclusively high ecological plasticity. The world main rice fields are located on plots of flat land, but it is also cultivated on slopes up to 2 600 meters above the sea level, as well as in the valleys flooded with rain water layer of 6–7 m [20].

Scientists isolate 20 species of the genus *Oryza* L. Many them are wild forms with colored grain pericarp varying from yellow to black. Two white grain species are widely cultivated: *Oryza sativa* L. is grown in all rice-growing country, and *Oryza glaberrima* Steud is cultivated only in Africa.

Despite the long history of rice cultivation, there is still no consensus about its origin. Thus, D. Grist [20] based on an analysis of published data has suggested that rice comes from mainland

Southeast Asia. From there it spread to the north of Asia as well as to the south and east through the Malay Archipelago. N.I. Vavilov [14] wrote that India, including the Ganges valley, the entire Hindustan peninsular and the adjacent part of the Indo-China and Siam (now Tailand) should be considered the birthplace of rice. Here you can meet both the wild forms, contaminating crops, and vast cultural diversity of varieties of primitive plants. G.G. Gushchin [19] narrows the area of the possible center of rice origin to the south-eastern slopes and foothills of the Himalayas. From its center of orgin – India – rice spread to the east, to China and Japan, and to the west, Persia and Mesopotamia.

Dao Tkhe Tuan [23] is of different opinion. He writes that rice is a very ancient crop of the Asian continent cultivated from the III millennium B.C. There are three centers of rice origin: South China (3000 years B.C.), India (2000 years B.C.) and Indo-China (1000 years B.C.). The relationship between these centers is not exactly established, wheather they are independent or derived from each other is the subject of botanists' research. From India rice spread to the west and north, from China and Indo-China it moved to the east and south [23].

Academician P. M. Zhukovsky [28] confirmed that the tropical countries in South-East Asia were the origin of the main species of cultivated rice *Oryza sativa* L. At the same time, he noted that for the other cultivated species, *Oryza glaberrima* Steud, the introduction center of the crop is tropical Africa.

Rice has a rather wide range of response to climatic and soil conditions, while its geographical origin has no effect on this trait. Currently rice is grown in 114 countries between 49° North of Greenwich and 35° South of Greenwich over the area of 155 million hectares. The largest rice producers are India and China. Together, they produce 62 % of Asian rice and 57 % of the world rice.

There are thousands of different varieties of rice in the world. In the rice paddies of Asia its own brand is grown in every field. It is a known fact that 65 % of all grown rice is consumed within 500 meters from the place of its growth.

For the most of the world's population (China, India, Japan, Indonesia, and other countries) and especially for the inhabitants of the tropical countries, rice is the main food, as wheat is the staple food for the population of the countries with a temperate climate. This is explained primarily by the fact that rice is the plant of monsoon climate, and by its nature it is most suited for growing under profuse precipitation. Other cereals cannot bear such conditions. Besides rice decoction known as medicine since a long time is the best way to treat stomach diseases common in these countries.

Artistic rice planting is developed in Japan. The plants used for that have different colors of leaves and panicles (Figure 1).

For the Russians rice is also a valuable food, dietary and medicinal product [49]. Its share of the volume of the consumed cereals exceeds 40 %. Since the main production of rice in Russia, about 80 % of it, is concentrated in the Krasnodar Territory (or the Kuban Region as this part of Russia is called traditionally after the river Kuban), the local rice growers determine the success of the industry in the country. In 2015, out of 1 220 000 t of paddy rice produced in the Russian Federation, the contribution of the Krasnodar Territory was 945 000 t. The yield of rice in the region reached 7.04 t/ha due to the introduction of new high yielding varieties and improvement of their agricultural practices including coharvesting with modern rotary combines. The efforts of breeders and practicing specialists are directed at breeding rice varieties meeting the requirements of the current level of the rice production.

Figure 1 – Artistic rice plantings in Japan

The author expresses his sincere gratitude to M.I. Chebotarev, Head of Department of Machines Repair and Materials, Dr. Sci. (Tech.), Professor, for support with Section 4.2 "Mechanized Rice Growing and Harvesting Practices in Russia".

The photos used in the book as illustrations were taken by the author while visiting rice growing zones in Russia and abroad.

CHAPTER 1

Rice as a Leading Crop of the World Agriculture

Rice grows in different soil-climatic zones with different water supply. Its plant has a special pneumatic tissue – aerenchyma whereby the roots are supplied with oxygen in the waterlogged conditions. This makes rice fundamentally different from other cereals. It is grown in the humid tropics and in the semi-arid areas with a moderately warm climate, on heavy clay and poor sandy soils. Rice can grow on dry fields and flooded areas, in both fresh and salt water. Its broad adaptability is explained by the existence of a huge number of varieties. For example, in India there are more than 5 000 registered cultivated varieties of this crop. The International Institute of Rice (IRRI), the Philippines, established a collection of varieties, shapes and types of rice including more than 100 000 specimens. One can choose the right rice variety practically for any conditions, in the presence of enough heat, sunlight and water. Rice has emerged as a crop in the zone of monsoon climate so it is an ideal plant for tropical conditions [98]. Other crops can not tolerate long-term excessive soil moisture or flooding, heavy rains and fungal diseases related to plants.

Due to its wide ecological plasticity rice grows everywhere from the equator to the temperate climatic zones (Figure 2).

Dozens of thousands of varieties of rice are grown in specially constructed irrigation systems. In different countries, they are located not only on the plains, but also on the hilly fields and even in the highlands.

Thus, any system is effective if it provides two conditions necessary for normal growth and development of the rice plant – the optimal temperature and enough water during growing season.

There are two methods of rice cultivation that are used in the world: seedling and sowing. In case of latter rice seeds are sown on water or dry land [57].

a b c d

Figure 2 – Rice fields:

a – terraces in the Philippines; b – in China;
c – water flooded rice fields in Russia;
d – rice harvesting in Russia

Seedling method is used in Asia, partly in Africa and South America (i.e. in the densely-populated countries). Rice seedlings are grown on special beds, often under a film, for 60 days. During this period the field intended for planting rice is used for other crops. 3–5 days before transplanting the seedlings the rice fields are flooded with a layer of water and soil tilling with rippers is started. In most Asian countries animals are used as drawing power (Figure 3 a). After ploughing of the upper soil layer the field is filled with water (up to 10 cm) and leveling the soil surface begins (Figure 3 b). In this case the water serves as a leveling tool.

a b

Figure 3 – Soil preparation for rice planting in India:

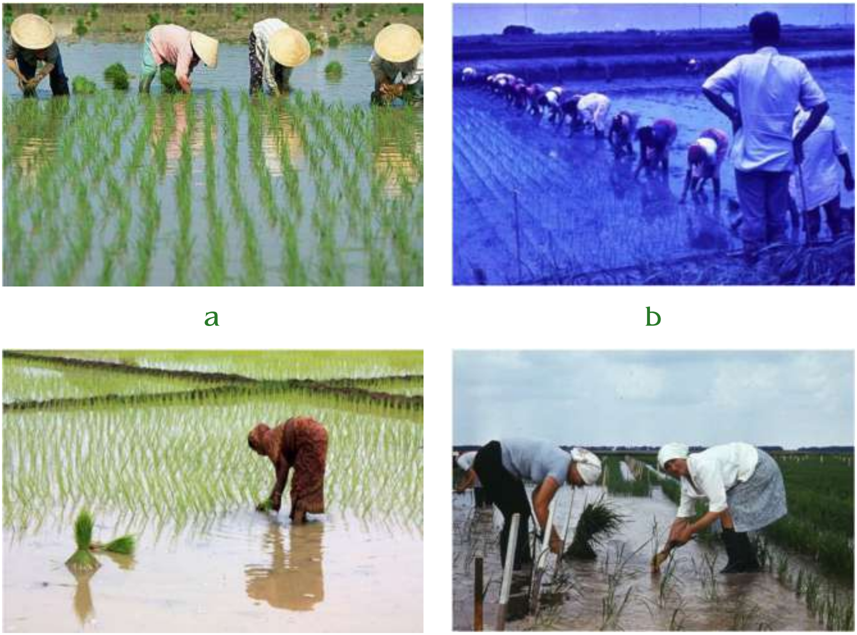
a – use of animals; b – levelling of the flooded field surface

Seedlings are planted mannually pressing the tillering node with roots into soft soil. In Vietnam, India and China and other Asian countries transplanting rice is done by women, with high speed and quality (Figure 4 a, b, c). Meanwhile men bring the seedlings to the field.

Planting rice seedlings is sometimes practiced by the Russian breeders in reproduction of the first generation of hybrids to improve seed multiplication factor. Thus, rice plants were grown till the tillering phase in vessels, and then they are transplanted in the field. If necessary, they are cloned by separating the side shoots from the main one and planted separately (Figure 4 d).

Nitrogen fertilizers stimulating further tillering of the rice plants are applied after planting.

Weeds in the rice fields of Asia are removed manually and used to feed animals or fish in ponds which are in almost every yard. The only exception among Asian countries is Japan where all kinds of agricultural works in the rice fields are mechanized – from tillage and transplanting, weed, pests and diseases control, to harvest. A special set of machinery is designed and used there for rice cultivation: rotary mechanisms for tillage on water, transplanters (Figure 5), high-performance sprayers, combine harvesters with stripper thresher and straw shredder.



a b

c d

Figure 4 – Planting of rice seedlings:

a – in Vietnam; b – in India; c – in the Phillippines (crop); d – in Russia (breeding)

Figure 5 – Rice seedling planting machine in Japan

Rice sowing method is adopted in the temperate zone (Australia, the USA, coutries of Europe and the former Soviet Union). The engineering systems built here consider the use of machines for growing rice and other crops in rotation. In these countries, the soil tillage and leveling are done on dry land. There are differences in farmimg practices. For example, in Australia and the United States fertilizer and granular herbicides are applied after leveling and then the rice fields are flooded with a minimal layer of water. Sowing is done from a special mini aircraft.

In Europe and in Russia rice is sown into a dry soil (Figure 6) with a minimum seed covering (1 cm) or randomly (with a special rotary drill) followed by flooding.

Herbicides are applied on the soil before flooding or on growing plants (depending on the accepted practice). In the European countries, herbicides are applied only by tractor-mounted sprayers with special narrow tires. In Russia, for this purpose the ground equipment (Figure 7 a) is also used, especially in the buffer zones, but more often it is done by agricultural aviation, i.e. specialized aircrafts or helicopters (Figure 7 b).

The negative aspect of the air treatment is herbicides or fungicides spreading over all parts of the rice engineering system including canals, roads and the surrounding territories. Such treatment often leads to increased environmental stress in rice growing area.

a b

Figure 6 – Rice sowing:

a – in Russia; b – in France

a

b

Figure 7 – Ground (a) and aerial (b) treatment of rice fields

The most important condition for any practice is the leveling of the surface of the rice fields so that all rice plants are in the same condition. In the industrially developed countries special machines with lazer device are used for leveling (alignment) (Figure 8 a).

Such machines are purchased also by the rice farm of the Krasnodar Territory. So, the farm "KubanAgroPriazovye" uses 8 Italian leveling complexes "Mara" (Figure 8 b). One of these machines during season can treat up to 300 ha.

After the leveling the rice fields are flooded with minimal layer of water (Figure 9).

a

b

Figure 8 – Special tools and machines used for rice fields leveling: lazer (a), leveling complex "Mara" (b)

Figure 9 – Control flooding after leveling
("KubanAgroPriazovye", 2011)

Thus, on the one hand, water is used to check quality of leveling and on the other it provides soil moisture. This provokes a massive sprouting of red-grain rice and other gramineous weeds that are destroyed by subsequent soil tillage.

1.1 The Role of the Rice Crop

Rice is consumed in almost all countries. For the people of Asia, Africa and Latin America it is the staple food. The volume of rice consumption differs significantly depending on the traditions of the country. Thus, in most countries in South-East Asia annual per capita consumption of rice is about 100 kg, in China, Japan, Vietnam, Thailand, Indonesia it is more than 100 kg, and in Laos and Myanmar – more than 200 kg. In other countries, it is much lower: in Latin America – 50–80 kg, Africa – 40–70, in EU countries – about 6 kg (medical standards) and in Russia – 4.5–5 kg [80].

The leading rice-producing countries of the world are China and India. They provide more than 56 % of the world production of rice. The population of these two countries as well as of other Asian countries, on average receives 35 % or more of total calories by rice, and in Thailand – 66 %, Bangladesh – 69 %, Myanmar – 73 % (Table 1).

One of the most important indicators of the nutritional value of food is their calorie content. Rice grain is a high calory, easily digestible product. This is confirmed by research of G.V. Nalivko and T.D. Titarenko [83] who studied these indices for the Russian-bred rice varieties. They note that the rice grain whitening or polishing while increasing the digestibility of rice, considerably reduces its nutritional value. The straight run possesses the highest calorific values (4 672 cal/g), followed by hulled grain (3 995), during cooking the groats calorific values slightly decrease (3 725). The calorific value of raw rice is 3 964 cal/g.

Table 1 – Rice consumption in some countries in 1987–1988 [132]

Country	Rice annual per capita consumption, kg	Total per capita number of calories	Share of rice derived calories in total ration, %
Myanmar	186	2518	73
Thailand	164	2440	66
Bangladesh	130	1859	69
Indonesia	146	2504	57
China	114	2564	35
Philippines	92	2313	38
Japan	81	2804	28
India	77	2161	35
Brasil	51	2629	19
Egypt	32	3262	10
Pakistan	21	2186	9
Nigeria	11	2061	5
USA	9	3652	2
USSR	6	3403	2
World, total	64	2666	24

Milled rice is of high nutritional value and pleasant taste. It occupies a leading position among the other cereals according to its assimilability (96 %) and digestibility (98 %) and, therefore, it is widely used as a dietary product indispensable for medical and infant nutrition [9].

The chemical composition of the grain varies depending on the rice variety, soil and climatic growing conditions as well as the conditions of nutrients supply. Rice grain is characterized by a high starch content (72.1–80.4 %), relatively low conteent of protein (6.9–10.4 %) and fats (1.6–3.3 %). Moreover, rice grain contains 4.6–6.9 % ash, and from 8.7 to 12.2 % fiber on a dry basis. Starch grains having a complex structure fill the central part of the kernel. They are located inside the protein matrix of endosperm.

Starch carbohydrates consist of two polysaccharides that differ in their physical and chemical properties: amylose (15–25 %) and amylopectin (75–85 %) [107], their ratio determines many properties of cooked rice: the higher is the amylose content, the more water is absorbed by starch grains. They increase in volume and do not disintergrate. The milled rice produced from rice varieties with low amylose content has low culinary properties [114].

Despite the low protein content in the rice grain, its nutritional value is much higher compared to other cereals. The rice protein is easily assimilated by the humans (98 %), and contains all essential amino acids, their amount in rice is higher than in other main bread cereals – wheat and rye (Table 2).

Table 2 – Amino acids in ptotein of rice, wheat and rye, % [4]

Amino acid	Polished rice	Durum wheat spring	Rye
Tryptophane *	1,08	1,24	1,13
Threonine *	3,92	2,88	3,70
Isoleucine *	4,69	4,34	4,26
Leucine *	8,61	6,71	6,72
Lysine *	3,95	2,82	4,08
Methionine *	1,80	1,21	1,58
Cystine	1,36	2,19	1,99
Phenylalanine *	5,03	4,94	4,72
Tyrosine	4,57	3,74	3,22
Valine *	6,99	4,63	5,21
Arginine *	5,76	4,79	4,78

Amino acid	Polished rice	Durum wheat spring	Rye
Histidine *	1,68	2,04	2,28
Alanine	3,56	3,50	–
Asparagine	4,72	5,46	–
Glutaminic acid	13,69	31,25	21,26
Glycine	6,84	6,11	–
Proline	4,84	10,44	–
Serine	5,08	4,61	4,13
Crude protein, %	7,5	14,0	12,1
* Essential amino acid.			

Along with carbohydrates and proteins the bulk of the grain organic matter is formed by lipids (fats), their content in rice grain varies from 1.6 to 3.3 %. Most of them are concentrated in the germ and aleurone layer.

The lipid composition of rice includes saturated fatty acids (21.2 %), their main component is palmic acid, and unsaturated fatty acids with oleic (37.8 %), linoleic (40.7 %) and linolenic (0,3 %) acids.

Rice kernel is also rich in vitamins. Almost all water-soluble *B*-group vitamins are found in it. However, in the grain, they are distributed unevenly. Thus, about 47 % of the total amount of thiamine (vitamin *B1*) is concentrated in embryo, 34.5 % – in the pericarp and the aleurone layer and only 8 % – in the endosperm. Among cereals the content of pyridoxine (vitamin *B6*) is the highest in rice (6.6 %). Niacin (vitamin *PP*) is mainly found in the rice pericarp and aleurone layer (82 %) and only 15 % – in the endosperm. The tocopherols (fat-soluble vitamin *E*) has been identified in rice oil [107].

Insufficient amounts of thiamine, niacin, riboflavin, folic and ascorbic acids significantly affect human health and it is an urgent issue in many countries. Even in the developed countries the partial lack of these vitamins is relatively common [73]. Therefore, in regions where rice is the staple food, unpolished rice grain is used.

In most countries, a variety of rice products is consumed: whole hulled grain, white rice, polished rice, brokens, immature grains, paddy rice, sprouted grains, jelly, flour, starch, bread, molasses, alcohol, oil, vitamin products and ash [110].

Rice grain is characterized by high calorie content: 100 g of it contain 350 calories (for comparison, the same amount of wheat gives 330 calories, corn – 348, sorghum – 332).

The rice grain contains 7–15 % protein (depending on the variety) with a high content of essential amino acids – lysine, valine, and methionine.

Peoples of the world cook a lot of various dishes using milled rice. About 5 000 recipes of various rice dishes are collected in the book "Dietetics of Rice" [117], there are more than 300 pilaf recipes alone in it.

Rice used as dietary and medicianl product for treatment of gastric diseases, high blood pressure, allergies, cardiovascular diseases.

It is known that rice decoction since a long time is used as a remedy for gastric diseases (many of us from childhood remember it as the first remedy for intestinal disorder). Milled rice is characterized by good cooking properties. Boiled rice does not spoil if cooked in pure water without additives even in the tropics.

Rice is widely used not only as a food product but also for other purposes. Bran covering, aleurone layer and germ of the rice grains are used to produce phytin, vitamins of *B* group and other pharmaceuticals. Oil for soap making and candle production is extracted from rice germ. Rice brokens are used for production of canned food, alcohol, special varieties of vodka and beer. Rice starch is also obtained from rice brokens, its output is 85–95 %. It is used for the preparation of rice powder, as well as in medicine and in the industrial perfumery.

Nutritionally rice bran is the best fodder. It contains 10–13,7 % protein and 14 % fats. Bran is characterized by high content of phosphorus compounds, among which organophosphorus substances are of value – phytin, lecithin and others, it is essential for young aninals and poultry.

Furthermore, rice bran is rich in vitamins and fats which are extracted to produce high quality edible oil. It has a high content of unsaturated fatty acids and has valuable therapeutic properties, particularly for treatment of heart diseases. Rice bran oil enjoys high demand in Japan, India and other Asian countries.

Technical rice oil due to its corrosion-resistant properties is used for the preparation of mineral paints used for coating of the ship metal hulls. The output of bran oil is above 10 %.

Rice grain is also processed into flour. It can not compete with wheat baking flour, as it contains no gluten, and hence may not retain the gases formed during the preparation of bread. Rice flour is used in production of food for infants, as well as breakfast for adults and as an additive to meat products [111]. In Russia, milled rice is often used to cook gruel, the Caucasus and Central Asia pilaf is the national dish of rice, in Europe – puddings, in the countries of Southeast Asia rice is used to cook curry, the most common dish there.

Husks (grains coating flakes) contain about 20 % silica. This is an excellent raw material to obtain silica which is used in the production of solar batteries and in metallurgy to produce special grades of steel.

Rice straw is a good fodder for livestock, especially when silage is mixed with the green mass of alfalfa or peas. The higher grades of paper, paperboard, durable and cheap cordage, ropes and bags, as well as a variety of woven products are produced from rice straw. Among the latter are hats, floor mats, bags, house shoes, souvenirs, etc. It contains 50 % cellulose, 20 % pentosans, 11.7 % lignin, 14.6 % minerals (mainly silicon).

Straw is an excellent substrate for the cultivation of mushrooms. It is used as an organic fertilizer and fuel for cooking.

Figuratively speaking, the rice plant does not only feed and heal humans but also warms them. [49]

1.2 Rice as Wholesome and Dietary Product

As already noted, the milled rice occupies one of the highest places among other kinds of cereals due to its caloric content and digestibility [73].

It is known that when treating crops to control diseases, pests and weeds, the chemicals get on leaves and stems. Penetrating inside the plant, pesticides are included into the plant's metabolism and eventually accumulate in the storage organs (potato tuber, sugar beet roots and grains of cereals).

Concurrently as shown by tests the caryopsis accumulates the chemicals that enter the embryo via conducting vessels and remain there, since scutellum prevents them from getting into endosperm (Figure 10) [121]. Outside the caryopsis is covered with two bran coatings (layers) – fruit and seed coats (2). The aleurone layer is located under the coatings. The entire kernel cavity is filled with grains starch parenchyma (4), in its lower part there is the embryo (3) separated from the endosperm by the coating (5).

The scutellum is a layer of special cells acting as a biological filter that allows the pass of only the molecules inherent in this organism. To illustrate it we can give a medical example. There are cases when women affected by leprosy give birth to healthy children. The doctors explain this phenomenon by the role of the placenta that serves as a biological filter. The same function in the rice caryopsis is performed by the scutellum impermeable to chemicals since their molecules are different from those of the rice plants and thus the endosperm is protected.

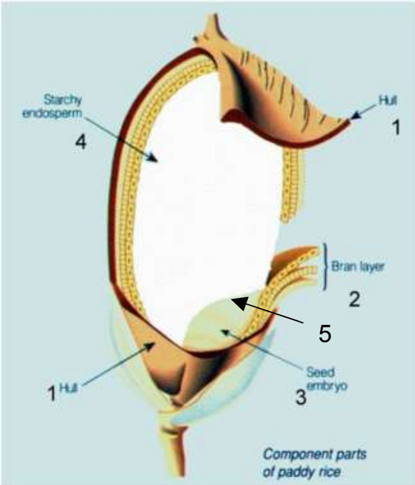


Figure 10 – Rice grain structure [121]:

1 – hull;
2 – bran layer;
3 – embryo;
4 – endosperm;
5 – scultellum

To get marketable milled rice the grain husks are removed by special machines. Then clean grain is subjected to whitening and polishing. Thus, milled rice obtains market condition.

However, during polishing the embryos and aleiron layer containing proteins, fats and vitamins are lost thus depleting the chemical composition of cereals. But removing the embryos to waste, all chemicals used for growing rice and possibly absorbed by the grain are also removed. Thus, after polishing milled rice becomes clean. It has repeatedly been confirmed by specific chemical analyses.

It should be noted that rice producers are forced to polish rice since rice grain can be stored for a long time only as unhusked grain or polished milled rice. This is proven by archaeological findings of paddy rice in buried vessels preserved for hundreds and thousands of years.

Polished rice grain is stored in bags in dry storage for 3–5 years or longer (if the storage pests do not settle). But after dehusking the grain begins to deteriorate (fats oxidize and go rancid) within 5–7 days, especially under high humidity and temperature. So, farmers growing rice for their own consumption (especially in Asia), get paddy rice dry after the harvest and store it under cover in special well ventilated wicker containers [49]. As required the amount of grain for up to 2–3 days' consumption is hulled (no polishing) and different dishes are cooked. In this case, wholesome grain rich in protein, fats and vitamins is used for food. Surplus grain is sold to processing plants to produce polished milled rice and then to be delivered to shops.

In recent years, the choice of rice varieties in Russian stores has become very wide. Along with rice of local production many types of imported rice are offered in beautiful packaging. It should be noted that rice from abroad is brought to Russia in bags, but here it is put into smaller packages. Imported rice does not arrive to our country immediately after harvesting. To protect grain against various pests, especially in tropical countries, the rice bags are treated with fumigants that are potent poisons both in warehouses and during transportation in the holds of ships. Thus, contamination of rice grain during fumigation is quite possible since it is a strong absorbent. N.G. Tumanyan [111] writes that large shipments of rice received during the period of 2001–2007 from Vietnam, India and Thailand were rejected by the border quarantine inspection in connection with the milled rice contamination with pesticides, their level being 2–3 times higher than the permissible limits. For this reason, the imported rice is not recommended for use as a therapeutic product in Russia.

Domestic rice grain does not require fumigation because its way from processing to retail shelves is short. It can be used for any diet, and for medical purposes. The drawback of Russian rice grain is that it is an average blend of several varieties. But for each variety of rice the scientists of the ARRRI and other research institutes develop and recommend not only the elements of farming, but also the parameters of technological processing of grain to milled rice, as well as the recipes of culinary use. However, the grain of different rice varieties in the rice mills in most cases is poured into one intake pit. Thus, the varieties are depersonalized, and the produced milled rice has the common trade name "Rice of Kuban". It is known that breeding of a new variety takes 12–15 years, sometimes longer (for example rice variety Snezhinka took 23 years to be bred and it is 24 years for Kumir). Thus, each variety has been attributed its own specific characteristics. In such a way depersonalization of varieties neutralises the results of the breeders.

To solve this problem, in 2008 the Administration of the Krasnodar Territory decided to move to rice procurement based on the variety principle. However, its implementation revealed serious difficulties. The fact that the elevators accepting rice in storage and processing were built in the Soviets period when local rice farmers grew 1–2 varieties. In this regard, only 3–4 rice reception points were provided. For comparison, in Italy rice mills have 15–17 reception points, so each rice variety is received and processed separately.

Nowadays in Russia some steps are taken to reconstruct the rice mill, after that rice grain will be received and processed according to variety. In addition, in 2011 the company "Agro-Alliance" (St. Petersburg) established in Abinsky region of Krasnodar Teeritory a rice processing plant of new generation. Its capacities allow receiving processinf and packaging up to 20 different types of rice varieties, including exclusive (glutinous and with colored pericarp).

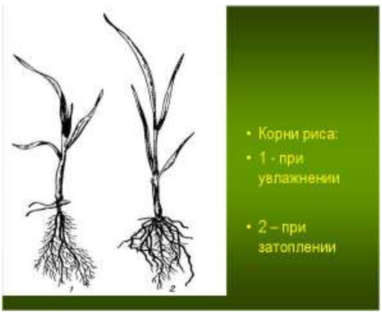
The scientists of the ARRRI organized the first rice tasting of 13 samples of rice gruel cooked from grains of different varieties. The event was attended by the representative of the Legislative Assembly of the Krasnodar Territory, the Department of Agriculture and Processing Industry, the Department of Consumer Services and Regulation of the Alcohol Market, association “Rice Farmers of Kuban”, processing plants, rice-growing farms, trade and restaurant business (all in all 60 participants). They had a possibility to make sure that rice varieties vary considerably in taste and therefore can be used for preparing various dishes. A detailed report on this event can be read in the magazine "Rice Breeding" [112].

At present more than 30 different types of rice varieties generated by the plant breeders of the Krasnodar Territory have been accepted into the State Register of Breeding Achievements approved for use in the Russian Federation [67, 68]. It should be noted that in Russia the cultivated rice varieties are only of domestic breeding, among them there are varieties with low- and average amylose contect; short, medium and long grain varieties. There are also varieties with special qualities (the so-called exclusive) – Snezhinka, Viola, Violetta and Vita. They differ significantly from the other cultivated rice varieties by their grain quality and therefore recommended for dietary and nutritional therapy [42, 45, 52, 62].

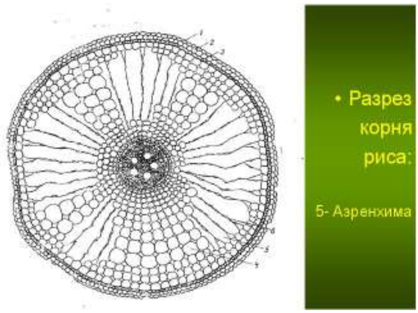
1.3 Morphological Features of the Rice Plant

The cultivated rice, *Oryza sativa* L., is an annual grass plant belonging to the Poaceae family.

During germination of rice grains the main seminal root is formed and after the appearance of the green leaf the adventitious roots of the primary root system develop. During tillering the secondary roots appear forming a fibrous root system. If the plants are grown under wetting conditions without water layer, their roots are covered, as in upland cereals, with root hairs (Figure 11 a).



a



b

Figure 11 – Development of rice root system under different conditions (a): Rice roots: 1) under wetting, 2) under flooding ; rice root aerenchyma (b) [98]

The roots of the rice grown in the water layer have hairs and form of an aeration tissue – aerenchyma (Figure 11 b) which is a conductor of oxygen from the aerial organs to soil. This allows the plant to develop properly under flooding. The bulk of the roots (mat roots) is in the soil layer of 5–15 cm, a smaller part of them (ordinary roots) get down to 30–40 cm [98].

The rice leaves are composed of rice sheath, blades, ligules and auricles. The leaf blades (leaves) are narrow, long and linear. Their length generally varies from 20 to 50 cm, width – from 0.8 to 2.0 cm (Figure 12).

The top leaf or flag is shorter and wider than those located below. The leaf sheath tightly covers the stem internode. The auricles and a ligule are located at the place of the sheath transition to the leaf blade. The auricles embrace the stems and are generally strongly pubescent. The ligule is a colorless elongated scale, split lengthwise; its size is 1–1.5 cm [98].

a

b

c

Figure 12 – Rice leaves:

a – short; b – long and drooping;
c – vertical

The number of leaves corresponds to the number of the stem nodes. In late maturing varieties, there are more leaves than in the early maturing ones. On the side shoots the number of leaves is less than the main shoot. Studying the rice variety Coloro, E. Copeland [125] determined that the main shoot had 15 leaves; the first side shoot had 9, and the fifth side only 6. Similarly, the leaves are formed on the rice varieties bred in Russia. Rice varieties vary considerably in the number of shoots and leaves and that should be considered when defining the density of plant stand.

Rice flower head is a panicle (Figure 13). Its length is 10 to 35 cm, and the number of spikelets in the cultivated varieties varies from 50 to 300. Some of the collection samples can have 400–450 speikelets. In 1983 in the hybrid nursery we selected a rice plant which had 650 spikelets on the main panicle and on the five panicles there were an average of 600 spikelets [31].

Spikelets in rice are single-flowered. They have two lemma scales tightly pressed to the caryopsis, and two glumes. The size and shape of the spikelets are very diverse.

The flower in rice is bisexual, covered by two paleas. Unlike other cereals the flower has 6 stamens and a pistil with two feathery stigmas. The stamen consists of the anther and filament housing about 1 000 pollen grains.

a b c d

Figure 13 – Rice panicles:

a, b – large; c – short; b, c – vertical; d – drooping

The lemma can have an awn or awn-like outgrowth. The color of lemma and awns is varying from straw yellow to black or it can be two-colored (Figure 14). These features form the basis of the classification of rice varieties.

a b c

Figure 14 – Color of lemmas:
a – straw yellow; b – golden brown;
c – violet

Rice seed is a caryopsis located between the flower lemmas but not coalescing. The kernel consists of endosperm and the embryo is covered with a bran layer and a seed hull under which the aleurone layer, rich in protein, is located.

The form of the kernels depending on the variety can be round or elongated in varying degrees, with a length of 4–10 mm and a width of 1.2–3.5 mm. In the subspecies *japonica* the kernels are round, oval, oblong – up to 7–8 mm. Their color depends on the presence of the pigment in the fruit shell and ranges from silvery-white to dark brown and black (Figure 15).

The endosperm is filled with starch grains. Depending on their composition and location the milled rice can be vitreous or farinaceous. In glutinous varieties, the milled rice is chalky (Figure 16).

Rice grain vitreousness should be considered to obtain high-quality milled rice. In the cultivated varieties, the vitreousness index ranges from 57–60 % to 95–98 %. It level depends on the varietal characteristics and on greater degree on weather conditions and agricultural practices compliance during rice ripening. Lower temperature during grain filling, early water discharge from the field contribute to the formation of chalky endosperm.

Figure 15 – Color of the rice kernels

a b c

Figure 16 –Milled rice:

a – round; b – elongated;
a, b – vitreous; c – chalky [67]

An important varietal feature of rice is its hull content. In most varieties cultivated in Russia it ranges from 17 to 22 %. This indicator is closely related to the total yield of milled rice which can be from 63.0 to 72.0 % depending on the variety. The vitreousness and fracture prorosity of endosperm have a direct impact on the yield of the head rice.

To have the variety included into the list of the most valuable varieties according to the quality of milled rice, it should have some technological parameters (Table 3).

Creation of high quality varieties, especially the ones with a long grain, is not easy due to some problems. One of the main hardships is that yield of such varieties is significantly inferior to the yield of short grain varieties; they also tend to be late maturing. Until now the Russian rice collection has no forms of early maturing Indian subspecies of rice with vegetation period of 100–110 days.

Table 3 – Quality features of rice varieties producing valuable milled rice

Index	Variety	
	with round grains	with long grains
Grain length / width ratio (l/b) not less	–	3,0
Total vitreousness, % not less	85,0	90,0
Brokens, % not more	10,0	5,0
Hull content, % not more	18,0	22,0
Total milled rice, % not less	68,0	64,0
incl. head rice, % not less	85,0	80,0

This makes the breeders to carry out a special selection work for obtaining such samples. Complex crossing and backcrossing is done to this purpose using as parents the early maturing rice varieties with short grain and late maturing ones with long grain received from the countries of the tropical zone.

1.4 Main Biological Features of Rice

1.4.1 Water

The main biological feature of the rice plant, in contrast to other cereal crops, is its ability to grow in water. This is provided by the aerenchyma that develops in rice plant and supplies oxygen from the leaves to the root system.

Among Russian scientists there is no consensus about the need to maintain a layer of water during rice growing season (this issue is not discussed abroad). Ye. B. Velichko [18] considers rice as a water resistant mesophyte, and therefore believes that a layer of water on the rice field is subject not to the requirements of rice plant but is needed for weed control. That is why it is proposed to grow rice without flooding; only watering it periodically. Weed control is provided by herbicides application.

P. S. Yerygin [27] believes the opposite that rice flooding is a mandatory agricultural practice, especially during the formation of the basic elements of the crop. This is stipulated by the fact that rice belongs to hygrophytes that grow on excessively wet, water saturated soils. Rice tissues can not withstand even the most insignificant dehydration. The root and leaf cells of the rice plant have a low suction force.

Accordingly, in all rice-growing countries of the world rice is grown mainly in the water flooding conditions. In the areas with a monsoon climate where precipitation is 1000–2000 mm during the rainy period, in some countries rice is grown without flooding. [22]

Compared with other crops rice has a low transpiration rate. Under the conditions of the Krasnodar Territory, it averages 500 in case of flooding growing practice. In ontogenesis the amount of evaporated water rises till rice flowering phase, it is associated with an increase in leaf surface. During the period from paniculation to the middle of milky ripeness the rice plant transpiration requires about half of the water that it evaporates during the whole cycle of ontogenesis. During this period, the level of transpiration approaches maximum. Afterwards the leaves begin to die and evaporation reduces. Over the entire period of vegetation 1 ha of rice crops consumes by transpiration about 3000–4200 m^3 of water. Out of all quantity absorbed by the roots, only 0.2 % is used productively [27].

It is discovered that the rice plant contains in its tissues less water than many upland winter and spring cereals. In wheat, barley and oats one part of dry matter corresponds to 4.5 parts of water, while in rice – not more than 3. The amount of protoplasma in the cells of the rice plant is limited and that not only reduces the possibility of direct water consumption, but also passing it through the plant. Moreover, the cells of rice roots and leaves have low suction capacity. All this necessitates continuous and abundant water supply of the rice plant. The least value of transpiration rate in rice is 230–290, and the highest – 977–1106. This means that for the formation of 1 gram of dry matter the rice plant needs from 0.3 to 1 liter of water. Under the conditions of the Krasnodar Territory a single rice plant during growing season uses about 5 l water [27]. Upland rice varieties consume more water than the flooded ones. When grown in a layer of water the plant forms a root system with weak lateral mat roots and spends 3 times less energy obtaining elements of soil nutrition than in just moist soil. In the 1950-ies the Russian breaders produced special varieties of rice for upland cultivation (White Skoms snd other varieties). However, when they were grown in the water layer, they gave much higher yield than without flooding.

All this explains the need for a continuous and generous rice plant supply with water. In addition, a layer of water on the rice field controls the microclimate, leveling the fluctuations of the day and night temperatures, increases the relative humidity at the soil level, as well as soil temperature, all of which positively affects the productivity of plants and the quality of the milled rice [6].

In the process of growing the rice plants go through several phases – germination, sprouting, tillering, booting, paniculation and flowering, maturing. Each of them requires specific weather conditions.

1.4.2 Rice and Heat

Rice is a heat-loving plant, so the temperatures facilitating normal passage of each phase should be considered when growing it (Table 4).

To start sprouting rice seeds enough moisture should be available (25–30 % of the seed weight) and the ambient temperature should not be lower than 10–12 °C. The best for germination is 20–25 °C, when the temperature reaches 39 °C, it stops [22].

Table 4 – Temperature indices for every phase of the rice plant development [7]

Growing phase	Temperature, °C		
	min	optimal	max
Germination	14	24–28	36
Sprouting	16	24–28	36
Tillering	16	24–28	36
Booting	18	19–22	36
Paniculation – flowering	18	24–28	36
Maturing	16	18–26	32

Germination begins with the proliferation of the germ and root. Depending on the oxygen provision, this process runs differently (Figure 17). If the oxygen content in the water-flooded layer of soil is less than 2 %, the first to grow is coleoptile and when it reaches the zone containing more oxygen the roots appear.

If the medium contains more than 10 % oxygen, the sprouting of the germ is followed incipiently by fast roots growth, coleoptile bursts open and the green leaves develop vigorously [98].

The first variant is observed in germination of seeds embedded into the soil and covered with a layer of water more than 15 cm. In this case, there is a sharp decrease in field germination of rice, due to the death of seeds drilled more deeply. The second option is when seeds are placed on the soil surface under water layer up to 5 cm. The third option is with the germination of rice seeds embedded in moist soil to the depth of 0.5 cm, and no water layer. Therefore, obtaining rice seedlings is preferable under moistening condition or when the water layer is the least. This is easily achieved with good leveling of rice fields.

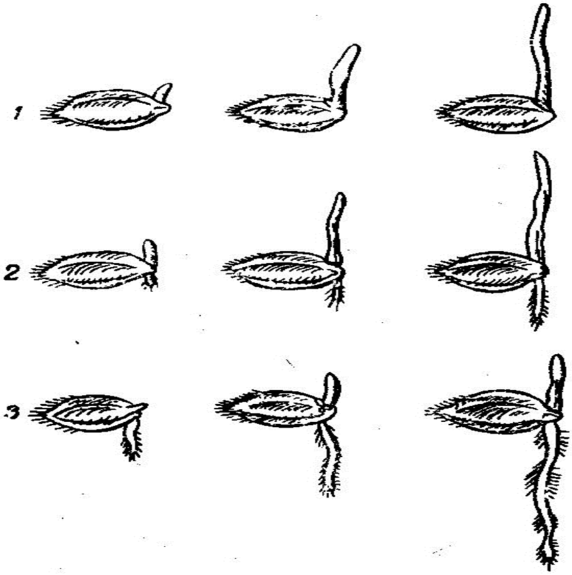


Figure 17 – Rice seed germination under different levels of oxygen [98]:

1 – 0–2 %; 2 – 2–10 %; 3 – 10–20 %

Rice leaves grow at temperatures not below 13–15 °C, at lower temperatures the chlorophyll breaks down, and they die [6]. Tillering in rice starts during the formation of the third and fourth leaf and ends with the appearance of the eighth-ninth leaves. Tillering intensity depends on the varietal characteristics, availability of nitrogen nutrition, plant density, light intensity and depth of flooding.

Two features of rice tillering should be noted. First, the lateral branches are formed only from sheath of the living leaf. Therefore, they should be saved, no flooding is recommended (under a layer of water the leaves die) and they should not be burnt with herbicides. It is known that the piniculation of the lateral shoots formed from a later leaf occur later compared with the main shoot. Second, if during the tillering period the layer of water is above

20 cm, the lateral shoots may appear from the leaf sheath located above water. This phenomenon is sometimes called rice branching. It is not at all desirable as it leads to productivity decrease of both the plant and the cenosis as a whole.

Tillering is the longest phase; the lengthening of the rice growing season is due to it. In fast maturing varieties tillering continues 20–25 days, for the late maturing varieties it takes 40 days or more. During tillering the transfer from the vegetative to the generative stage takes place. In the phase of the sixth and seventh leaf in early maturing varieties and eighth – ninth leaf – in the late maturing varieties the differentiation of growth apex on the main stem occurs and formation of the future panicles starts.

Booting begins with the emergence of 8–9th leaf and ends after the formation of the top leaf (flag). The plant reaches its maximum height. The emergence of the panicles from the sheath of the top leaf is called paniculation; it coincides with the flowering phase. It begins from the upper spikelets of the panicle and lasts 4–7 days. Bad weather like rain, temperatures below 14–15 °C adversely affects flowering. This increases formation of sterile spikelets reducing panicle productivity. If the temperature drops to 12–14 °C, the flowering of rice stops [22].

The studies conducted in the Krasnidar Territory [97] prove that in the most common rice varieties the type of flowering is open. However, at low temperatures at the later stages of flowering, with strong wind and rain it can also be of closed type. At temperatures above 22–23 °C flowering of rice plants begins at 9.30–10 AM; with the temperature decrease to 19–20 °C, it is moved to the hotter time of the day. Most of the flowers are open until 2–2.30 PM.

The most intensive opening of flowers per panicle is observed on the 2nd–3rd day from the beginning of flowering, at lower temperatures on the 4th–5th days. Floral scales open when the stamens move forward to the half of their length and more. This process occurs instantly, but often divergent scales form a slit that stays for 5–6 minutes, then it rapidly expands, and the stamens come out. First, the slit is small, but gradually it reaches 50–55°, in 10–15 minutes the scales move closer to 45–35°, and then gradually close completely. The flower stays open for about 45–60 minutes (Figure 18). These specific flowering features of the rice plant must be considered for the success of the artificial hybridization.

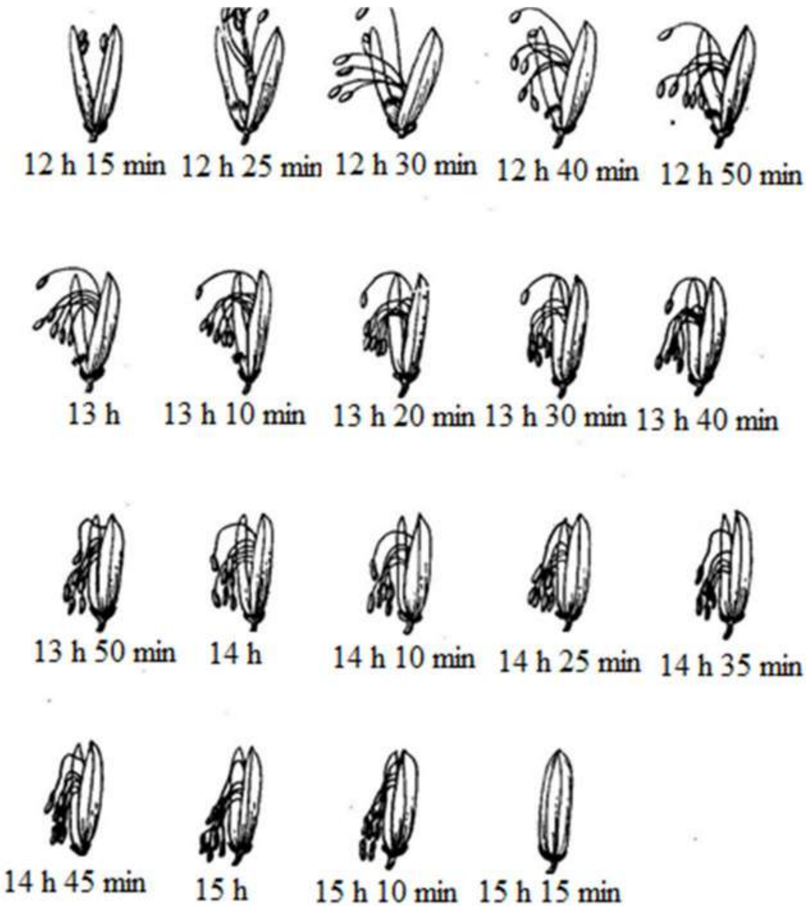


Figure 18 – Development of the rice flower [98]

The pollination of the flower occurs at the time of opening and the anthers emit a small amount of pollen. In caase of wind and low temperature the lemmas either form a small slit or do not open at all, and pollination takes place with closed lemmas. If lemmas are open under these conditions, they may stay like that up to 4 hours or more.

Rice is a self-pollinating plant, but cases of cross-pollination under natural conditions have been observed. The number of spontaneous hybrids among the varieties was registered within 0.41–1.4 %, and between varieties and red rice forms 0.14–0.17 % [12]. In some years, such hybridization occurs much more frequently. Apparently, this can explain the appearance of a large number of different types of the red rice forms, often outwardly similar to cultivated varieties.

The ovary is formed from the fourth day and the embryo is set within 10–12 days after fertilization, Growth of kernel ends in two weeks. The time from the start of flowering to full maturity depends on rice variety and weather conditions and varies from 10 to 75 days [22].

Grain filling and maturing take place in stages. Maturing can be subdivided into milky, dough, and maturity stages. Under conditions of the Northern Caucasus the duration of each phase for the released varieties varies from 10 to 12 days, total duration of thematuringperiod is 30–35 days and during the years with cold weather it can reach 40 days or more. During maturing, complex transformations go on inside the seeds. Starch accumulation in endosperm is due to the action of phosphorylase. Sucrose is synthesized in the leaves and stems of the rice and moves to the kernel where it transforms into starch [98]. Rice reaches full ripeness when 85–90 % of the grains in the panicle are at this phase.

1.4.3 Vegetation Period

The period from germination to full maturity varies in different varieties of rice. There are varieties of Japanese rice finishing their development within 50–60 days, and floating rice in Kambodia with the 10-month growing season [27].

The length of the growing season of a variety is important only for the area where the tests are held. Three main factors influence the length of the growing season of rice as a whole and its individual phases:

1. Biological (early maturing of the variety);
2. Climatic (the temperature conditions of the vegetation period);
3. Economic (planting dates).

Early maturing of the variety is closely linked with the sum of effective temperatures for rice (+15 °C) during the growing season. It is experimentally shown [106] that under the conditions of Krasnodar territory is is possible to ensure growth of the rice varieties that require during the growing season the amount of effective temperatures is not more than 2700 (Table 5).

Table 5 – Maturity groups of the rice varieties under conditions of the Krasnodar Territory [106]

Group of varieties	Vegetation period, days	Sum of diurnal temperatures above 15 °C
Very early maturing	95–100	2000–2200
Early maturing	100–110	2200–2300
Middle maturing	110–120	2300–2500
Middle late maturing	120–125	2500–2600
Late maturing	125–135	2600–2700
Very late maturing	No heading	above 2700

The duration of the growing season in the years with the different heat supply can reach high values. Thus, middle late maturing variety Krasnodarsky 424 in 1975 (a very warm year, $\sum \geq$ t 15 °C 3556) matured within 116 days, and in 1978 (cold year, $\sum \geq$ t 15 °C 2760) was ripe within 148 days [30].

The works of foreign authors showed a significant difference of the duration of the rice growing season before flowering depending on sowing time. So, Lord (1931), in Ceylon, changing the planting dates of the same rice variety, received periods from sowing to flowering from 195 to 339 days. The Indian scientist Ramiah (1933) worked with a variety that had vegetation period of 90–95 days, and sowing it at different dates, received lengthening of the growing season (before flowering) up to 224 days. These facts are interesting because the average temperature in these zones is above 20 °C and the duration of the light period throughout the year changes little, eliminating the reaction of photoperiodism [22].

Thus, it is shown that rice refers to short day plants (12 h daytime and 12 h nighttime). For most varieties under the conditions of the Krasnodar Territory heading and flowering start earlier when the number of hours of daylight is reduced from 16 to 12 hours. Some varieties do not exhibit photoperiodic response, being fotoneutral. Thus, in our experiments, in middle-late variety Kulon at a 16-hour and a 12-hour photoperiod the heading stated in 77 days and in the early maturing variety Soyuzny 244 with a long day it began after 62 days, with a short day – after 48 days. At the same time variety VNIIR 8847 with a 16-hour day was heading after 77 days as a middle late maturing variety, and with a 12-hour day – in 48 days as an early maturing variety [32].

High photosensitivity of varieties of tropical countries is a major deterrent to their growing in northern rice-growing regions. In the context of the Krasnodar Territory with 16-hour photoperiod clear majority of these varieties do not ripen, and some of them do not even reach heading phase [33].

1.4.4 Rice Nutrition

Rice belongs to crops undemanding to soil conditions. It can be grown in the marsh, meadow, peat, saline soils, and solonetz. The water layer promotes the desalinization of the upper horizons of the soil, so rice is often used as an ameliorating crop [113].

Rice is very sensitive to lack of nutrients. It has been established that under the conditions of the Krasnodar Territory for the formation of 1 ton of rice grain, and the same amount of straw the plant takes out 24.2 kg nitrogen, 12.4 kg phosphorus and 25 kg potassium. In the Far East of Russia (the Primorsk Territory), these figures are 23.5 kg, 9.8 kg and 31 kg; Uzbekistan 20–25 kg, 10–12 kg and 30–54 kg respectively [8]. Different removal of nutrients is explained by soil and climatic conditions, specific features of rice varieties, as well as the obtained yield.

Insufficient amounts of soil macronutrients result in low yeilds. Thus, without nitrogen the plants turn yellow, their tillering weakens, photosynthetic productivity is reduced and the grain formation in the panicle is poor. Nitrogen is consumed by the rice plant throughout the whole growing season. But its excess, especially without other nutrients leads to blind-seed disease, surrender to fungal diseases, especially blast (Figure 19).

Phosphorus deficiency damages the exchange of energy, leads to changes in protein metabolism that interferes with normal growth and development of plants. Phosphorus starvation at the beginning of the growing has a negative impact on the next phases and cannot be made up for by its introduction at a later date. Hence, the need in phosphorus is particularly high in the first half of the growing season.

Figure 19 – Rice plants infected by fungus *Pyricularia oryzae* Cav.

Potassium is involved in carbohydrate and other types of metabolism, it influences on the resistance of plants to unfavorable conditions of the environment and disease susceptibility. Lack of potassium impairs fruiting, increases the propensity to lodging, leads to various diseases. It was found that potassium deficiency in rice plants impacts carbon and nitrogen ratio (C: N) and this leads to a sharp increase of spikelets sterility. Potassium is most effective in the period of booting. At that silicon metabolism is also regulated.

Along with nitrogen, phosphorus and potassium rice absorbs silicon in high quantities; it is no coincidence that rice is considered a siliciphilous plant. Entering in a plant this chemical element is accumulated in the conductive vessels and leaf blades [2]. It is the accumulation of silicon in the conducting vessels that makes rice plants resistant to lodging, blast, as well as rice borer and leafhoppers. During the growing season the plants remove from 1 ha about 1 ton of silicon [27].

In addition to these elements the rice plants need other elements: iron, manganese, copper, zinc, sulfur, molybdenum, boron, cobalt. Their absence or imbalance with the main nutrients dramatically reduces the effectiveness of fertilizers. Therefore, the mineral nutrition of rice should above all be properly balanced.

The ratio of nitrogen, phosphorus and potassium determined earlier is 1.5: 1.0: 0.5 and it should be the benchmark for the calculation of the fertilizer rates.

At present the most important index is cost recovery (return) of fertilizers, particularly nitrogen, via rice grain yield. The proposed formula for calculating this index is given below [91]:

$$O_N = \frac{Y_{+N}}{R_N},$$

where Y_{+N} – rice grain yields under fertilization, kg/ha; R_N – nitrogen rate, kg/ha.

If the rice farming practices, including mineral nutrition regulation, are observed, this return should be more than 50 kg of grain per 1 kg of nitrogen.

It is known that the level of productivity is determined by the element which is available in the minimum amount. In recent years, many farms do not apply potassium fertilizers. Consequently, potassium deficiency in rice is noted. This leads to rice lodging even in short stem varieties, enhanced sterility and grain shriveling and blast. Thus, rice yield reduces.

1.4.5 Rice Lodging Problem

Among the many requirements to modern varieties of rice, the main condition along with high yields and grain quality is resistance to lodging. The highest yield will be lost during harvesting of laid crops.

Academician V.M. Shevtsov speaking about the role of the variety in the increase of yield reminds of the wheat field seen after heavy rains. He writes: "From the top of the hill I had a view of a beautiful wheat field. One half was planted with old varieties Novoukrainka 84. Here you could see the sad consequences of the recent rainfall. It was painful to look at the twisted or broken stalks. Many of the wheat ears not filled yet were nailed to the ground by the rain, spattered with mud, they looked doomed. On the other side of the field the new variety Bezostaya 1 was planted. The 30-ha field had no broken stems, ears; they were like soldiers in formation, caressing my eyes with fresh and striking uniformity. Clean healthy leaves, fat ears of wheat promised high yield" [116].

Due to advances in wheat breeding achieved by Academician P.P. Lukyanenko and his students [74] it became possible to resolve the problems of rice lodging. However, in many crops, including rice, the task of creating varieties resistant to lodging remains relevant [37, 105, 119].

Lodging is a problem of practically all cereals. The study of this phenomenon was carried out by many scientists of different specialties. The monograph of I.V. Lukyanova [75] devoted to the problem of resistance to lodging of ten cereals contains a list of 540 sources of from Russia and other countries. Having done a sufficiently detailed analysis of the causes of lodging of different varieties and types of crops, the author notes the high harmfulness of this phenomenon and a significant scatter of opinions among researchers on how to address the problem. Citing the data of her research on the static and dynamic stability of the stems as the elastic rods, the author proposes a number of measures to address the problem of lodging. In particular, for rice it is recommended increase the diameter of the stem and the elasticity of the stem through breeding.

First and foremost, it is necessary to increase the elasticity of the rice stalks, a mechanism to implement this task has to be found. However, the recommendation to increase the diameter of the stem contradicts the current trends in breding of cereals. Thus, breeders of winter wheat see the reserve for increasing crop yields by increasing the number of ears per unit area without reducing their efficiency. For example, a decrease in plant height and the increase of the number of ears per 1 m2 from 464 (in Bezostaya 1) to 776 (in Skifyanka) resulted in higher yield by almost 2 t/ha and increased harvest index from 34 to 45 % [13]. Nowadays wheat breeding continues in this direction.

A similar situation and we observe in rice breeding. But unlike other cereals it is grown in the water layer and this is an additional negative factor influencing plant lodging resistance [47]. Rice root (due to bending of roots) and stem lodging (due to stem bending or fracture) are distinguished.

As for the strength of rice stem it can be weak (resistance to fracture is below 200 g/cm), medium (201–800 g/cm), durable (801–1100 g/cm), and very durable (more than 1100 g/cm) [6].

Rice lodging can be caused by environmental conditions or specific variety traits [20] (Figure 20). According to V.B. Zaitsev [29] lodging of rice is often caused by failure to comply with agricultural practices and water regime.

However, G.G. Gushchin [22] considered the problem much broader. He noted that all different forms of rice lodging can be reduced to four basic types.

1. Lodging is manifested in a gradual and moderate flexion of the whole stem without damaging the tissues or with very little damage to them. This type appears on very fertile soils, where a rich harvest of rice is expected, usually only at the end of the grow-

ing season; with the absence of adverse weather conditions during rice maturing and harvesting, it does not lead to yield losses.

a

b

c

d

Figure 20 – Lodging and not lodging rice varieties:

a – Khankaysky 420, Khankaysky 52;
b – Leader; b – Kumir; d – Gamma

2. The second type of lodging is characteristic of varieties of rice with a very "open" tillering node, whereby the side shoots are weakly rooted, "hanging in the air." In this case lodging is not usually accompanied by damage to the stem tissue and its breaking, so that yield loss under unfavorable weather conditions is insignificant.

3. The third type is the lodging of the whole plant when it falls to the ground.

This type of lodging is due to the weak development of the root system; rice roots are distributed on the soil surface and they can be easily extracted. This lodging is common in early maturing varieties, as well as on very heavy soils with rice random sowing without covering the seeds.

4. The fourth type of rice lodging, the most serious and dangerous, is always accompanied by heavy losses at harvest and it is due to broken stems, usually a few centimeters above the surface of the soil. It is believed that in addition to the rice varietal traits this type of lodging is due primarily to the presence of the water layer, and in particular to its height variations in the rice fields. The alternating drying and wetting of the stem leads to weakening of the supporting tissue of the stem and partial destruction of sheaths and stems.

In an effort to establish the correlation between the lodging of rice plants and a number of morphological and anatomical traits on the basis of the published data, G.G. Gushchin came to the following conclusions:

1. There is no correspondence between the length of internodes and lodging of rice.

2. The lodging forms have thin sheaths, easily degradable in water and near its surface. The erect and not prone to lodging forms typically have strong, not collapsing leaf sheaths that can completely cover the lower internodes of the stem providing them with a good protection and strengthening the stem as a whole.

3. In rice forms resistant to lodging the diameter of the internodes (with sheaths and without them), and in particular the lower ones, exceeds that of the forms susceptible to lodging.

4. There is no corespondence between panicle weight and lodging in rice; no correlation is detected between height of stems and lodging.

5. The thickness of the stem walls, especially its sclerenchyma part, in forms resistant to lodging, is significantly higher compared to that of the lodging varieties.

6. Parenchymal part between the outer row of the stem vascular bundles and the empty center of the straw is definitely wider in forms resistant to lodging.

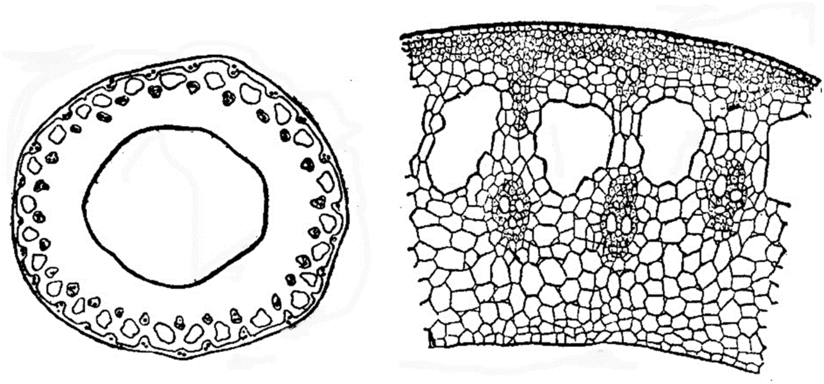
All the above indicates the great complexity of the lodging trait in rice, its dependence on several factors – both plants genetic constitution and environmental factors [22].

These conclusions reached by G.G. Gushchin nearly 80 years ago, deserve the most careful attention at present, because they are supported by many years of breeding practices, as well as several works on the anatomy, physiology and biochemistry of rice. High resistance to lodging of modern semi-dwarf varieties is due to the stem structure that can withstand heavy loads; short-stem varieties like Spalchik contain silica in the straw up to 10 % of dry matter, which is 1.5–2 times higher than in the tall variety Krasnodarsky 424 [6].

To clearly understand the differences between varieties let us consider what is a stem of the cultivated rice. It is a culm divided by solid nodes into hollow internodes. The lower internodes are the shortest, usually with thickened walls. The thickness of the stem wall is of practical value, since it is closely related to its strength, which, in turn, determines the resistance to lodging.

G.G. Gushchin [22], referring to Yu.A. Rozhevitz gives a cross-sectional diagram of the rice stem, thus emphasizing that in the 30-ies of the XX century the study of anatomy and tissues of rice plants was conducted and sections micrograph were made (Figure 21).

Anatomical studies performed by L.G. Petrova and A.G. Lyakhovkin in 1960-ies (i.e. 30 years after G.G. Gushin) [93], have shown significant differences in the pattern of the cross section of the stem internodes and leaf sheath of rice varieties with different lodging resistance (Figure 22).



a b

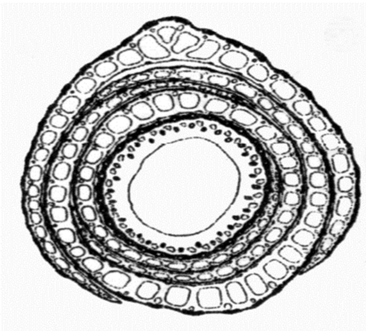
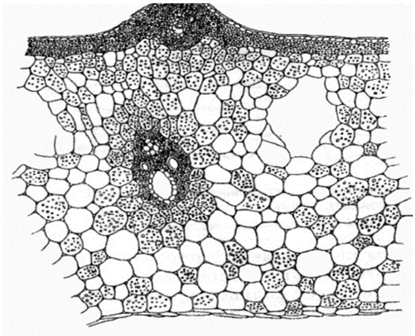
Figure 21 – The stem cross section of *Oryza sativa* L.:

a – small and; b – large magnification [22]

Anatomical studies performed by L.G. Petrova and A.G. Lyakhovkin in 1960-ies (i.e. 30 years after G.G. Gushin) [93], have shown significant differences in the pattern of the cross section of the stem internodes and leaf sheath of rice varieties with different lodging resistance (Figure 22).

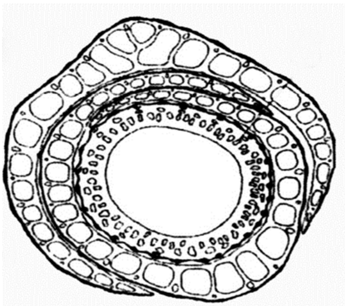
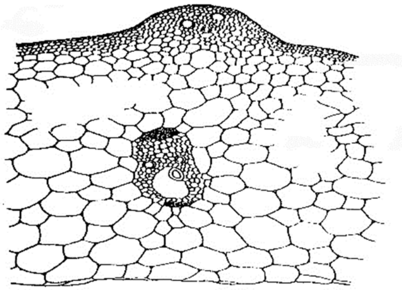
The authors could show that the anatomical structure of the stem of the undersized non-lodging variety Anao and tall variety Arpa-shaly prone to lodging due to breaking of the lower internodes of the stem, varies and clearly confirms, thus, their agrobiological characteristics. In describing the results of the anatomy study, the authors conducted the quantitative and anatomical analysis of the stem and leaf sheath structure of these varieties (Table 6).

1

a b

2

a b

Figure 22 – Rice stem cross section:

1 – Anao, resistant to lodging;
2 – Arpa-shaly, lodging variety
a – internode section with leaf sheath;
b – stem section [93]

Table 6 shows that the thickness of the mechanical tissue in the variety Anao is higher than that of Arpa-shaly, as well as there is a higher number of rows of this tissue. Fibrovascular bundles in the first variety have 7 pieces more than in the second. Ultimately, this leads to differences in resistance to stem lodging in these varieties. The above data are consistent with the materials given D. Grist [20].

Table 6 – Rice stem and sheath parameters in different rice varieties [93]

Variety / Plant organ		Number of cell rows in mechanical tissue	Thickness of the stem filled part, mm	Ratio of larger stem diameter to smaller	Number of fibrovascular bundles		
					in screlerenchyma ring	in parenchyma tisue	total
\Anao	Stem	3–18	1,38	1,66	32	32	64
	Sheath	2–10	–	1,50	–	–	–
Arpa-shaly	Stem	2–10	1,20	1,88	28	29	57
	Sheath	2–6	–	2,10	–	–	–

According to the results of the studies the short stem variety Anao, received from Portugal, was recommended for hybridization as a donor of dwafness and lodging resistance.

This variety, despite its flaws – small rounded grains of low quality (Anao belongs to the subspecies *brevis*) – has successfully been used in breeding programs. It was involved in the breeding program of the short stem breeding material of a new-type which gave origin to the widespread rice variety Liman (Baldo / Anao // Cha-shih-1) [119]. Arpa-shaly, an ancient Central Asian variety, gives excellent quality grains for cooking pilaf. Therefore, despite the susceptibility of the plants of Arpa shaly to lodging, this variety is still cultivated in Uzbekistan and is used as a donor in breeding of high quality milled rice.

Thus, there are two important components affecting the resistance of the rice plants to lodging to a large extent – anatomical characteristics (stem wall thickness, the width of the parenchyma part between the outer row of the stem vessels and the culm hollow center) and biochemical index (the silica content in the culm).

To work on breeding programs with “open eyes” considering the anatomical and biochemical characteristics of rice plants, one must know the details of these parameters in the original parental forms and received hybrid offspring. It is necessary to understand the inheritance of the anatomical traits that define the degree of the plants resistance to lodging and their variability in the hybrids of the first and subsequent generations. In addition, the scientists should have informative and not labor-consuming methods of analysis of anatomical and biochemical properties of rice plants. These methods have been developed by the scientists of the All Russian Rice Research Institute (ARRRI).

The studies on the anatomy of rice have been widely conducted at the Institute in the 70–80-ies of the XX century. In the guidelines "Anatomy of Rice" prepared by E.P. Aleshin and V.G. Vlasov in 1982, the authors’ objective was to describe the structure of rice tissues and organs having significant differences from other species of plants of the cereals tribe [10]. The research was based on one variety. Despite the limitations of the material and the use of the data of optical microscopy, the relevance of these studies even 27 years after only increased.

The anatomical structure of the flag leaf of nine rice varieties is shown in one of the sections of the thesis of S.A. Gusar [21], performed with the help of V.G. Vlasov and G.G. Fanyan. The most contrasting in anatomy were varieties Khazar and Leader, the difference of their total section of the leaf veins of the flag leaf was almost double. This once again underlines the diverse nature of the varieties, the necessity and the possibility of their anatomical evaluation.

The studies conducted in the laboratory of biochemistry and molecular biology of ARRRI under the direction of E. R. Avakyan, showed a close relationship between the content of silica in rice plants and their resistance to lodging [2, 72]. It remains only to extend this work and to assess the maximum amount of the material selection en masse.

Thus, to solve the problem of further increase of rice yields due to its high resistance to lodging the research of anatomical structure of plants of different types of collection samples, varieties and hybrids of rice should be expanded. In addition, the content of silica and other biochemical indicators that directly or indirectly affect the resistance to lodging, diseases and other stresses of these plants have to be determined. This problem can be solved by joint work of the breeders and the specialists in the anatomy and biochemistry of rice.

1.4.6 Salt Tolerance in Rice

As already noted rice can be grown on saline soil only under a layer of water, as its salt tolerance has turned out not as high as previously estimated. It is lower in rice as compared to barley, wheat, sorghum and sugar beet. At the same time the study of the global collection of rice shows that there are significant differences in salt tolerance of different varieties. This indicates a necessity and an opportunity to create rice varieties tolerant to salinity. Rice breeding programs of salt-tolerant varieties carried out at the ARRRI have given positive results. Rice variety Spalchik with increased salt tolerance was recognized in 1980. In 1997 rice variety Kurchanka was included into the State Register of Selection Achievements, and in 2001 – Serpan-tin, both superior to the recognized variety [67]. In subsequent years, a few more salt tolerant varieties were produced. Two of them Sonata (2009) and Sonet (2010) were included in the State Register of varieties admitted for use [68].

The middle of the 60-ies of the XX century was a turning point in the development of Soviet rice production. The program of providing the population of the USSR with rice of its own production was adopted. In 1966 the All-Union Scientific Research Rice Institute (ARRRI) was established on the basis of the Kuban Rice Experimental Station. By this time more than 15 million hectares of saline soils were identified in the territory of the country; they were not used for other crops but were potentially fit for rice growing. The largest areas were in Sarpinskaya lowlands (Kalmykia), Central Fergana (Uzbekistan), the Kyzylkum massif (Kazakhstan), as well as at the delta of the river Kuban, lower reaches of such rivers as the Terek, the Don, the Dnieper, the Syr-Darya, Amu-Darya and others.

The resuts of research [103] show that rice can tolerate salinity up to 1,5 % at flooding (Table 7).

Table 7 – Rice variety Krasnodarsky 424 response to chloride-sulphate salination at different growth phases [103]

Salination level	Plant height, cm	Productive tilling capacity	Grain mass per panicle, g	Spikelets sterility, %
Emegence (2–3 leaves)				
0	82,4	2,1	2,1	9,6
1,5	74,3	1,9	1,6	9,8
3,5	60,3	1,1	0,8	26,0
Tilling (5–6 leaves)				
0	74,0	1,2	1,7	12,6
1,5	67,3	1,3	1,3	16,0
3,5	56,3	1,4	0,4	52,4
Flowering (10– leaves)				
0	76,5	1,3	1,8	8,5
1,5	72,1	1,3	1,9	30,3
3,5	58,3	1,2	0,5	80,1

At this level of salinity, the rice plants develop quite satisfactorily with only insignificant reduction of productivity. Therefore, if the quantity of the wash water is sufficient the saline soils can be effectively used for rice production, and after desalination other crops can be grown there [113].

During the period from 1966 to 1975 on saline lands of the North Caucasus, southern Ukraine, the Volga region, in the catchment areas of the Syr Darya, the Amu Darya and other rivers engineering rice irrigation systems were put into operation of the total area of over 600 000 ha. By 1980, only in the Krasnodar Territory the area of rice systems was brought up to 250 000 ha and about half of them was built on the saline soils.

The breeders faced an important task to create rice varieties capable of giving a satisfactory yeild on saline soil while accepting flooding with mineralized water.

Re-use of irrigation water is an important reserve of expansion of sowing areas under rice [102]. After a fairly long and intensive selection in 1980 a short-stem variety Spalchik characterized by high salt tolerance was established and included in the State Register [11].

In addition to the Krasnodar Territory it was recognized in the Crimea and Kherson region of Ukraine and in Dagestan. Sown area under Spalchik in the areas where it was recognized were increasing rapidly. If in 1980 this variety occupied 3 500 ha, then in 1989 this crop covered 143 700 ha (the first among all varieties of rice sown in the country). The main reasons for wide spreading of this variety are its resistance to low air temperatures in the period of germination (+11–14 °C), increased tolerance to soil salinity, the active use of nitrogen fertilizers, thus leading to high yields (up to 10 t/ha). The tendency to reduce the areas under Spalchik was observed later due to spreading of other varieties.

Experience has shown that the effectiveness of breeding is directly related to the presence of sources and donors of the right traits. Nearly 85 years of the studies of rice growing in Russia under the local climatic and soil conditions performed at VNNIR have allowed to accumulate a significant number of samples with a complex of economically valuable traits. Among them there is a special group of isolated samples and formsp possessing enhanced salt tolerance (Table 8).

One of the effective methods to identify donors in breeding salt-tolerant rice varieties is a genealogical analysis. It shows that Spalchik and several other Russian-bred rice varieties orginated with participation of Italian variety **Balilla grana grosso** which proved to be a universal donor of the short stem, lodging resistance and salt tolerance (Table 9, Figure 23).

Table 8 – The collection samples of early maturing rice as souces of salt tolerance

Number in ARRRI Catalog	Number of days from flooding to maturing	Plant height, cm	Salt tolerance, grade
0812	103	73,5	7
02231	109	82,7	7
02432	96	69,0	7
02611	102	106,0	7
02625	93	69,9	7
02712	106	70,7	7
02734	106	75,8	7
02865	94	79,7	7
03064	101	91,5	7
03230	113	85,3	7
01318 (standard)	110	85,0	7

Table 9 – Origin of some Rusian-bred rice varieties

Variety	Year of release	Origin
Spalchik	1980	Balilla grana grosso // Krasnodarsky 3352/ Kendzo
Zhemchuzhny	1982	Balilla grana grosso / Kuban 9
Kulon	1987	Catalao / VNIIR 6031 (Balilla grana grosso/ Cross 3830)
Aprelsky	1988	Balilla grana grosso / Kuban 9 // Sputnik
Privolny	1990	Balilla grana grosso / Cross 652 // Cesario
Primorets	1990	Balilla grana grosso / Dubovsky 129
Vevel	1994	VNIIR6427 / Krasnodarsky 424 // Balilla grana grosso / Cross 68 /// Baldo
Kurchanka	1997	Kulon/ Raduga (Balilla grana grosso / Nakhodka)
Leader	2000	Kulon / Kuban 3 // Belozerny
Gamma	2010	Kurchanka / VNIIR 554-90 // Leader / Talisman

As can be seen from the table 9 above, most of the modern varieties are the product of a complex and distant hybridization. "Cross the best with the best" – wrote P.P. Lukyanenko [74]. This recommendation is followed by the rice breeders when creating these varieties. For example, rice variety Gamma was created by individual selection from a complex hybrid population Kurchanka / VNIIR 554-90 // Leader / Talisman. The parent forms, in turn, are the product of many years of difficult crossings where Russian and foreign rice varieties were used.

Among the varieties shown in Table 9 special place belongs to Kurchanka that shows a high salt tolerance at tillering and flowering phases (the most vulnerable stage in rice).

Chinese originario

↓

Ballila

↓

Balilla grana grosso / Nakhodka

↓

Kulon / Raduga

↓

Kurchanka

Figure 23 – Pedigree of the rice variety Kurchanka

After the rice variety Kurchanka was included into the State Register of varieties admitted for use the breeders and physiologists have adopted it as a standard of salt tolerance in rice. Moreover, this variety is often included in the hybridization as a donor of salt tolerance.

1.5 Main Pests and Diseases of Rice

Diseases and pests of plants cause the loss of 20–30 % yield. [25]. The losses observed in rice are not less, especially during epiphytoties. D. Grist [20] wrote that brown rice leaf spot contributed to a large extent to famine in Bengal in 1942, and mass propagation of bacterial blight caused famine in some parts of Japan in 1941.

1.5.1 Pests

Rice pests cause an enormous economic damage. G. Russell [97] wrote that the estimated world rice losses of yield due to pests reach 26.7 %. In the tropics, in addition to insects, birds and small animals are also considered harmful. Mice and rats devastate whole fields and can destroy a large part of the harvest during storage.

Among rice pests there are more than 100 species of insects, but only about 20 of them significantly reduce crop yield. The various types of rice moths and leafhoppers are the most harmful pests.

Rice moths (*Chilo suppressalis*) are common pests of rice in Asia. The larvae (caterpillars) boring into the rice stems and leaf sheaths cause significant losses in grain yield. Insects pupate inside the plant stem, the adult moth emerging from the pupae laid large quantities of eggs on the rice leaf blades. New rice moth larvae come out of eggs and the cycle is repeated several times during rice growing phases [145].

In the tropical countries, serious damage to rice is cause by **leafhoppers** – brown (*Nilaparvata lugens*) and green (*Nephotettix virescens*). Damaging plants leafhoppers infect them with viruses and mycoplasmas. The brown leafhopper carries rice dwarf virus, and the green one spreads several viruses causing various diseases, the most dangerous among them is Tungro. In many rice growing countries there is ongoing rice breeding reaserch for resistance to both species of leafhoppers [145], but it is particularly active at IRRI. Here there have been bred rice varieties with resistance to blight, brown leafhopper and rice moths (donor TCM-6), to blast, Tungro virus and green leafhopper (donor Gam Rai 15), as well as to the dwarfism (donor *Oryza nivara*) [133].

A significant number of pests are noted in the rice fields of Russia. So, in the Krasnodar Territory rice is damaged by 24 insect species and 2 species of crustaceans [66]. The greatest damage to rice crops is caused by barley miner, rice midge, coastal fly, common cereal aphid and shield shrimp. The harmfulness of other species does not reach tangible economic dimensions.

Leaf miner (*Hydrellia griseola* Fall.) is a small fly of ash-gray color laying eggs at rice emergence. Its larvae settle within the rice leaves and feed on their parenchyma. The leaves contacting water are damaged most. Therefore, the basis for the prevention of the harm caused by the miner is good soil leveling and observation of the water regime.

Rice midge (*Chironomus sp*.) is the most common pest of rice in Russia. The harm to rice plants is caused by its larvae. They scrape parenchyma of the underside of the leaves in contact with water and gnaw the stems of young plants. The growth of the infected seedlings is retarded and in case of larvae mass breeding the rice plants decay and die. Particularly strong damage is observed in the rice fields covered with a deep layer of water when the leaves of the seedlings are positioned on the water surface. Under the conditions of the Krasnodar Territory the rice midge develops in three generations damaging rice seedlings of all planting dates.

Triops cancriformis Bosc. feeds on rice seedlings thus leading to thinning of the rice plant stand. In some years 15–20 % of rice fields are damaged by this pest. It appears during initial flooding of the fields and develops in one generation. The triops are accumulating in the lowe parts of the rice field and die without water. Consequently, one of the ways to combat triops is a complete water discharge from the rice field for 1–2 days.

During normal years, the propagation of **common cereal aphid** (*Schizaphis gramina* Rond.) in the rice crops is not high. Many predatory insects suppress aphids' development. However, in the years with very cold winters, when many predatory insects do not survive wintering in rice fields, favorable environment conditions are created for the reproduction of aphids. Thus, the density of aphids can reach 200–250 specimens per plant. The leaves of the affected rice plants lose color, become yellow and take on a reddish hue. In case of strong aphid infestation, the leaves curl and wither. The resulting yield in such rice fields can decrease 25–30 %. The chemical treatments (2.5 % Metaphos aerial dusting) of the rice fileds with aphids' high density are recommended [66].

Considering the high level of the harm caused by cereal aphids, starting from 1977 the ARRRI conducted the study of the biology of the pest and the response of rice varieties to damage caused by aphids. Thus, 2711 selection samples of rice varieties were evaluated in 1977–1980 for resistance to aphids under natural infection. No rice samples with complete resistance to the phytophag were detected. Rice variety Plastic under state tests at that time was characterized by high endurance to aphids. In 1978–1982 the total of 1363 samples from the collections of the VIR and the ARRRI were studied. The study revealed only 30 samples of rice resistant to common cereal aphids, 18 of them are of interest as sources of resistance to aphids combined with number of positive traits [82]. Unfortunately, only two of them belong to early-maturing group (Soyuzny 244 and VNIIR 1450), the rest are medium and late maturing.

Important observations on rice cultivation practices were made in the process of studying the reaction of varieties to the damage caused by aphids. With aphids' mass reproduction, it was observed that 100 % rice plants were infested regardless of the degree of the variety resistance. However, the rates of the further aphid development on different varieties differ. During the period of maximum density of the pest in rice crops the number of aphids on resistant varieties Soyuzny 244, Zhemchuzhny, Mutant 210 is 3–6 times less than in the susceptible varieties such as Krasnodarsky 424, Spalchik, Kuban 3, on each plant of these varieties there were found 120–170 aphids. It has been determined that when aphids fed on the susceptible varieties, the pest fertility increased 28–42 % [82]. These findings allowed differentiating the use of insecticides in the fields depending on the resistance of the rice varieties, as well as adjust the breeding program of the ARRRI.

In 1989–1992 the conditions in the rice fields were unfavorable for the development of cereal aphids. Therefore, the aphids' harmful impact in production crops was hardly mentioned, but possibility of reliable check of the selection material also disappeared. In subsequent years, this work in the ARRRI was practically stopped. However, periodically (every 5–7 years) a surge of cereal aphids'propagation is observed. In this regard, it is necessary to organize the evaluation of the rice varieties and hybrids for resistance to the most common pests, including aphids, under artificial inoculation of plants.

1.5.2 Fungal Diseases

Rice plants and grain are subject to a huge number of fungal diseases. There are more than 270 species of fungal pathogens causing rice diseases, which attack tissues, organs and kernels during the growing season, as well as seeds during storage [77]. The most common diseases in rice in Russia are early blight or *Alternaria* blight caused by *Alternaria oryzae* Har ital.), other names: *Alternaria* leaf spot, blackspot; *Helmintosporium* spot disease or *H. blight* (*Helmintosporium oryzae* Br de Haan.); rice blast (blight) (*Pyricularia oryzae* Cav.); fusarium, causing root rot (*Fusarium oxysporum*) and bakanae disease of rice (foot rot, stem elongation disease of rice) caused by *Fusarium graminearum* Seh.

Of all fungal diseases rice blast deserves the most attention as the most harmful disease of rice.

Rice Blast

Blast is the most harmful among fungal diseases affecting rice. The disease is caused by the imperfect fungus *Pyricularia oryzae* Cav. Rice is susceptible to blast through all vegetation phases. The disease affects all plant aerial organs – leaves, stems, nodes, panicle (Figure 24). This is the most common and dangerous disease of rice in the world [37, 58].

a

b

c

Figure 24 – Forms of blast affecting:
a – panicles; b – nodes; c – leaves

According to various estimates crop losses in normal years reach from 5 to 25 %, and during the epiphytotic development of the disease – up to 60 % and even to 100 %. The harm increases significantly due to a sharp decline in the quality of grain produced by the infected plants. Almost all rice-growing countries suffer from heavy losses of rice yield due to blast.

Over the 80-year period of rice growing in the Krassnodar Territory a certain cyclce of blast epiphytoties have been observed. The first heavy blast outbreak occurred in 1937–1938. Then epiphytoty occurred in 1948–1949. The next blast epiphytoty was registered in almost all rice sowing regions of the Krasnodar Territory in 1972–1973.

In 1984–1985 another epiphytotic spread of blast was observvered. The losses of rice crop were significant. Ye.F. Granik and I.I. Begunov [19] wrote that in 1984 the rice variety Krasnodarsky 424 before the harvest was 88 % infested with blast, while in 1985 it was only 40 %, and the collected grain yield was 1.8 t/ha and 3.5 t/ha, respectively.

In 1984 at the farm "Protochny" of the Slavyansky region the rice variety Kuban 3 was infested to such an extent that in some rice fields there was practically no yield received.

In Teuchezhsky region of the Republic of Adygeya over 500 hectares of rice fields sown with variety Krasnodarsky 424 were affected by the paniculate form of *Pyricularia oryzae*. During inspection of these fields not a single "live" plant could be found. The yield was 0.7 t/ha of shrunk immature grain unfit for food purposes. Significant reduction of productivity caused by blast infestation of almost all varieties of rice was registered in the experiments of the Teuchezhsky State Test Plots (Table 10).

Strong development of the disease on rice plants of varieties Kuban 3 and Krasnodarsky 424 was the main cause of rapid reduction of their sowing area. There were released new regionalized varieties to replace them – short-stem varieties Spalchik, Start, Kulon, Liman, less susceptible to blast. With timely treatment with fungicides the plants of these rrice varieties are considerably less damaged by blast than the old varieties.

Table 10 – Yield of rice varieties at Teuchezhsky State Trial Plot in 1983–1984, preceding crop – perennial grasses (Krasnodar Test Station, 1984)

Variety	Yield, t/ha		Rice blast development in 1984, %	
	1983	1984	on nodes	on panicles
Kuban 3	5,62	1,88	60	24
Dubovsky 129	4,94	0,82	71	36
Antonovsky	5,69	1,92	52	22
Liman	5,20	3,85	48	20
Mutant 210	6,12	1,49	70	49
Start	6,28	3,26	36	31
Spalchik	6,64	3,66	32	28
Salsky	5,50	0,87	60	42
Krasnodarsky 424	7,20	1,62	62	34
Zhemchuzhny	7,30	1,49	68	35
Kulon	7,66	1,02	64	38
Urozhayny	5,48	0,46	72	50

The registered 10–12-year periodicity of *Pyricularia oryzae* gave grounds to forecast the next blast epiphytoty in the Krasnodar Territory by the middle of the 1990-ies. [37]. It was confirmed by the disease conquering the varieties on which it had not been previously observed.

For example, in the Crimea in 1991 blast largely affected early maturing variety Mutant 428, and in 1992 the early maturing variety VNIIR 18 hardly gave any yield in the Krasnodar Territory.

Blast was registered on the red grain forms of rice and in the late-sown varieties of Krasnodarsky 424, Laguna and others. These facts showed accumulation of infection, which as a rule occur 2–3 years before blast epiphytoty.

In 1996 in late August there were optimal weather conditions for the development of blast, when the main rice crops in the Krasnodar territory reached milky-wax and waxy ripeness. The disease caused harm only to late maturing varieties. Climatic conditions in 1997 were extremely favorable for the accumulation of infection. Already in July, at several farms the epiphytotic development of blast was observed. However, most farms had no fungicides, so by the end of the growing season about 30 % of rice crops in the area were hit by the disease. At the same time in some fields sown with Liman and Regul the plants were completely "burned" by blast.

Then favorable conditions for blast epiphytotic development were formed in 1998. The fungus survived wintering on unharvested straw and stubble. The number of red grain forms of rice, the most susceptible to the disease, increased dramatically. The farms had no means for chemical pest control. Before rice tillering, the weather favored the outbreak of blast, so the disease was detected in many farms of the region. But then came dry and hot days and that stopped blast development.

Over the next three years (1999–2001) a similar picture was observed. Blast development was restrained, on the one hand, by the weather conditions, and on the other by the lack of fertilizers (no farms "overfed" rice crops). Then some decline in the formation of this disease was noted during several years. The disease was spotted at some farms only.

As is known, optimal nutrition of rice is the necessary condition of obtaining high yield. In most farms the amount of the applied mineral fertilizers for rice has permanently been increasing since 2004. Unfortunately, this increase was mainly due to nitrogen. In 2009, the average amount of applied mineral fertilizers in the Krasnodar Territory was 178 kg a.i. per 1 hectare, the highest indicator in 16 years. However, from the point of view of the ratio of major nutrients it is the worst. In 2010, this negative trend did not change. The amount of applied fertilizers increased, but again due to nitrogen. As it was mentioned at the regional meeting of rice farmers, the share of nitrogen is 70 %, phosphorus – 26 %, and potash only 4 % in the total volume of fertilizers. With the recommended application rate of potassium 50 kg a.i. per 1 ha, in 2010 the average figure was 6.5 kg [90]. This imbalance led to execessive growth of rice plants and massive manifestation of blast. (In addition, the peak of the 11-year cycle of blast approached). The weather conditions were also favorable for the development of *Pyricularia oryzae* Cav. Warm, rainy weather in June and July caused epiphytotic increase of blast. The first signs of the disease appeared like never too early: in late June. First to be affected were the fields with dense rice stand where high nitrogen rates were applied. The situation was aggravated by the lack of reliable fungicides at the farms. For a long time fundazol and benazol were recommended and in recent years the farms started applying *Colosal* with the rate of 0.75–1.0 l/ha [102]. To save the harvest, some farms treated rice fields with fungicides two, or even, three times. These treatments and the establishment of dry weather stopped the progression of the disease. However, the negative impact of blast brought about a considerable decrease in rice yield in the affected areas and the sharp deterioration of the grain quality. In addition, lodging of the recovered crops and those overfed with nitrogen led to additional costs in harvest.

In 2011, rice farmers faced a new problem. Heavy rains in April and May prevented timely rice sowing and the sowing campaign lasted a month. Many rice growing farms used rotary spreaders SNZ-500. At the places where sowing passes met the rice plants stand was dense, and these places became blast hotbeds after nitrogen fertilization. This happened at the rice tillering phase, and at the next phase – the heading – the rice plants are particularly vulnerable to disease. In addition, weather conditions during the next two weeks were very favorable for the development of fungal diseases. In this regard, the affected rice crops had to be immediately treated with fungicides.

Early failure of crops due to rice blast (starting at tillering phase) was observed in 2012. However, in the subsequent period the weather was not favorable for the disease development. Similar development of pathogene (at rice tillering phase) was observed in 2013, but from the heading stage the epiphytotic development of paniculate forms of the disease began. It happened due to confluence of several conditions. Thus, due to the warm winter of 2012/13, the fungus wintered well on plant residues in the fields and the surrounding areas. Favorable conditions of spring and summer did not hold back its development and the facilitated the spreading of mycelium. Against nitrogen-rich background used for rice intensive technologies, with heavy fog in the mornings caused by fluctuations of day and night air temperatures, the first signs of the disease appeared at the early tillering. The massive losses of rice crop due to leaf form of the disease was prevented by proactive fungicides treatments and cutting infected plants in local spots of disease outbreaks.

The two weeks of rains in late July – early August created exceptionally favorable conditions for the development of blast. In rice crops of the average term of flooding (May 15–20) that were in the flowering stage, in the third week of July the disease turned into epiphytoty. The area of such rice fields in the Krasnodar Territory was approximately 25 000 ha. Prolonged rains did not allow timely application of fungicides or reduced their efficiency. Yield losses in such fields were very high.

Increased frequency of rice blast epiphytoties is observed in all rice-growing regions of the world. This is due, above all, to the introduction of new practices, providing for the use of high trates of mineral fertilizers, especially nitrogen. In plants overfed with nitrogen the disease develops most intensively.

In all countries fungicides are used to limit the severity of blast in rice crops. According to "Rosselkhoztcenter" in Krasnodar Territory in 2006–2012 the treated areas increased from 107 000 ha to 115 200 ha. In 2013, due to the development of blast epiphytoty 192 300 ha of the rice fields were treated with fungicides thus reaching 152.3 % of the rice sown area [3]. Some fields are treated three, four or even five times.

Russian rice growers are forced to apply fungicides using light aircrafts because there are no special machines for ground treatment of the flooded fileds, as well as due to the tight schedule of fungicide application at large areas.

Aerial application increases the cost of rice production and enhances the ecological stress since not only rice fields are treated but all other elements of the irrigation system (channels, bunks, roads.

In the Krasnodar Territory about 30 % of rice systems are located in some buffer zones where the range of the allowed chemicals is limited and the use of aerial application is prohibited. The permitted pesticides should be applied only using the ground machinery and only when necessary in accordance with the requirements of health authorities' regulations.

Practice shows that chemical products of plant protection in some cases are either inefficient (due to wrong application timing) or unprofitable (due to increasing prices of fuel, pesticides and aerial services) or cannot be used due to environmental issues. In addition, in the rice fields where chemical crop protection products are systematically applied there is a real danger of the fungus mutation, emergence of its new forms resistant to the used fungicides. Therefore, the main method of control of *Pyricularia oryzae* Cav. should be the introduction of high yielding and immune to the pathogen rice varieties. In this regard, the relevance of breeding for resistance to blast is constantly increasing, and it is impossible without creation of a reliable infection background, united efforts of the plant breeders and plant pathologists.

Biological Features of fungus Pyricularia oryzae Cav.

The biological features of the development of pathogens under specific conditions of rice growing must be known for effective control of blast. Scientists in almost all rice-growing countries are engaged in the study of this problem. A complex plant / parasite genetic system is under permanent environment impact. It produces a significant pressure on the pathogen, the host plant and their relation. Therefore, in immunological research it is important to know and consider the main environmental factors affecting the resistance variability.

The fungus *P. oryzae* is stored in the form of conidia and mycelia in rice infected seeds, on rice post-harvest residues and wild and cultural cereals. In this case, the agent of rice blast does not perish in winter at temperatures up to minus 23 ºC. The fungus maintains its viability in rice kernels for several years [150].

In rice fields the disease carriers are false wheat (*Agropyron repens*), common foxtail (*Alopecurus pratensis*), reed (*Phragmites australis*), creeping finger grass (*Cynodon dactylon*), cocksfoot panicum (*Echinochloa crus-galli*), cocksfoot (*Dactylis glomerata*), cut grass (*Leersia orysoides*), timothy grass (*Pfleum pretense*), etc. In addition, the intermediate cereals in the rice crop rotation: wheat, oats, barley, sorghum, corn are also likely to be infected by blast. Therefore, their cultivation in rice crop rotation system without scientific approach contributes to the accumulation of infection in the rice irrigation system [3].

P. oryzae multiplies through asexual reproduction by conidia. In spring at a temperature above 8 ºC the fungus mycelium grows on the overwinter stubble or straw where the spores are formed. The sporulation begins at temperatures above 10 ºC, its intensity gains momentum with rising temperature and reaches its maximum at 25–28 ºC, at 35 ºC it practically ceases. The sporulation escalates with increasing humidity above 93–95 % [134]. During the growing season the pathogen can produce 10 or more generations. During the plants intensive growth, the pathogen causes the leaf form of the disease at tillering phase, then at heading phase it involves nodes and panicles. Necrotic spots appear on infected leaves and spread into elongated oval shapes with a grayish-brown center and dark brown rim. The spots gradually increase to such an extent that the leaf dries up. In severe cases the whole plant dies. Similarly leaf form of the disease develops at the later shooting and heading phases.

When nodes are infected, the spots are usually brown, depressed, gradually turning black. These nodes usually break and the stem dies. When the upper internodes decay, the panicle dries up or breaks off. The rhachis, ramuli and kernels can be affected partially or fully. *P. oryzae* infection at the heading phase and flowering causes profound loss of kernels. In this case, 10–15 days after flowering, the seeds turn hollow, partially filled with chalky endosperm. If the infection satrted before harvest, the kernels look healthy. However, their germination is reduced; weight of 1000 grains is reduced by 15–20 % or more. It has been revealed that the toxins produced by the fungus suppress emergence of seedlings or seed germination capacity, often causing embryo death [65].

The development of blast disease is stimulated by the excess of nitrogen fertilizers. But negative correlation is revealed between potassium content in rice leaves at the shooting and flowering phases and the development of the disease. Potassium top dressing at this period increases the rice plant resistance to blast disease. It is established that nitrogen excess reduces silicon content in the leaf epidermis cells, thus causing increased vulnerability of rice plants to blast disease [153]. However, the resistance in some varieties is not affected by the type of nutrition. For example, the immunological features of the variety Tetep do not change under any conditions of nutrition [158]. Similar features are observed in the Russian rice variety Paritet originated through joint research of plant breeders and plant pathologists.

The fact that the population of *P. oryzae* consists of the races with different virulence was reported for the first time by the Japanese researcher R. Sasaki (1922). A joint effort of U.S. and Japanese scientists in 1967 generated a unified identification methodology for races of rice blast disease and proposed the unified international set of differentiators consisting of eight grades [120]. K. Ling and S. Ou (1969) proposed a system where each variety according to its reaction of susceptibility to the pathogen is the key to one of the race groups. This system allows identification of 256 races, theoretically defined with a set of eight varieties. To indicate the races that affect none of the varieties-differentiators, the authors introduced an additional group – 11.

The standard set of international varieties-differentiators was sent to almost all rice-growing countries where phytopathological and breeding research is performed. It is also available in our country being registered at the Russian Institute of Crop Production named after N.I. Vavilov (VIR) (Table 11).

Table 11 – International set of rice differentiator – varieties for *Pyricularia oryzae*

Variety	Catalog number
Raminad Str. 3	MNIIR, K-231128
Zenith	VIR, K-4765
NP-125	VIR, K-5553
Usen	VIR, K-5552
Dular	VIR, K-5551
Kanto 51	VIR, K-5550
Sha-tiao-tsao (S)	VIR, K-5280
Caloro	VIR, K-5771

This set of varieties-differentiators allows exploring any *P. oryzae* populations and determining the spread of the pathogen races in different countries of the world.

In the USSR, the study of *P. oryzae* race composition was started in 1969 by the scientists of the ARRRI [76]. From 1969 to 1979 there were identified 19 races represented by all known groups of fungus races – IA, IB, IC, ID, IE, IF, IG, IH, IJ.

Distribution of *P. oryzae* races in rice-growing areas of the USSR and then the Russian Federation was studied by the scientists of the All Union Research Institute of Phytopathology. In 1967 there were 25 races of *P. oryzae* revealed: in the Primorsk Territory (Far East) – 20, in Krasnodar – 4, in Ukraine – 5, in Azerbaijan – 4, in Astrakhan – 2, in Dagestan and Karakalpak – 1 race for each region [70].

As it was shown by the research of some authors the new races of the fungus appear from time to time. They become especially noticeable if extremely aggressive. The appearance of such races was reported from India. B. Padhi and N. Chakrabarti (1982) described a new race of *P. oryzae* isolated from varieties Tetep, Tadukan and Zenith, though these varieties were extremely resistant to the pathogen in the Indian context for quite a long time.

It is known that through the rice vegetation period *P. oryzae* gives many cycles of asexual reproduction, the duration of each of them is about one week. The blast develops according to the law of compound interest. At that, different varieties have small differences at the beginning of epiphytoty and significant differences are observed at the end.

1.5.3 Bacterial Diseases

In addition to fungal diseases on crops of rice a significant damage is caused by different bacterial diseases. One of the most common, the harmful and studied is bacterial blight caused by *Xanthomonas campestris* p.v. *oryzae*, Uyeda et Ishiyama, Dye 1978 synonym of *X. oryzae*, Uyeda et Ishiyama, 1922, Dowson). Widespread in tropical Asia is bacterial streak (*Xanthomonas campestris* p.v. *oryzicola*, Fung et al, 1957, Dye, 1978) [142]. This disease is quite harmful. In India, for example, it annually causes – 90 % reduction of the rice crop.

In 1955 in Hungary Z. Klement discovered bacterial sheath rot (*Pseudomonas oryzicola* Sp. Nov. Klement, 1955). Later it was also found in China [126], in northern Japan, as well as in Australia, where it affected the rice variety Carlrose. In 1977 bacterial root rot of rice was identified in Japan (pathogen *Erwinia chrysanthemu* – rice pathotype) [130].

A bacterial black rot of rice seeds (pathogen *X. itoana*, Tochinai, Dowson) [155] it described in Japan, it was also registered in Korea and China.

1.5.4 Viral diseases

Significant yield losses in main rice growing areas is caused by viral diseases, such as leaf discoloration, Tungro, dwarfism, grassy dwarfism, as well as viral stripe disease [96]. The most common and harmful is Tungro disease. In 1971 and 1972 it caused heavy damage to rice crops in the Philippines. The virus disease is transmitted by several species of leafhoppers. In case of infection the rice plants suffer from dwarfism, leaf spot and chlorosis.

Very malicious disease is dwarfism of rice (the causative agent is a virus *Oryza virus* l Smith.). It is transferred by leafhoppers. Infected plants are depressed in growth, tillering and root development. In heavily infested plants the panicles are absent or very small, with many sterile spikelets. At maturing the diseased rice plants remain green than makes them stand out among healthy plants. Widespread, especially in India, Ceylon and the Philippines, is a grassy dwarfism. In the years of mass infestation, the losses of rice harvest of non-resistant varieties reach 70–80 %. Plants infected at the stage of 2–4 leaves, are stunted, have too many tillers. Growing leaves become narrow and rigid. Panicles of such plants are developed weakly, with shrivelled grains [77].

The most effective form of combating viral diseases is by breeding rice varieties resistant to diseases and transmitting agents [145].

1.5.5 Rice diseases caused by nematode

Nematodes being parasitic to the rice plants are found in almost all rice-growing countries. In Russia, significant economic losses are caused by the rice leaf nematode (*Aphelenchoides besseyi* Christie, 1942, sin. *A. oryzae* Yokoo, 1948). It is also called a rice afelenhoid. The rice leaf nematode is the causative agent of one of the most dangerous diseases of rice – rice white tip. It was first discovered in the Krasnodar Territory in 1939 [77].

Besides leaf nematodes rice plants are affected by some other nematode species. Rice stem nematode (*Ditylenchys angustus*, Butler, Filipjev, 1936) is spread in East Bengal, East Pakistan, Thailand, Egypt and other countries. In 1949, it was discovered in

Uzbekistan and now it is a quarantine object. This nematode is parasitic only for rice, and is considered one of the most harmful. Nematodes pierce epidermic cells and suck out plant juice. Damaged plants have white tips of the leaves, the stems produce many tillers of the upper internode, the panicles often do not come out of the sheaths and rot inside.

In several countries, the nematodes found on rice parasitize on the underground parts of plants. These are rice root nematode, root nodosity, upland cyst nematode and other nematodes migrating in the soil of rice fields. V.P. Lukyanchikov et al. [77] provide a list of nematodes infecting rice plants. It includes 37 species. Besides rice nematode affects wheat, oats, corn, soybeans, peas, potatoes and other plants. Mass spreading of nematodes is usually regisytered in the fields where rice is grown for two years or more.

In Japan, it is found that the population of nematodes in rice fields can have up to 48 species belonging to 25 genera. Many of them are harmful for rice. After flooding the number of nematode species is reduced by half. It is considered that the creation of a water layer in the rice fields is one of the effective means to reduce damage caused by nematodes. However, breeding varieties resistant to the nematode diseases is the priority way to protect rice from the pathogen.

CHAPTER 2

Biological Principles of Rice Breeding

Breeding can be treated as science, art and a branch of agricultural production

N.I. Vavilov [15]

The application of achievements of Genetics, Physiology, Plant Pathology, and other biological sciences brings more control into the breeding process, but success is still largely determined by the practical experience and intuition of the breeder. In this, each efficient breeder is distinguished by its "hand" in the development and realization of the breeding programs [91].

The development of science-based breeding program requires knowledge not only of laws of individual plants formation but also their growth and development in the phytocenosis. It is necessary to consider the biology of the plant, its response to changing environment.

Analysis of the parameters of the production process requires a systematic approach which considers agrophytocenosis as a biological photosynthetic system capable of producing vegetative products. Carbon dioxide, water and elements of mineral nutrition are used as raw materials, while the sunlight is the source of energy.

Rice compared to other cereals does not have such an important limiting factor as water if it is not grown as upland crop. When rice is grown in water, the other biological life supporting patterns are functioning in the plants compared to upland plants. And that should be considered by the rice growers and breeders in particular, "laying" in the future cultivars productivity parameters, resistance to lodging and stress factors of the environment, as well as quality indicators of the grain. The knowledge of the crop biology should be the the foundation of the breeding programs.

Resistance of crops to diseases and pests is an important condition of the transition to the system of adaptive crop production.

2.1 Main Rice Growing Zones in the Russian Federation

In the Russian Federation, rice is cultivated at Northern Caucasus (Adygea, Dagestan, Kalmykia, Karsnodar Territory, Rostov Region and Chechnya), in the lower reaches of the Volga and in the Primorsk Territory (Far East). The grown rice varieties are only of domestic breeding.

Rice breeding in Russia, as well as rice industry has a relatively short history, less than 90 years. It is made up of events and facts: creative labor of the breeders and their varieties that played a notable role in the development of rice production. Creation of rice varieties is carried out in the main rice-growing areas: in European part of the country – in the Krasnodar Territory and Rostov Region, as well as in the Far East – in the Primorsk Territory.

2.1.1 Rice Breeding in the Far East

Rice breeding in the Russian Federation first was launched in the late 20-ies of the XX-th century in the Far East, the Primorsk Territory. About 400 000 ha of lands are suitable for rice cultivation there and supplied with water resources, not to the detriment of rainfed crop production [53]. Regional Primorsk Rice Experimental Station was established in 1926 for the development of rice production in the region. In 1927–1928 massive selection of rice populations of variety Kenzo cultivated in this area was done. The result was a series of awned and beardless varieties selected from the original population. In 1929–1930 G. A. Volozhenin started scientific rice breeding. The aim was to create a fast maturing, productive, resistant in lodging and blast variety with high quality grain. The work was carried out mainly by selecting early maturing plants with complex positive qualities from the local populations and the borrowed ones. In subsequent years, intervarietal hybridization was performed with simultaneous individual and mass selection.

In the 30-ies of the last century such varieties as Santakhezsky 13, Santakhezsky 21, Santakhezsky 52, Dichroa 213, Zeravshanika 215 were released for production. The variety Santakhezsky 52 (authors G.A. Volozhenin and V.Ye. Aleshina) was released in 1939 and widely recognized in rice growing areas. Later this variety got another name – Novoselskiy and was grown for many years by the state farms of the Primorsk Territory.

The synthetic selection combined with different selection methods was widely used during the next twenty years (1940–1960). Hybrid material exchange was organized between Dalnevostochnaya, Kubanskaya and Uzbek Rice Experimental Stations. Thus, the following rice varieties were obtained: Primorsky 6, Primorsky 10, Dalnevostochny, Dalnevostochny 5, Sputnik, DVROS, DVROS 15, Primorsky 11, Severny, Stodnevny and others. All of them have passed production tests and such varieties as Primorsky 10 (1969) and Dalnevostochny (1975) were released. The authors of these varieties are A.I. Yelagina and K.D. Krupnova.

At the next stage of breeeding (from 1960) the rice breeders of the Far East used modern hybridization methods including various complex combinations of repeated crossings, as well as radiation and chemicals to produce directed mutations. It allowed creation of a range of new varieties characterized by short stems and resistance to lodging. Precocity of these varieties combined with sufficient high productivity. Three of these varieties were released as follows: Malysh (by K.A. Kudinov et al.) in 1982 and recognized in the Primorsk Territory and Ukraine, Dalris 11 and Primorets (authors V.N. Shilovsky et al.) were recognized in 1988 and 1990, respectively, in the Primorsk Territory. In addition, in 1996 rice variety Kasun was included into the State Crop Variety Register for that area (authors V.N. Shilovsky et al.).

Despite some scientific work rice growing in the Primorsk Territory in the 1990-ies suffered: the acreage was reduced; the yields went down and low gross rice production was low. By 1997 rice sown area occupied 3700 ha, grain production was reduced

10 times. However, research and breeding activities were not stopped. Under the direction of V.N. Shilovsky who in the 1980-ies was moved from the ARRRI to help colleages from the Primorsk Territory, such rice varieties as Kasun, Primorets, Darius 8 were released and recognized.

In the recent years, there has been some recovery in rice growing in the Far East. By 2008 the rice sown area increased to 7 800 ha. Breeding research is carried out at the Primorsk Agricultural Research Institute under the leadership of V.A. Kovalevskaya, PhD (Agric. Sci.). Several early maturing varieties, among them large grain Darius 23 and Priozerny 61 and long grain Khankaysky 429 and Khankaysky 52 were accepted to the State Register of selection achievements, for the Far East area of rice cultivation [53].

2.1.2 Rice Breeding in the Don Region

The second center where rice breeding was started in the 1920-ies was the Don region. In 1926 at Percy-anovskaya Pilot Land Reclamation Station P. Witte released several varieties for periodic irrigation (White Skoms, Brown Skoms) [53]. However, these varieties had no great practical importance. Geographic location of the rice production in the Don Region, the northernmost in Russia, dictated specific requirements to rice varieties that could grow under these conditions. The varieties should be fast maturing, high yielding, undemanding to heat, suitable for early sowing dates, surviving long periods of temperatures below +8 ºC.

For a long time, the main commercial variety in the region was Dubovsky 129 created in the Krasnodar Territory. It was only from 1957 that rice breeding research as well as seed production and development of the farming practices was started at Zernogradskaya Plant Breeding Stationon (Don Breeding Center, now the All-Russian Research Institute of Grain Crops named after I.G. Kalinenko). It was led by an experienced rice breeder N.I. Kosarev. Within 10 years of research he created an original material characterized by early maturity, high productivity, resistance to lodging and diseases. Based on this material several varieties were obtained, among them Donskoy 2 and Donskoy 3 stood out, they were common in the local rice production. The variety Donskoy 2 in 1966 occupied 42 % of the rice sown area in the Don Region; it was recognized in the Ukraine and Hungary.

In subsequent years, breeding work in this region was continued by A.L. Sindetsky. He created several varieties, among which are precocious Donskoy 402, recognized in the Chechen-Ingush Autonomous Soviet Socialist Republic in 1975, and middle maturing Donskoy 63. The authors of these varieties were N.I. Kosarev and A.L. Sindetsky. Donskoy 63 became a well-known variety. It was recognized in 1969 in Kherson region, in 1970 in the Rostov region and the Krasnodar Territory, since 1973 in Rumania, since 1974 – in Hungary. These varieties played an important role in expanding the acreage of this crop in the northern boundaries of rice cultivation.

In the 1970–1980-ies the breeders of the Don Region intensified their research in connection with the arrival at the Research Institute of Grain Farming of several young scientists. Thus, at this stage nine new varieties were released, three of them were recognized: Zernogradskiy, Primanychsky and Salsky.

The middle maturing variety Zernogradskiy obtained from hybrid population Don 212 / Dubovsky 129 // Donskoy 62 was recognized in 1981 in the Chechen-Ingush Republic and replaced Donskoy 402. The authors of this variety are N.I. Kosarev, A.L. Sindetsky, V.P. Rossikhin.

Fast maturing variety Primanychsky was obtained by selection from hybrid population Dubovsky 129 / Bolshevik, recognized in the Rostov region since 1982. The authors of the variety are A.L. Sindetsky and others. The variety has an elongated grain; it is one of the best varieties with quality milled rice.

The variety Salsky was recogniazed in 1985 in Ast-rahan region, in Kalmykia since 1987, in the Rostov region – since 1988. Their authors are A.L. Sindetsky and others.

All of the above-mentioned varieties of rice bred at the Don Region are based on the variety Dubovsky 129 and therefore have milled rice of excellent quality. A common shortcoming of these varieties is very high susceptibility to blast, especially when grown in the areas with the prevalence of the disease. This is one of the impediments to the expansion of the areas under varieties of the Don Region breeding. Therefore, in the Rostov and Astrahan areas (coverage area of the Donskoy Breeding Center) Kuban 3 remained the main variety till 1991, occupying 62 % of the rice sown areas.

To enhance the stability of the genetic basis of rice resistance to blast the Don breeders during the period of 1981–1984 conducted a large-scale research for obtaining interspecific rice hybrids. Following the hybridization between the varieties of cultivated species *Oryza sativa* and 14 wild rice species using embryo culture, there were obtained 107 combinations of interspecies hybrids. All of them were resistant to *Pyricularia oryzae*. From hybrids with *O. nivara*, *O. perennis*, *O. rufipogon* in the second – fourth generation, after backcrossing, followed by selection some plants of significant interest were isolated as a starting material for further breeding. Obtaining interspecific hybrids of rice in such a large amount has implications not only for theoretical purposes but for breeding practice, this is an important stage in rice breeding research in Russia.

In the following years at the Donskoy Breeding Center several varieties were released based on the hybrid material received as exchange material from the ARRRI. Two of them were recognized: Privolny since 1989 in the Rostov region and Budennovsky from 1991 in Dagestan. The variety Privolny was created by selection from a hybrid population VNIIR-5001 / Cesario (France). The authors of the variety are V.P. Rossikhin and others. The variety Budennovsky was selected from the population Anseatico 230-67 / Spalchik. The authors of the variety are V.P. Rossikhin and others.

By means of individual selection the variety Razdolny was created from the variety Budennovsky. The authors are V.P. Rossikhinb and others. This variety is included in the Register of selection achievements for the region of the North Caucasus since 1993, and in 1994 – for the Lower Volga.

The variety Contact is created by selection from a hybrid population K-5885 × (M-210) / Belozerny. The variety M-210 is a mutant obtained in the VNIIR from the variety Donskoy 63. The authors are V.P. Rossikhin and others. This variety is included in the Register of selection achievements for the region of the North Caucasus since 1994.

The early maturing variety of rice Virage was created by selection from hybrid population Budennovsky / Primanychsky. The authors are P.I. Kostylev and others. The variety possesses field resistance to blast. It is included in the State Register of the Russian Federation for the region of the North Caucasus since 2000.

Boyarin, the middle maturing rice variety, was received by selection from hybrid population Salsky / Privolny. The authors are P.I. Kostylev and others. The variety is included in the State Register of the Russian Federation for the region of the North Caucasus since 2002.

The long grain variety Svetly was obtained by selection from hybrid combination Ortikon / Primanychsky. The authors are P.I. Kostylev and others. The variety is included in the State Register of the Russian Federation for the region of the North Caucasus since 2006.

The middle maturing variety Comandor was received by the selection from the hybrid combinations Proletarsky 2 / Privolny. The authors are P.I. Kostylev etc. The variety is included in the State Register of the Russian Federation for the region of the North Caucasus in 2009. The variety Comandor has field resistance to blast, it is cold-resistant, so it can be used for sowing in early April obtaining seedlings using natural reserves of moisture in the soil [53].

Thus, rice breeders of the Don Region under the direction of P.I. Kostylev, Dr. Sci (Agric.) reached high results.

2.1.3 Rice Breeding in the Krasnodar Territory

The third and the main center for the breeding of rice in Russia developed in the Kuban area (the Krasnodar Territory). In 1931 in Krasnodar All-Union Scientific Research Institute of Rice Farming was organized on the base of the Azov Experimental Rice Station, reorganized then into the All-Union (1937), and later the Kuban rice experimental station (1956). From the latter All-Union (now – All-Russian) Rice Research Institute (ARRRI) was established in 1966 [118]. Here in 1932, G.G. Gushchin and T.I. Dubov began a large-scale rice breeding research by studying 1509 collection samples collected by N.I. Vavilov. In those years, the breeders had the task to create productive early maturing varieties resistant to blast. Simultaneously the research was directed at rice seed production and agricultural practices.

Several stages can be highlighted in the history of rice breeding of the Kuban area. During the first stage, in the early 1930-ies, several high-yielding varieties were created by method of analytical selection, three of them were recognized – Kenzo, Krasnodarsky 3352 and VROS 3716 [53].

The first in the Kuban area commercial rice variety Kenzo (Figure 25) was created by a massive selection from the population brought from the Far East. It was grown over more than 20 years. Kenzo was the progenitor of more than twenty new varieties of rice (Figure 26).

Figure 25 – Rice variety Kenzo
at panication and maturing

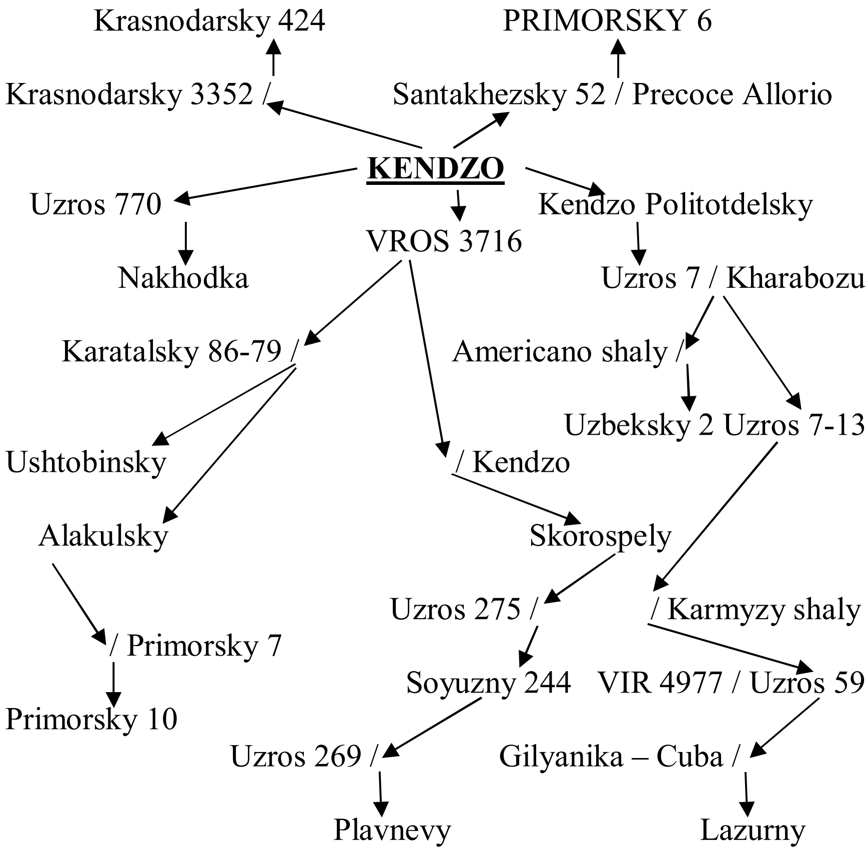


Figure 26 – Rice varieties created with participation of the variety Kendzo

The variety Krasnodarsky 3352 (created by T.I. Dubov) was recognized in the 1942–1964 and it was widely used in commercial rice production. Furthermore, it is often used in the hybridization. Based on Krasnodarsky 3352 some new rice varieties were created Dubovsky 129, Krasnodarsky 424, Horizont, Spalchik, etc. (Figure 27).

The rice variety VROS 3716 (authors O.S. Natalina and T.I. Dubov) was also widely cultivated. It was in production till 1966 and often used in breeding. Such early-maturing varieties as

Soyuzny 244, Alakulsky, Ushtobinsky, Primorsky 10, and others were bred from it.

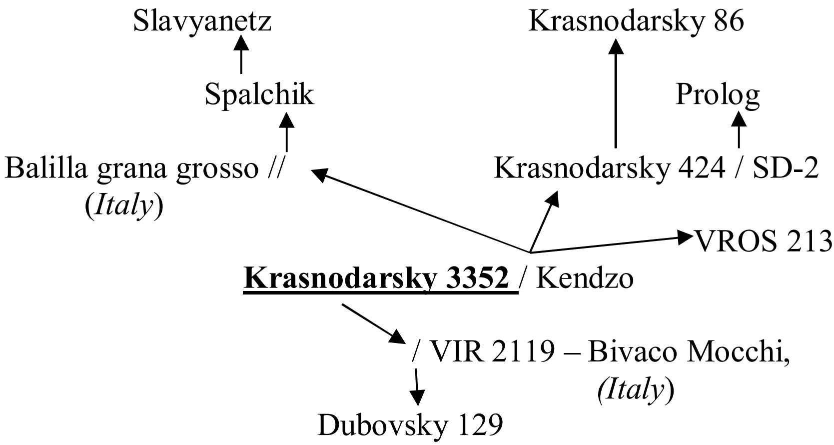


Figure 27 – The varieties of rice created with participation of krasnodarsky 3352

Starting from 1937, the synthetic method of breeding began to be added to the analytical one, thereby creating a few varieties that are not inferior in terms of productivity to the former varieties, but more early maturing. Some of them were recognaized: VROS 5133 in 1951, VROS 213 in 1952, VROS 5123 in 1953 (Table 12).

Table 12 – Rice varieties created at the first stage of breeding (1932–1950)

Variety	Handover for State Variety Tests, year	Year	
		of insertion into State Register	of exclusion from the State Register
Kendzo	1934	1936	1956
Krasnodarsky 3352	1939	1952	1960
VROS3716	1944	1961	1994
VROS5123	1945	1953	1966
VROS5133	1945	1951	1964
VROS213	1948	1952	1964
Dubovsky 129	1948	1952	1982

VROS 213 was recognaized in 1952–1964 and occupied up to half of the rice sown areas in the Krasnodar Territory (authors O.S. Natalina, T.I. Dubov). A significant achievement in rice breeding in Kuban area was creation of high yielding earlymaturingvariety Dubovsky 129 (authors S.A. Yarkin, T.I Dubov, O.S. Natalina).

With the growing season of 100–110 days, this variety formed yield, not inferior to the middle maturing varieties, it also gave graoats of excellent quality. The variety was recognized in 1952, first in the Krasnodar region, and then in other rice-growing areas of the country, occupying about 30 % of the total area under rice in the then USSR.

In 1956, Dubovsky 129 was recognized in Hungary, where it was the main rice variety and cultivated for more than 20 years. In Russia, the variety Dubovsky 129 was grown commercially until the end of the 1970s. (Figure 28).

Figure 28 – The rice variety Dubovsky 129

Based on Dubovsky 129 such regognized varieties as Altair, Solaris, Zernogradskiy, Primanychsky, Danay and others were bred (Figure 29).

It should be noted that the plants of Kenzo and and Dubovsky 129 varieties were spinous. The subsequent varieties created in our country were beardless.

At the second stage of rice breeding research the hybridization became the main method of creation of the source material. This allowed breeding varieties that best met production requirements.

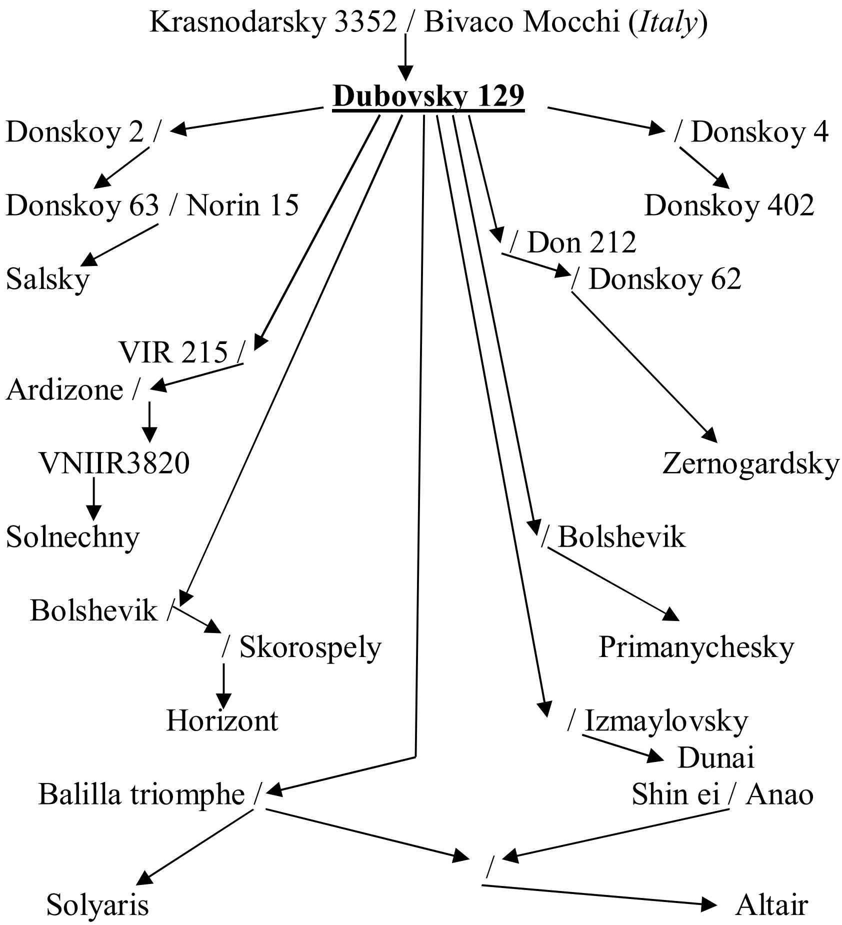


Figure 29 – Rice varieties created with participation of Dubovsky 129

Among these varieties was Krasnodarsky 424 (Figure 30), selected from the hybrid population Krasnodarsky 3352 / Kenzo. The authors of this variety are O.S. Natalina, S.A. Yarkin, N.P. Krasnook, F.K. Dayanov, T.I. Dubov. This highly productive meddle latematuringvariety, characterized by the plasticity, resistance to adverse environmental factors, was recognized in 1956 and occupied the major sown area in the European part of Russia, Ukraine and in Kyzyl-Orda region of Kazakhstan.

Figure 30 –Krasnodarsky 424 rice variety

In 1981, the area covered by Krasnodarsky 424 reached its maximum 227 100 hectares, in the subsequent years its acreage decreased significantly due to the introduction of new varieties. Krasnodarsky 424 was recognized in Bulgaria and Romania, where it also occupied main rice sown areas. Its recognition in Turkey was also reported.

Krasnodarsky 424 "worked" in the commercial rice production for 45 years. This is a record beaten only by the rice variety Kuban 3, which was cultivated for 52 years and still is not excluded from the State Register.

From 1957 at the Kuban Rice Experimental Station (formerly Institute of Rice Farming) there are two clearly identified areas in rice breeding: creation of middle maturing varieties with growing period of 119–125 days and fast maturing ones with growing period of less than 105 days. Over a ten-year period (1958–1967) there were created four fast maturing varieties: Krasnoarmeysky 313, Skorospely 8, Nakhodka, Soyuzny 244, which excelled standard Dubovsky 129 for individual or multiple traits. [19]

The rice variety **Krasnoarmeysky 313** was recognized in the Kuban region in the period from 1959 to 1965. The authors of the variety are T.I. Dubov, O.S. Natalina, S.A. Yarkin, N.P. Krasnook.

The variety **Kuban 3** (Figure 31) created by individual selection from the rice variety Krasnoarmeysky 313 was recognaized in 1963.

Figure 31 – The rice variety Kuban 3

The authors of the variety are S.A. Yarkin and A.P. Smetanin. Kuban 3 was exceptionally undemanding to growing conditions, which explains the large increase in its acreage. In 1981, the area sown with this variety reached a maximum value of 195 000 hectares, occupying the second place after varieties Krasnodarsky 424. These two varieties together occupied in 1981 more than 67 % of rice sown areas in the then USSR (Table 13).

Compared with other varieties Kuban 3 tolerates deep flooding better, it is less sensitive to low temperatures, is also characterized by a fast growth during the first growing phases. Therefore, it is best suited to the zero herbicides agricultural practices.

Table 13 – The rice varieties created during the second stage of breeding (1951–1969)

Variety	Handover for State Variety Trials, year	Year	
		of insertion into State Register	of exclusion from the State Register
Krasnodarsky 424	1952	1956	2001
Krasnoarmeysky 313	1953	1959	1965
Kuban 3	1960	1963	–
Kuban 9	1964	1974	1983
Horizont	1970	1975	1992

Only the variety's weak resistance to lodging and blast limited its spreading. However, the variety Kuban 3 is still cultivated in the Astrakhan and Rostov regions, Kalmykia and Kazakhstan. In subsequent years, the varieties Kuban 9 and Horizont were created and recognized in the Astrakhan region and Kalmykia.

With the re-creation on the base of the Kuban Rice Experimental Station of the All-Union (now All-Russian) Research Rice Institute in 1966 rice breeding received a powerful impetus for further development. The fact that almost all created in the country varieties of rice until the mid 1960-ies were characterized by tall plants and that caused their lodging when the rates of the mineral fertilizers were increased. This made difficult rice harvesting and resulted in increased grain losses.

The program for rice breeding was headed by A.P. Smetanin. The breeders had a task to create a new type of rice varieties – of short stature, combining high productivity with excellent grain quality, resistant to lodging, diseases and pests, thus meeting the requirements of the intensive agrotechnologies allowing obtaining yields of 9.0–10.0 t/ha.

Based on many years of work on creation of rice varieties A.P. Smetanin developed a new shortened breeding program for this crop. It was started at the ARRRI in 1967. The breeding nursery was laid against two backgrounds of nitrogen nutrition. This allowed assessings the breeding materials for resistance to blast, lodging and high nitrogen rates at the early stages of breeding. The further acceleration of the breeding process was proposed by obtaining two plant generations per year and conducting environmental research [104, 105].

During this period the collection of the All Union Institute of Plant Industry (VIR) received a series of short-stem, resistant to lodging foreign rice varieties: Anao (Portugal), Norin 19, Norin 25, Shin ei (Japan), Balilla grana grosso (Italy), Balilla triomphe (Morocco), and others. These varieties were widely used in hybridization. Preference was given to samples of the short geographical distance, especially Italian and Japanese. This was the beginning of the third stage in rice breeding.

To expand opportunities of the breeders in the selection of the starting material in 1968 at the ARRRI, N.N. Davydov initiated research of the experimental mutagenesis. The used mutagens were chemicals: methylsulfate and di-Nitrozometilurea, and radioactive emission: Gamma-rays (Cs137). As the result, there were received the first mutants with several valuable breeding traits: short stature, early maturity, resistance to lodging, high yeild, etc. At the same time the research on the genetics of rice was resumed.

In 1968, in the population of the variety Krasnodarsky 424, as well as in several other hybrid populations G.A. Singildin selected plants with male sterility. The discovery of sterility in rice gave new opportunities to improve the efficiency of hybridization. Using the form with the genetic male sterility (from Krasnodarsky 424) 20–25 % hybrid seeds were received with free pollination with minimal manual labor. Genetic analysis revealed that this type of sterility is monogenic recessive trait. This determined the technique of multiplication of the sterile forms and methods of its use in the breeding program. In addition, R.V. Tretyakov and T.G. Mazur conducted active research on improving methods of artificial cross-breeding of rice, as well as propagation of the hybrid material.

In 1970, the development of methods for receiving polyploid plants of rice was started at the ARRRI. The first polyploids were created by S.V. Shcherbak in five varieties and samples. It was foreseen that this method could be used to obtain polyploids of interspecific hybrids to overcome their sterility.

To accelerate the development of advanced varieties and their rapid introduction into commercial production in 1971 the All-Union Rice Breeding Center was established at the ARRRI, this center united the efforts of scientists of Russia, Ukraine, Uzbekistan and Kazakhstan. New departments, laboratories were set up in many scientific institutions, staff expanded, new equipment was received and new greenhouses were built.

One of the tasks of the Breeding Center created at ARRRI was to provide research institutes working in the sphere of rice breeding in other regions of the country with the source materials. Exchange of collections and hybrids resulted in breeding several varieties with the joint authorship of the ARRRI and the corresponding institute.

In the Donskoy Breeding Center, in addition to the rice varieties Privolny and Budennovsky, the rice variety Ortikon was selected from ARRRI hybrid material and sent for the State Trials; in the Far East, the rice variety Primorets was created and recognized in the Primorsk Territory; rice variety Tolmas was bred in Uzbekistan and recognized in Karakalpakia, Syrdaria, Tashkent and Khorezm regions; in Ukraine, the rice variety Perekat was bred and recognized in Kherson region. These facts testify to the efficiency of the ARRRI Breeding Center.

Such intensive breeding and genetic research at the ARRRI produced a few of rice varieties of the new short-stemmed plant type. In 1972–1973 the best of them were transferred for the State Variety Trials. Among them there were the fast maturing variety Belozerny, middle maturing Kubanets 575 and middle late maturing VNIIR 1160 with longish grain of excellent quality. However, despite the range of positive qualities, these varieties were not recognized. One of the reasons was the farms inability to cultivate these dwarf varieties. Agrotechnical support of the new type of rice varieties was not provided in full. However, the positive experience in the process of production testing of these varieties was accumulated and it allowed changing the agricultural methods and psychology of the rice farmers, and by the end of the 1970-ies – early 1980-ies the short stem varieties began to be commercially grown in the Krasnodar Territory and then across the country.

In 1980, for the first time in the Krasnodar Territory the two varietis Spalchik (by A.P. Smetanin et al.), semi-dwarf of intensive type, and Start, of the middle maturing (by V.N. Shilovsky et al.) were recognized.

In 1982, several varieties were included in the State Register: Zhemchuzhny of middle late maturing (by A.P. Smetanin et al.), Solnechny of middle maturing in Kalmykia and Kazakhstan (authors V.N. Shilovsky et al.), Altair, middle maturing with elongated grain, in Chechen – Ingushetiya (by L.A. Kucherenko et al.) and early maturing Solaris in Kalmykia and the Astrakhan region (by L. A. Kucherenko et al.).

So, over the 50-year period the industrial base of domestic rice production was created in the Kuban, the area of rice engineering systems increased from 50 hectares in 1930 to 256 000 ha in 1980. The total rice yield in the Krasnodar Territory gradually reached 1 016 000 t. The total gross rice yield of rice produced in Russia in 1980 was 1 486 000 t. This result was obtained due to the collection of rice varieties created over the period by the leading breeders of the country. Among them were the G.A. Volozhenin and A.I. Yelagina in the Primorsky Territory, N.I. Kosarev and

A.L. Sindetsky from the Rostov Territory, T.I. Dubov, S.A. Yarkin, O. C. Natalina and A.P. Smetanin in the Krasnodar Territory. They provided the foundation of rice breeding science in Russia, and a galaxy of talented breeders grew there in the coming years. They, in their turn, created a new generation of modern varieties for the modern domestic rice production [53].

The main achievement in rice breeding in Russia was the establishment of the beginning of the 1980-ies of the varieties of the new generation: Spalchik, Start, Zhemchuzhny, Solnechny, Altair and Solaris. All new released varieties fully met the requirements of modern production. They were of short stature, characterized by high productivity, resistance to lodging, responsive to mineral fertilizers [54].

Out of this series of varieties, Spalchik was the most widely used. Besides the Krasnodar Territory it was recognized also in the Crimea and Kherson regions of Ukraine and in Dagestan. The rate of increase in acreage covered by this variety (Figure 32) in the regions where it was recognized were quite significant: in 1980 – 3 500 ha, in 1981 – 6 800 ha; in 1983 – 22 200 ha; in 1985 – 70 100 ha; in 1987 – 137 500 ha; in 1989 – 143 700 ha (the first place among all the varieties of rice sown in the Soviet Union). With the advent of new varieties, the sown area under Spalchik began to shrink, in 1991 it was sown at 88 900 ha.

This variety was widely used due to its resistance to low air temperatures in the period of emergence (+11...+14 °C), increased resistance to soil salinity, effective use of nitrogen fertilizers that makes it possible to form a high tield (up to 10 t/ha). Spalchik was included in the list of the most valuable varieties with high quality milled rice. The third stage selection was crowned by the creation of the varieties Liman and Kulon.

The rice variety Liman (authors V.N. Shilovsky et al.) was received from the hybrid population Baldo (VIR 4990) / line (Anao // Cha-shih-1) and recognized in the Kuban Region in 1986, and in Kyzyl-Orda region Kazakhstan since 1987 (Figure 33).

The rice variety Liman (authors V.N. Shilovsky et al.) was received from the hybrid population Baldo (VIR 4990) / line

(Anao // Cha-shih-1) and recognized in the Kuban Region in 1986, and in Kyzyl-Orda region Kazakhstan since 1987 (Figure 33).

Figure 32 – The rice variety Spalchik

Figure 33 – The rice variety Liman

Liman matures within 118–122 days, plant height is 75–86 cm, the yield can be 6.0–7.0 t/ha. In 1986, the maximum yield of this variety – 10.2 t/ha was received in Krasnoarmeysky State Trials Center on alfalfa as predeceeding crop. Later it became known that Lyman is less demanding to growing conditions than Spalchik, and in a short period of time Liman was replaced by Spalchik.

The variety Kulon (authors A.P. Smetanin et al.) was receieved by individual selection from the hybrid combination Catalano (VIR 5206) / VNIIR 6031 (Balilla grana Grosso / Cross 3830). This variety is middle maturing, its growing season is 122–132 days, plant height 85–90 cm, with the yield of 6.0–8.5 t/ha, long-grain, with the highest quality of the milled rice. This variety was recognized and sown from 1987 to 2001, and it was only because of its late maturing that Kulon was removed from commercial production.

Kulon, Spalchik and Liman stayed longer than any other varieties in the commercial production (14, 25 and 28 years, respectively) compared to the other varieties that belonged to the same breeding stage (Table 14).

Table 14 – Rice varietied received at the third stage of breeding (1970–1985)

Variety	Handover for State Variety Trials, year	Year	
		of insertion into State Register	of exclusion from the State Register
Start	1974	1980	1987
Spalchik	1975	1980	2005
Solyaris	1978	1981	1997
Altair	1978	1982	1990
Zhemchuzhny	1978	1982	1990
Solnechny	1979	1982	1994
Liman	1983	1986	2014
Kulon	1983	1987	2001

The increased demands of these short-stem varieties Spalchik and Lyman to the growing conditions served as a motive for the scientists and rice farmers to change rice cultivation methods: increasing its intensity, using higher rates of fertilizers and changing their application schemes.

The negative reaction of plants of these varieties to the water layer at emergence predetermined dramatic expansion of the volume of leveling in the rice fields. The biological features of the short stem varieties displyed during their commercial production, made the breeders look for the factors to be considered when planning new breeding programs. [54]

The late 1970-ies – early 1980-ies are characterized by beginning of the new (fourth) stage in the breeding programs of the ARRRI:

1. New directions in breeding appeared: in addition to early maturing (V.N. Shilovsky) and middle maturing varieties (A.P. Smetanin, V.S. Kovalev) the research was launched on the creation of cold-resistant (L.I. Bubieva) and salt tolerant varieties (V.K. Sorokin).

2. The scope of biotechnological research was expanded to benefit breeding programs (L.A. Kucherenko).

3. The construction of the ARRRI phytotron was completed, operation of artificial climate chambers allowed the transfer of the rice breeding cycle to all year-around chedule.

4. The contacts and interaction of plant breeders, geneticists, physiologists, plant pathologists, specialists in Biotechnology, agricultural machinery, and other specialists of the ARRRI and other research institutes significantly expanded. Special infection background facilities were establisged for the evaluation of the breeding material: in 1982 to check the resistance to blast and in subsequent years – to the rice leaf nematode and bacterial blight, to use them for the dedicated breeding programs to develop these traits (G. L. Zelensky).

To carry on the research by this time a strong scientific and industrial base was created in the ARRRI. The Institute moved to a new contemporary building. All laboratories necessary for the implementation of the research plan were organized as well as offices with comfortable conditions for the employees. The work on installation of the phytotron complex with artificial climatic chambers (ACC), greenhouses and the growing plots were completed. An experimental irrigated plot (EIP with various types of fields was built to carry out field tests. In addition, several farm buildings: a car garage, a mechanical workshop, seed warehouses with complexes of seed thrashing and drying machines, etc. were built. Besides a residential area for the employees of the Institute with the symbolic name "Belozerny" was established with developed infrastructure (schools, kindergarten, shops and other facilities).

Creation of the ARRRI as a leading research center is largely the merit of G.A. Romanenko, the then Director-General from 1969 to 1978, now Academician and Vice-President of Russian Academy of Sciences. In a short time with his participation, many organizational and technical issues associated with the construction of the complex of buildings of the Institute, the formation of the research team have been resolved. In addition to the experienced scientists a few dozens of young researchers were admitted at the ARRRI. Under the guidance of hardy mentors, they were actively involved in the research.

In 1982, after A.P. Smetanin, Head of the Breeding Department, left the ARRRI for teaching in the Kuban Agricultural Institute, the department was headed by V.A. Dzyuba, Dr. Sci. (Biol.), an experienced specialist in the genetics of rice. He devoted much attention to the organization of joint research of plant breeders, geneticists, plant pathologists, biotechnologists, physiologists, agricultural technicians and other specialists.

In subsequent years, the Breeding Department was headed by a number of scientists each of them contributing to the development of the breeding research the ARRRI: V.S. Kovalev, G.L. Zelensky, A.I. Aprod, V.N. Shilovsky, all of them the Doctors of Agricultural Sciences [54].

With the advent of the new research trends at the fourth stage the breeding programs for the short stem rice plants were started. Due to the complex approach to the research the new rice varieties with short culm appeared sufficiently quickly and they became widely used in the production. Each variety handed over for trials was accompanied by a passport of technology, the development of which was attended by almost all specialists of the Institute.

One of the first results of the fourth stage of rice breeding were the rice varieties transferred to State Variety Trials in the late 1980-ies and regionalized in the Kuban region in the early 1990-ies (Table 15).

Table 15 – Rice varieties received at the fourth stage of breeeding (1986–1996)

Variety	Handover for State Variety Trials, year	Year	
		of insertion into State Register	of exclusion from the State Register
Aprelsky	1985	1987	1989
VNIIR8847	1986	1990	1996
Krasnodarsky 86	1986	1990	2004
Slavyanetz	1987	1991	2007
KPH-1	1987	1993	1997
Pervotzvet	1987	1992	2001
Vevel	1988	1994	2000
Nautico	1990	1995	2001
Laguna	1991	1995	2001
Regul	1992	1995	–
Pavlovsky	1992	1995	2003
Nafant	1992	1997	2003
Rapan	1993	1996	–
Sprint	1993	1996	2008
Kurchanka	1994	1997	2011
Viola	1994	2001	–
Izumrud	1996	1999	2006
Serpantin	1996	2001	2011
Snezhinka	1996	2004	–

In 1990, rice variety Krasnodarsky 86 was recognized for growing under zero herbicide technology. It was obtained by selection from the varieties Krasnodarsky 424. The group of authors (12 scientists) included specialists of the Kuban Agricultural Institute and the ARRRI: N.P. Krasnook, S.B. Mosin and others.

In 1991, the medium-ripe variety Slavyanets with short stem was recognized (by G.L. Zelensky and others). It was received by individual selection from rhe variety Spalchik. Slavyanets is the most resistant to blast among other varieties cultivated in the Krasnodar Region in this period.

In 1992, two cold-resistant varieties were recognized for sowing in early April: middle maturing KPH-1 (by L.I. Bubieva and others) and ultra-fast maturing within 80–87 days, Pervotzvet (authors L.I. Bubieva and G.D. Los). Pervotzvet was of particular interest to the northern rice-growing areas of the country: the Astrakhan and Rostov regions and Kalmykia.

Besides, during these years several varieties created according to special programs were released for the State Variety Trials: Bioriza obtained by Biotechnology methods, cold-resistant varieties Rodnik, Surprise, Vernaris, SPH-258 and KPH-152, salt-tolerant Pilot, blast resistant Paritet and Blastonik with the blast race specific resistance, Pavlovsky and Sprint with the field non-specific resistance to blast. At the same time Paritet was high salt tolerant.

In 1994, the rice variety Vevel bred from the compound hybrid population VNIIR 6427 / Krasnodarsky 424 // Balilla grana Grosso / CROS 68 /// Baldo was accepted for the State Register of Breeding Achievements approved for use in the North Caucasus. The authors of this variety are V.S. Kovalev and others. In 2001, the variety was excluded from the State Register.

The same year the variety **Viola** is included in the State Register, the first domestic glutinous rice intended for the development of children's and wholesome food. The variety was created by selection from hybrid population received after complex multi step crossing. The authors are G.L. Zelensky, G.D. Los, V.G. Krasnikov. In 2001 this breeding achievement was protected by the patent (No 0946).

Since 1995 four different types of rice varieties: Nautico, Pavlovsky, Laguna and Regul, were included into the State Register of Breeding Achievements approved for use in the North Caucasus, (the breeding programs in the ARRRI were gaining momentum due to intensive research of the young breeders).

The rice variety **Nautico** Variety was created by selection from hybrid population VNIIR 2342 / CP 584. The authors are V.S. Kovalev and others. The variety was intended for no-herbicide cultivation. But due to its high susceptibility to blast this variety was excluded from the State Register.

The variety **Pavlovsky** (by G.L. Zelensky et al.) was received by individual selection from the hybride population Prikubansky / VNIIR 1614-90 under conditions of blast infection nursery. The variety is characterized by a large elongated high quality grain.

The variety **Laguna** obtained by selection from samples of VNIIR 9009, which in its turn was the product of selection from a complex hybrid population. The authors of this variety are V.S. Kovalev et al. This variety is intended for no-herbicide technology.

The variety **Regul** (the authors – V.N. Shilovsky et al.) was received by reselection from a line derived from hybrid population VNIIR 6427 / Krasnodarsky 424. It is a universal variety with excellent quality of elongated grains.

In 1996, the early maturing rice variety **Sprint** was introduced in the State Register; it was selected from hybrid population Kr-3-84 / Spalchik. The authors of this variety are G.L. Zelensky et al. This variety is intended for no pesticide technology. Given its fast maturing (90–95 days), Sprint can be used as a kind of insurance at the later sowing dates, as well as the second crop after harvesting winter barley.

The same year, 1996, the rice variety **Rapan,** middle late maturing, was accepted into the State Register. It was selected from hybrid populations VNIIR 8847 / Belozerny. The authors are V.S. Kovalev et al. This is a multi-purpose variety, with good adaptive traits.

The year 1997 was marked by the inclusion in the State Register of varieties of the new type of rice plant: the first domestic salt tolerant variety Kurchanka and the first Russian bred long-grain variety Nafant.

The variety **Kurchanka** was received by multiple selection from the hybrid population Kulon / Raduga that had been received, in turn, as a result of the complex hybridization. The authors are G.L. Zelensky et al. In contrast to other salt tolerant rice varieties, the plants of Kurchanka were resistant to salt stress at both critical phases: a) emergence – sprouting and b) heading – flowering.

The variety **Nafant** was selected from the hybrid population VIR 7936 / VNIIR 6454. The authors are V.S. Kovalev et al. This variety belongs to the Indian sub-species, provides the highest quality milled rice. Only its weak resistance to lodging contained commercial spreading of this variety.

In 1998, the early maturing long grain rice variety **Izumrud** was introduced in the State Register. It was derived from the same hybrid population as Nafant. The authors are V.S. Kovalev et al.

In the 1990-ies, when the economical situation in the country changed and the prices for fuel, fertilizers and pesticides went sky-high, commercial production required low demanding rice varieties, allowing application of low energy consuming technologies, disease-resistant, capable of producing shoots from the water layer, not requiring high rates of mineral fertilizers. The breeders started the breeding programs in this direction well in advance aiming at development of such varieties, and they were fast enough to offer them for commercial production.

These are varieties Leader, Regul, Sprint, Fontan, Druzhny, Atlant, Flagman and others. Undemanding to growing conditions these varieties made it possible to overcome the crisis in the rice growing in Russia and continue its dynamic development. The varieties of this period can be to referred to as the fifth stage of rice breeding in Russia (Table 16).

In 2000, the middle late maturing variety Leader was accepted into the State Register for the North Caucasus, it was selected from hybrid population Kulon / Kuban 3 // Belozerny. The authors of the variety are G.L. Zelensky and others. The plants of this variety upon emergence grow quickly and easily overcome the water layer and this allows growing rice without herbicides. This feature is successfully used in Kazakhstan, where on the saline lands the seedlings are obtained only through the water layer. In 2010, the rice variety Leader occupied in Kazakhstan 20 % of the rice sown areas.

Table 16 – Rice varietied created at the fifth breeding stage (1997–2007)

Variety	Handover for State Variety Trials, year	Year	
		of insertion into State Register	of exclusion from the State Register
Leader	1997	2000	–
Zhemchug	1997	2001	2006
Khazar	1998	2000	–
Serpantin	1999	2001	–
Fontan	2000	2002	2011
Druzhny	2000	2004	2011
Yantar	2001	2004	–
Bioletta	2001	2007	–
Ametyst	2002	2004	–
Atlant	2003	2007	–
Novator	2004	2006	–
Garant	2004	2007	–
Flagman	2005	2007	–
Severny 8242	2007	2009	–
Sonata	2007	2009	–
Yuzhny	2007	2009	–

The same year 2000 the middle maturing variety **Khazar** of the intensive type selected from hybrid population VNIIR 9531 / VNIIR

9020-84 was accepted in the State Register. The authors of the variety are V.S. Kovalev and others. The plants of this variety germinate slowly, and this special feature should be considered and "soft" water regime shall be observed.

In 2001, a fast maturing variety **Serpantin** selected from hybrid population Szarvashi carsu / Unggi 9 was introduced into the State Register for the North Caucasus. The authors of the variety are N.V. Ostapenko and others. The variety is salt tolerant during emergence and that is why rice growers of Astrakhan, Rostov Region and Kalmykia are interested in it.

In 2002, a fast maturing variety Fontan selected from hybrid population Liman / Line (KP-99 / L-33) was included in the State Register for the Lower Volga Region. The authors of the variety are N.V. Ostapenko and others. The variety has the rapid growth in the initial period of ontogenesis, thus these plants easily overcome the water layer.

The year 2004 was a particularly fruitful for the recognition of rice avrieties: the State Register admitted four new varieties characterized by high quality grain – Amethyst, Druzhny, Snezhinka and Yantar.

Middle maturing **Amethyst** was created by the method of individual selection from variety VNIIR 8847. Its authors are V.S. Kovalev et al. The plants of this variety grow slowly after germination, so they require a "soft" water regime.

The middle late maturing variety **Druzhny** was selected from the hybrid population VNIIR 6473 / VNIIR 5200. It was bred by V.S. Kovalev et al. The variety has increased tolerance to salinity.

The long grain mid-term late variety **Snezhinka** was selected from the hybrid population VNIIR 7630 / NF-DZ-84 (VNIIR 7630 / Spalchik), belongs to the Indica subspecies. The authors are G.L. Zelensky et al. The variety is highly resistant to blast and lodging; it gives grain of excellent quality.

Middle maturing variety **Yantar** was selected from of hybrid population ST-101 / M 705. The authors are V.N. Shilovsky et al. It has large elongated grains.

In 2006, the early-maturing variety of rice **Novator** was included in the State Register in the North Caucasus and the Volga region. It was selected from the hybrid population Prikubansky / Italica 10. The authors are V.N. Shilovsky et al. The variety is characterized by rapid growth at emergence so it can be grown without applying herbicide against gramineous weeds.

In 2007, three rice varieties: Atlant (by G.L. Zelensky et al.), Garant (by V.S. Kovalev et al.) and Flagman (by V.N. Shilovsky et al.) were included in the State Register and admitted to commercial production and in 2008 there were four new varieties: Kumir, Yuzhny (by G.L. Zelensky et al.), Severny 8242 (by V.S. Kovalev et al.) and Sonata (by N.V. Ostapenko et al.). All these varieties belong to the group of short grain varieties with high quality of the milled rice. At the same time, they significantly differ in morphological and economical valuable traits and they are intended for the cultivation using various agricultural practices. In addition, in 2007 a patent № 3647 was received for the glutinous variety **Violetta** intended for children's and clinical nutrition (by G.L. Zelensky and others.).

In 2010, two new varieties Victoria (by V.S. Kovalev et al.) and Sonet (by N.V. Odstapenko et al.) were included into the State Register. In 2011 the rice variety Gamma (by G.L. Zelensky et al.) was also accepted. These varieties are high yielding, with high resistance to disease and give milled rice of excellent quality.

By the middle of the 2000-ies rice growing in Russia there faced significant changes aimed at intensification of production. The farms had possibility to increase scope of field leveling, apply higher rates of mineral fertilizers and new generation of herbicides with a broad spectrum (Nominee, Naris, Citadel), suppressing both millet and marsh weeds. Under such conditions the demand for new varieties of rice expanded. In effect, such intensive varieties like Kumir, Victoria, Gamma, Sonet, Diamant and others signify the new, sixth stage, of the research of the Russian breeders (Table 17).

Table 17 – Rice varieties received at the sixth breeding stage (from 2008 to date)

Variety	Year of handover for State Trials	Year of including into State Register / obtaining patent
Kumir	2007	2009
Victoria	2007	2010
Sonet	2007	2010
Gamma	2007	2011
Diamant	2008	2012
Anait	2008	Patent № 6630 (2012)
Rubin*	2008	Patent № 6526 (2012)
Mars*	2008	Patent № 6525 (2012)
Renar	2008	2012
Fisht	2008	2011
Avstral	2009	Patent № 6835 (2013)
Sharm	2009	2014
Visit	2009	2013
Kurazh	2010	2013
Ivushka	2010	Patent № 7000 (2013)
Privolny-4	2010	2014
Krepysh	2010	2015
Favorit	2011	2014
Olymp	2011	2015
Titan	2011	Patent №7839 (2015)
Yuzhnaya noch*	2012	Patent № 7566 (2014)
Mavr*	2012	Patent № 7565 (2014)
Vita **	2012	Patent №7643 (2014)
Gagat*	2012	Patent №7642 (2014)
Tsaryn	2012	Patent №7644 (2015)
Ryzhik*	2013	Patent №7644 (2014)
Polevik	2013	2016

* The variety with colored grain pericarp;

** Glutinous long grain variety.

At this breeding stage, apart from the standard varieties there were created several exclusive rice varieties for dietary and clinical nutrition, long grain varieties and varieties with colored pericarp. The presence of such diversity of varieties allows complete resolution of the problem of import substitution, providing population with all kinds of rice groats produced domestically.

In 2015, total of 42 varieties of rice, 30 of them being created at the ARRRI, were included into the State register of breeding achievements approved for use in Russia. In addition to these varieties the Register of breeding achievements protected by patents of the Russian Federation accepted 13 varieties orginated in the Kuban area (see Tables 15–17).

All these rice varieties were developed by th leading breeders of the ARRRI: V.N. Shilovsky, V.S. Kovalev, G.L. Zelensky, N.V. Ostapenko and Yu.K. Goncharova [54].

Currently in production in addition to traditional round grain varieties (Rapan, Khazar, Amethyst, Leader, Atlant, Garant, Leader, Kumir, Yuzhny etc.) there are varieties with elongated half-spindel shaped kenel (Regulus, Serpantin, Amber, Novator, Kurazh) and long spindle-shaped kernal (Snezhinka, Avstral, Sharm, Ivushka). Glutinous domestic varieties Viola and Violetta with rounded grain were bred as well as a long grain variety Vita for production of baby food and therapeutic nutrition, the varieties with colored pericarp – Rubin, Mars, Mavr, Gagat, Ryzhik and Yuzhnaya Noch were also received.

These varieties differ in duration of the vegetative periods, height and type of plant, morphological and qualititave characteristics of grain [67, 68].

All created varieties are united by high potential yield and adaptation to local soil and climatic conditions, as well as different cultivation technologies, including zero pesticides method.

Currently, Russian breeders are working at creation of new generation of rice varieties with the potential productivity of 12–13 t/ha.

The breeders of the ARRRI have good base for their work: a comprehensive bank of genetic resources, effective hybridization center, well-equipped vegetation plots and experimental fields of the right size. The Breeding center is provided with modern equipment for sowing, all types of agricultural operations and harvesting. A comprehensive evaluation of the breeding material is conducted by specialists of relevant laboratories provided with the necessary equipment. The varieties released for production are accompanied by technological passport and recommendations for optimal placement of varieties in production.

Every year the ARRRI releases for the State trials 3–4 new rice varieties, and 2 or 3 of them based on the results of state inspection are included into the State Register of selection achievements. For each rice microzone of Krasnodar territory, the scientists of the ARRRI propose optimal varietal complexes; the choice for the active variety rotation is more than sufficient.

It is due to the introduction in the production of the new varieties released during the last years of breeding in the Krasnodar Territory that in 2009 the threshold of rice yields of 6.0 t/ha was overcome. In 2010, the yield was 6.25 t/ha, which significantly increased the ability to produce 1 million tons of rice in the Kuban Region.

The importance of the successful reaserch of the ARRRI breeders is enhanced by the factor that the share of the Kuban rice on the total national rice harvest exceeds 80 %.

The fact that in the Russian Federation are cultivated only domestic rice varieties, testifies to the high level of the research of the Russian rice breeders. It is confirmed by the widespread cultivation of the Russian-bred varieties in Kazakhstan and the Ukraine over the past 30 years. Among these prominent scientists are: in the Krasnodat Territory: V.N. Shilovsky, V.S. Kovalev, G.L. Zelensky, N.V. Ostapenko; in the Don Region: P.I. Kostylev, V.P. Rossikhin; in the Primorsk Territory: V.A. Kovalevskaya. Together with their co-authors and numerous colleagues they continue writing the story of rice breeding in Russia.

The overall result of rice breeding in our country is: over 85 years only in the Kuban area there were created 83 recognaized varieties that were included in the State Register of Breeding Achievements Approved for use in the Russian Federation and there is no foreign rice variety in it. This is the best evaluation of the results of the Russian rice breeders [54].

In conclusion, it should be noted that the creation of varieties of rice takes 12–15 years, and sometimes even more than 20 years of daily laborious work of the breeder and his assistants. The introduction of the variety in the State Register is the highest point of breeding and the breeder's award as wwell as its worthy completion.

2.2 Rice Breeding for Blast Resistance

An event that radically changed practical and scientific activities of the Russian plant breeders and pathologists working with rice happened thirty-three years ago. In 1982, on the basis of the Georgian branch of the Institute of Phytopathology an infection nursery for evaluation of rice was opened to study rice resistance to blast. This gave a possibility for the first time in Russia to begin a purposeful work on rice breeding for immunity to this harmful disease. A complex group of experts including breeders, geneticists and pathologists was established in the ARRRI. They had established close contacts with the specialists of the Institute of Phytopathology (Bolshiye Vyazemy, Moscow region), Georgian Branch of the All Union Research Institute of Phytopathology (VNIIF) in Kobuleti, and North Caucasian Research Institute of Phytopathology in Krasnodar. The complex research program of rice breeding for resistance to blast was developed by the cooperative efforts of the scientists of these institutes. The researchers were assigned to specific programs. For 10 years (until the collapse of the USSR) the specialists of these two scientific institutions carried on an active work.

The result of this activity was a unique breeding material that allowed creating a series of rice varieties resistant to blast. And during the following 20 years, this material was widely used in breeding new generation of rice varieties [55].

The work was conducted according to our breeding technology for resistance to the disease in general and to blast in particular (Figure 34) [63].

Following the classical scheme of crop breeding the breeding of a variety consists of several stages:

1. Creation of population (it takes several years);
2. Selection of ancestral plants (one day);
3. Comparative study of progeny (several years).

Our modification of the diagram of breeding process contains several additional items.

Stage 1. Populations for the selection of ancestral plants are created by various methods; hybridization is used most often – intraspecific or inter-species. The donors as parent forms are selected from the collection. To isolate the source of resistance the collection is studied on infection background, the infection is spread artificially using both the local fungus populations, and virulent races. The samples selected from the collection are tested in special greenhouses, where the resistance genotype is identified.

After the selection of donors, they are included into hybridization programs. At the ARRRI it is done round the year. Reproduction F1 is conducted in a greenhouse or a growth plot. The hybridism of these plants is estimated, comparing them with the parental forms. The hybrids F2–F5 are sown in the field for selections. Part of the hybrid seeds are sown in the infection nursery for plant resistance evaluation, selection and determination of the further perspective of the population.

Stage 2. The parent plants are selected from hybrid populations on a range of agronomic traits (including resistance to the pathogen) for further study according to the scheme of the selection process.

Stage 3. Seeds of the selected plants, each with the assigned number, are divided into two parts. The first is sown in the breeding nursery, the second – in the infection nursery (IN), where assessment of resistance to rice blast is carried out.

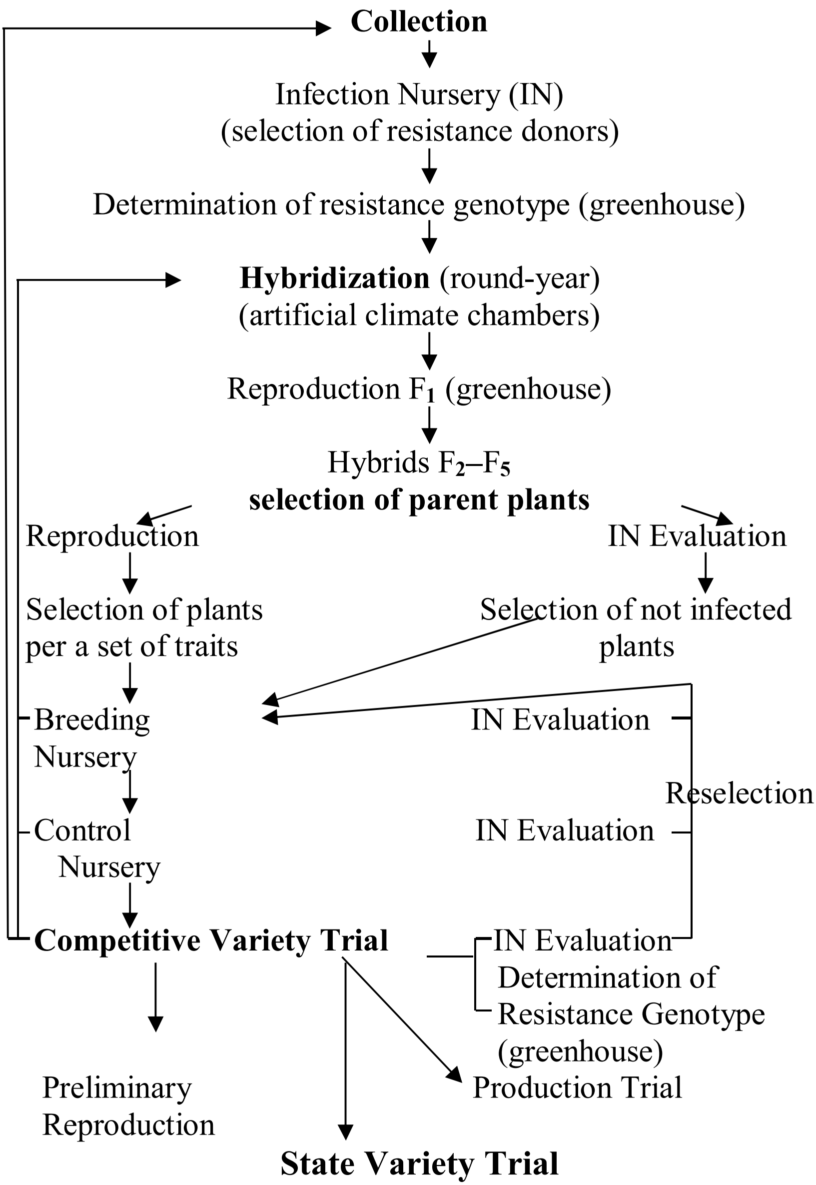


Figure 34 – Diagram of rice breeding for blast resistance

The test samples are sown in in one row plots, in blocks of 50 numbers. In each block, there is a standard, i.e. the main recognized variety and an indicator variety (susceptible to blast). Infection of rice plants by a fungus suspension is done twice: at the phase of rice tillering (the first phase of infection) and at heading phase (the second, main, phase of infection). Two weeks after infection the contamination degree of the plants is evaluated and compared with the standard and indicator varieties. The unaffected samples are selected at full ripeness. In plots where splitting of economically valuable traits and resistance to blast is noted, the best plants are selected for re-examination. It should be noted that if a sample is hit by blast in the IP, it is also rejected in the breeding nursery, where it was sown under the same number.

Likewise, the samples of the control nursery are competitive trials are studied (Figure 34). The samples of competitive trails not affected by the disease are sent to the Research Institute of Phytopathology to determine the resistance genotype. All samples with effective resistance genes to blast are included into the collection and the best of them with outstanding yield and other valuable traits are propagated and evaluated under production conditions. By the re-sults of the comprehensive study of the best variety is handed over for the State Variety Trials.

The result of many years of research according to our scheme of rice breeding for resistance to blast are the varieties with race specific resistance to the pathogen: Paritet, Blastonik, Vityaz, Vodoley, Talisman and Snezhinka handed over for the State Variety Trials.

Evaluation of the hybrid material under conditions of the infection nursery allows also selecting plants and samples with field resistance to blast. Such plants can be partially affected by the disease under artificial infection, but the infection on them develops slowly, and the plant productivity is almost not reduced. A good example of this resistance is observed the rice variety Slavyanetz isolated in the infection nursery in 1984–1986, and several other varieties created in the years that followed: Leader, Atlant, Gamma, Kumir, Yuzny, Olymp and others.

Thus, evaluation of samples, forms and varieties in terms of infection background is an important step in rice breeding for disease resistance. The efficiency of breeding has significantly increased [63].

It should be noted that along with disease resistance the bred varieties should be high yielding and quality products, but also be adapted to local conditions.

2.2.1 Genetic Foundation of Rice Breeding for Blast Resistance

The foundation for the successful breeding of rice for blast resistance is the availability of the initial material with a wide range and a high level of resistance. The selection of donors of resistance is based on the identification of genes controlling this trait in rice.

Genetic basis of the interaction of the host plant and the pathogen is shown in Flor's theory of "gene-for-gene", the essence of which is that for each resistance gene of the host plant there is a corresponding virulence gene of the pathogenic fungus [128].

Determining the degree of resistance in rice varieties to different races of the fungus, marked with virulence genes allows the identification of their resistance genes.

In 1966 Japanese researchers Y.Yamasaki and S.Kiyosawa identified genes of resistance in rice varieties of different origin using hybrid analysis on *P. oryzae* lines differing in virulence. Rice resistance genes to *P. oryzae* were marked with the symbol **Pi**.

By the middle of the 70-ies of the last century there were 16 described resistance genes: ***Pi-a, Pi-b, Pi-i, Pi-f, Pi-k,*** $Pi\text{-}k^{h}$, $Pi\text{-}k^{p}$, $Pi\text{-}k^{s}$, ***Pi-m, Pi-s, Pi -t, Pi-ta,*** $Pi\text{-}ta^{2}$, $Pi\text{-}ta^{n}$, ***Pi-z,*** $Pi\text{-}z^{t}$.

The efficiency of resistance genes in different regions of the world varies. Having the information on the distribution of resistance genes in varieties and virulence genes in populations of the pathogen, plant breeders can select and use in the breeding process the varieties with effective resistance genes for the given region.

There are several methods to determine the resistance genes to blast in rice varieties. The simplest but sufficiently effective is the method of the pathogen test cultures proposed by the Japanese researchers Yamasaki, Kiyosawa and Toriyama. The method is based on the complementary interaction of resistance genes of the host plant and virulence genes of the fungus according to the Flor's "gene-for-gene" hypothesis. To determine the resistance genes Yamasaki and Kiyosawa used seven differentiator-strains. The method of the pathogen test cultures allows separation of the varieties into different genetic groups. It is assumed that each group includes varieties with the same resistance genes. It was found that the varieties of japonica subspecies can be classified using seven strains of the Japanese differentiator-strains [136].

This set was sent to the VIR collection and is widely used for the genetic research in rice research institutes (Table 18).

Table 18 – Response of the rice F2 hybrids to *P.oryzae* infection (1986–1988) [135]

Variety	Number in VIR catalog	Resistance gene
Aichi-Fsahi	5557	Pi-a
Ishikari-Shiroke	5770	Pi-i
Kanto 51	5550	Pi-k
Minihikari	4784	Pi-m
Shin-2	5735	Pi-k^{s}
Tadukan	280	Pi-ta (or) Pi-ta^{2}
Zenith	4765	Pi-z и Pi-a

The availability of the set of *P. oryzae* differentiator-strains and the set of varieties with known resistance genes makes it possible to develop new areas of research:

1) Selection of donors with effective resistance genes among the collection samples;

2) Creation of breeding material immune to the disease on the new quality level;

3) Study of gene-based *P. oryzae* virulence range in different regions of the country. The latter is particularly important because the knowledge of the distribution of virulence genes is a fundamental fact in choosing breeding trends.

The spread of resistance genes to rice blast in rice-growing areas of the world is defined by the cultivated varieties. It is in India, China and some African countries where many varieties are grown and where the climatic conditions are favorable for the spread of the pathogen that the greatest number of resistance genes is detected. According to the third main immunity distribution law, the essence of the environmental laws is that immunity is generated under the impact of natural selection under conditions conducive to the development of infection (Vavilov, 1986). That is why the maximum variety of *P. oryzae* virulence genes, suppressing resistance in rice varieties is observed in the countries where the conditions in terms of the diversity of substrate and climate are ideal for the development of the pathogen.

The study of virulence genotype of individual strains allows creation of the set of the fungus lines with certain virulence genes. Monogenic set of *P. oryzae* lines is extremely necessary to assess newly generated breeding material. Genetic analysis of the virulence range of the pathogen population is essential for the implementation of rice breeding programs for resistance to rice blast disease. Knowledge of the distribution of virulence genes allows for targeted search for the sources of resistance and their involvement in the selection process.

Several researchers studied *P. oryzae* populations of major rice growing areas of the country. They identified all known blast virulence genes. The highest diversity of *P. oryzae* populations is observed in the Primorsk Territory where all 12 virulence genes were identified, complementary to 12 resistance genes in rice monogenic lines. Virulence genes **Av-ks +, Av-i +, Av-k +** are the most widespread in all studied populations of the pathogen. The frequency of such virulence genes such as **Av-z +, Av-zt +, Av-ta +, Av-b +** was quite low. The races containing them were registered in the Primorsk Territory and Ukrainian blast populations [101].

It is well known that the resistance of rice to *P. oryzae* infection is divided into vertical (race specific) and horizontal (field). According to the theory of Van der Plank (1975), the vertical resistance is general and the horizontal resistance is quantitative. The vertical resistance is controlled by major genes, while horizontal resistance is usually controlled by minor, or multiple genes. The nature of the vertical resistance has been thoroughly studied. The sixteen major genes (discussed above) controlling this type of resistance have been identified.

Based on numerous experiments S. Kiyosawa (1974) discovered that the nature of resistance controlled by specific genes is as follows:

1. Resistance reaction is caused by the interaction of the resistance gene with the virulence gene that exactly matches the resistance gene.
2. In most cases the resistance dominates susceptibility.
3. If a variety has two genes controlling various degrees of resistance, the gene that controls the highest degree of resistance is epistatic to another gene controlling the lower degree of resistance.
4. In the host-parasite conjunction where the two genes control various degrees of avirulence, the gene with higher avirulence degree is epistatic to the gene with the lower one.
5. The quantity and quality of resistance genes found in a variety depend not only on the quantity and quality of resistance gene in the variety, but also on the quantity and quality of avirulence genes of the strain used for inoculation.
6. There are many multiple alleloforms in the resistance locus.
7. The ability of the host (strain) to differentiate pathogen genotypes (variety) reaches the highest level in the variety (strain) with the single resistance gene (avirulence).

These basic rules give answers to many questions arising in the study of rice resistance to blast.

Our observations made in the infection nursery confirm the findings of many researchers that the resistance to rice blast is a dominant trait. The nature of resistance splitting in F2 hybrid populations was different (Table 19).

Table 19 – Response of the rice F2 hybrids to *P.oryzae* infection (1986–1988)

Population number	Crossing combinations	Ratio of resistant and susceptible plants, R:S
303	Krasnodarsky 424 / Maratelli 5A	3:1
369	VNIIR8444 / VNIIR 87	3:1
394	VNIIR7630 / NF-DZ-84	9:7
441a	VNIIR8444 / Dular	3:1
540	Yerua P.A. / L-5-80	3:1
543	Ham Nam / VNIIR1588	9:7
585	Maratelli 5A / L-5-80	3:1
586	Kr-3-84 / Maratelli 5A	3:1

The data show that the varieties Maratelli 5A, Yerua PA, VNIIR 87 and Dular 87 possess resistance to *P. oryzae* controlled by a single dominant gene, as evidenced by the ratio 3R : 1S). In hybrid populations bred after crossing VNIIR 7630 and Ham Nam varieties, the observed split ratio was 9R : 7S. This fact points to the presence of two dominant blast resistance genes in these varieties.

These findings have enabled us to get more reliable assessment of the hybrid material and select desired genotypes for the formation of breeding nursery. As for horizontal resistance, the study of its inheritance is extremely difficult because its manifestations are greatly affected by environmental conditions. This type of resistance does not include the interdependence of "gene for gene". It works equally against all races of the pathogen. According to S. Ou (1971), in rice plants two types of response point to the horizontal resistance: 1) a variety shows minor injuries, regardless the pathogen race; or 2) the injuries are scarce, though the damages point to susceptibility of the variety.

J. Bidaux (1977) and several other scientists have concluded that the horizontal (field) resistance is not race specific and it is polygenic inherited (Table 20).

Table 20 – Diffeerences between vertical and horizontal plant resistance to diseases [3]

Trait	Type of resistance	
	vertical	horizontal
Relation with pathogen	Race specific	Non-race specific
Phenotypic expression	Qualitative	Quantitative
Genetic control	Mono- and polygene control	Polygene control
Resistance mechanisms	Active protection reactions	Catalytical reactions
Environment impact	Weak	Strong
Resistanec duration	Short term (till the change of race	Long term

Most researchers believe that the horizontal resistance ensures albeit partial, but durable protection of rice from blast. However, M. Vales (1987) asserts that rice resistance to *P. oryzae* with a high degree of probability is durable if it is polygenic, but neither polygeny nor knowledge of the duration of the variety resistance from which it originated guarantees its durability.

Therefore, the most reliable factor, controlling the development of blast is timely replacement of the old varieties with the new ones having efficient genes of resistance to the pathogen [58].

2.2.2 Initial Material for Rice Resistance Breeding to Blast

Research of rice varieties and samples resistance to blast disease was begun at the ARRRI in the 1960-ies. A. G. Lyakhovkin thorough studied the world collection of the Research Institute of Crop Science (VIR). In 1972 practically all samples of the collection (2 130) were assessed on their blast resistance in field trials and 1 008 samples were tested at the specialised plot under artificial inoculation.

Assessment of varieties and breeding samples was continued in the years that followed. The conclusion made because of these tests was that the majority of varieties grown at that period in the Kuban Region and being under state trials had weak resistance to blast. In many of them even under natural inoculation *P. oryzae* infected up to 85–100 % plants. This can be explained by the fact that practically all varieties were bred from blast susceptible initial material [55].

Many years of research of population structure of *P. oryzae* showed that pathogen races differed in virulence genes. Thus, the most efficient resistance genes for these populations are ***Pi-z, Pi-z^{t}, Pi-ta^{2}, Pi-b*** [69]. Phytopathologists have found out that rice varieties both commercially grown and under state trials, have inefficient resistance genes **Pi-ks, Pi-a** or **Pi-i** and consequently are easily susceptible to blast.

The absence of the effective resistance genes in native varieties of rice does not allow them to be resistant to blast, especially in in case of epiphytotic development of the disease. This situation dictated the need to find effective donors of resistance and creation on their basis of the initial material tolerant to the pathogen for further breeding the species immune to pathogen. A valuable source of material for breeding for resistance to blast disease are varieties that combine race specific and field resistance (Table 21).

Along with the study of the global collection the sources of resistance to rice blast were looked for among working collection of the ARRRI due to their better adaptation to soil and climatic conditions of Russia.

Testing of 2,544 sample of the world collection for varieties best suited for soil-climatic conditions of Russia showed that most of them are susceptible to *P. oryzae*. Only 69 samples were not infected with foliar form of disease, 20 samples were slightly susceptible to panicle form (grade 1–2) and 18 samples combined immunity to both forms of blast. Varieties combining race specific and field resistance to blast are a valuable initial breeding material.

Among studied varieties such qualities were found in samples Insen/Tremesino (Spain) and Maratelli 5A (France).

Table 21 – Rice samples of the world collection with efficient resistance to blast [69]

Number in VIR catalog	Sample	Origin	Plant height, cm	Number of days before flowering	Re-sitance genes
European ecological and geographic group (EGG)					
6979	Insen / Tremisino	Spain	113	85	*Pi-z*
6951	Maratelli 5A	France	110	80	*Pi-z*
Eastern EGG					
7265	Shimokita	Japan	97	85	*Pi-ta*
3805	PN 170	China	132	92	*Pi-z*^{t}
7233	Ham Nam	Korea	87	88	*Pi-z*^{t}
Iranian EGG					
3787	Champa	Iran	138	80	*Pi-z*^{t}
Central Asian EGG					
5065	Bir-me-fen	Afganistan	120	95	*Pi-z*^{t}

Testing of collection samples resistant or slightly susceptible to *P. oryzae* continued at the Research Institute of Phytopathology resulted in discovery of samples with high resistance to local populations of blast due to resistance genes (Table 22).

Table 22 – Samples of the ARRRI working collection with efficient blast resistance genes

Number in ARRRI catalog	Sample origin and name	Plant height, cm	Number of days before flower-ing	Re-sitance genes
0590	*O. glaberrima* / Soyuzny 244	106,9	87	*Pi-z*^{t}
01016	Korbeta / Soyuzny 244	55,5	89	*Pi-z*^{t}
01717	Taichung Native / ДVROS15	97,8	84	*Pi-z*
01793	C. 6063 / Rialto	74,6	82	*Pi-z*
01907	VNIIR3657 / Rialto	86,2	86	*Pi-z*
02268	VNIIR7630	100,9	86	*Pi-z*
02360	Panoza sel. / VNIIR5001	110,6	85	*Pi-z*

Number in ARRRI catalog	Sample origin and name	Plant height, cm	Number of days before flowering	Re-sitance genes
02890	Mutant 744-82	92,8	86	*Pi-ta*
02919	Line 83-1-14-1	84,8	85	*Pi-z^t*
03186	BZ-600-436-85	90,6	81	*Pi-z*

As shown in Table 22, the sources of resistance to *P. oryzae* in creating samples included in the working collection were the varieties and forms of the world collection. Such varieties as mountain rice from Brazil, Catalao, Rialto from Italy, Nato, Saturn from the USA, Taichung Native from China and others used in the ARRRI for hybridization were donors, not only of the short stem, high productivity and excellent quality of the grain but as it was revealed by our research, resistance to blast.

The resulting samples became a valuable initial material for breeding rice varieties with race specific and field resistance to blast. They are used to create the new hybrid material. Thus, there were received more than 200 hybrid populations, and in most of them healthy plants were selected. They, in turn, were the basis for the selection of several varieties resistant to this dangerous rice disease.

2.3 Breeding Rice Varieties with Race Specific Resistance to Blast

The breeding trends in the research for rice resistance to blast depend on soil and climatic conditions of the rice growing area and genetic structure of the population of *P. oryzae*. The approach should be differentiated to determine initial material, methods of its evaluation and selection. Durability of variety resistance depends on how these issues are solved.

Race specific breeding is advisable for the areas where climatic conditions limit development of the pathogen. Many years of complex research proved that these are European part of Russia, Ukraine and Karakalpakia. For the Far East, it is recommended to work out breeding programmes for race specific and field resistance because of favourable climatic conditions for blast and high variability of pathogen.

Race specific, real or vertical, resistance relates to super sensitive reaction of host to pathogen and controlled by unique main gene. Thus, initial material should be genetically variable. Breeding based on one effective gene can result in appearance of races overcoming this resistance.

When planning hybridization program for breeding rice varieties with race specific resistance to blast the breeders based their theory on the fact that in the European part of Russia the effective resistance genes to *Pyricularia oryzae*, as noted above, were ***Pi-z, Pi-z^{t}, Pi-ta^{2}*** and ***Pi-b***. This predetermined the range of donors for hybridization. The crossing included the varieties with the gene ***Pi-z***: Zenith, VNIIR7630, Yerua P.A., Maratelli 5A and samples of P-LS-G-84, BR-600-436-85, as well as samples with the gene ***Pi-z^{t}***: 1-zhn-G-84 and 4-zhn-G-84. However, in the process of selection study, it became clear that simple pair crossings were not enough. Received breeding material despite its resistance to blast did not meet re-quirements of modern plant breeding. Necessity of back crosses with majority of donors was evident. Only among hybrids bred with French variety Maratelli 5A plants with promising results were found. Habitus of Maratelli 5A is close to that of Krasnodarsky 424, it is ripe only a few days later. But in hybrid population Krasnodarsky 424 / Maratelli 5A several dozens of plants with negative transgression were selected – they matured earlier and were shorter than both parent forms. They combined resistance to blast with complex of valuable economic features. Several samples were received and then sent for out for After three-year evaluation-the variety VNIIR 92–98 under trade name Blastonik was released for State Variety Trials in 1992. It was the first variety with race specific resistance to blast received from local hybrid material. Later other varieties were released for State Variety Trials: Vityaz, Talisman, and Snezhinka with similar race specific resistance to blast and thus not requiring chemical protection. However, in the State Register of varieties admitted to use, only the variety Snezhinka was included (Figure 35) and that was only due to its long grains and high quality of the milled rice [67].

Figure 35 – The rice variety Snezhinka

The other varieties were not included in the State Register. The main reason was that the testing of new varieties of rice was held by the State Commission without the infection load against a normal background, optimal for standards. Under these conditions, during the absence of blast epiphytotics the immune varieties often do not show the benefits in terms of yield compared to standard.

2.4 Breeding Rice Varieties with Field Resistance to Blast

The main feature of field resistance is that though it does not give a complete protection from blast, the available protection is permanent and it is not destroyed by the pathogen. Field, or horizontal, resistance is usually non-race specific and rather depends on environmental factors, than a true resistance, and in most varieties, it is polygenic controlled.

For varieties with field resistance Van der Plank [157] proposed to select forms: a) more difficult to infect; b) with a longer period from inoculation to sporulation; c) with less abundant sporulation. The varieties with a horizontal resistance are characterized by a decrease in spots area and their quantity per 1 cm.

Evaluation of breeding material in infection nursery under artificial infection gives the opportunity to select along with samples of immune varieties and forms of rice also those having high tolerance to disease.

The rice variety Slavyanetz (Figure 36) can be a ggood example. It was studied on infection background in 1984–1985 as L-5-80 and was chosen among other varieties due to its greater endurance to the blast. S. Ou [141] reports that the rice breeding lines that have the least number of pustules, are more resistant to the pathogen than other lines in case of infection by the fungus *Pyricularia oryzae*.

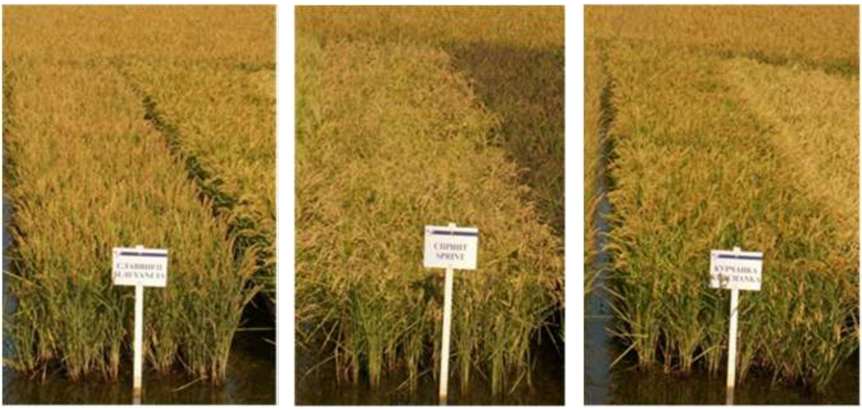


Figure 36 –The rice varieties Slavyanetz, Sprint, Kurchanka in the demonstration plots

The other picture has been observed in the rice variety Slavyanetz. After the initial artificial infection, the development of the disease on the plants proceeds very slowly, the sporulation is inhibited and repeated infection does not happen. This valuable qulity of the variety is important, especially during the blast epiphytotic development.

Slavyanetz has been recognized in the Kuban Region since 1991 as the variety most resistant to *P. oryzae*, and it has been "working" in production till 2007, when the new generation of varieties appeared [58].

In addition to this variety some samples with minor injuries caused by blast during its epiphytoty were selected in the infection nursery. They were used as parent forms for hybridization as possessing high field resistance. These included domestic samples VNIIR87, VNIIR1619-90, Mutant 533, VNIIR7630, Kr-3-84, as well as Japanese samples Shimokita and Reimei. T.

Thus, the ARRRI carries active breeding programs aimed at creation of varieties resistant to blast. Most of them are included in the State Register and approved for use: Slavyanetz (1991), Pavlovsky (1995), Sprint (1996), Kurchanka (1997), Leader (1999), Viola (2001), Snezhinka (2003) Violetta (2007), Atlant (2007), Kumir (2009), Yuzhny (2009), Gamma (2010), Olymp (2015). These varieties belong to the blast resistant varieties and do not require chemical protection (Figure 37).

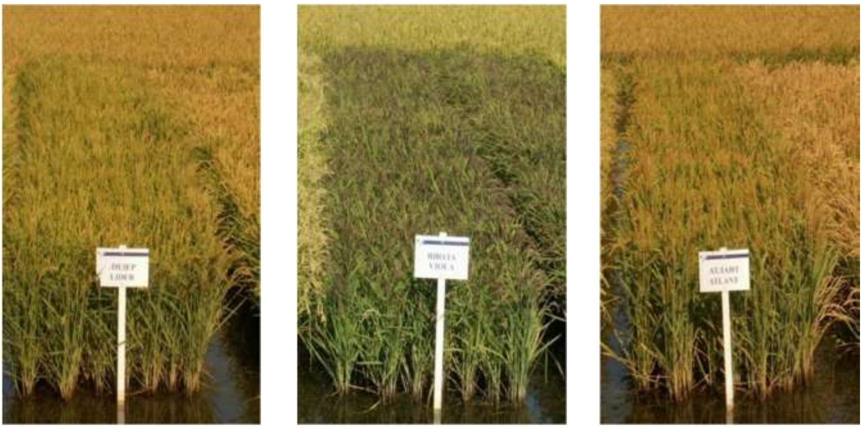


Figure 37 – The varieties Leader, Viola and Atlant, grown under zero pesticide technology

The rice variety Leader stands out among them; it is included into the State Register in Russia and in Kazakhstan, where on the saline soils it provides excellent yields from seedlings emerging through the water layer, and gives grain of high quality [55].

It should be emphasized that the selection of resistance to disease or other stress factors require additional expenses. It is necessary to regularly assess the breeding material in special infection and provocative backgrounds. However, these costs are paying off both economically and environmentally. Growing varieties resistant to blast is more profitable than other varieties, even if the received yields are the same. Note that the total cost of each aerial fungicides application in the rice crop, including the cost of the fungicides, was 1300–1500 rubles/ha (in prices of 2013).

Of interest to the Russian rice production are four varieties– Kumir, Yuzhny, Gamma and Olymp, their resistance to blast is combined with high productivity (Figure 38).

Thus, the joint work of breeders and plant pathologists provides a real opportunity to provide rice farmers of Russia with the varieties of genetically protected from blast and not requiring chemical protection. This is an important result of 33 years of work in the rice breeding for resistance to this disease.

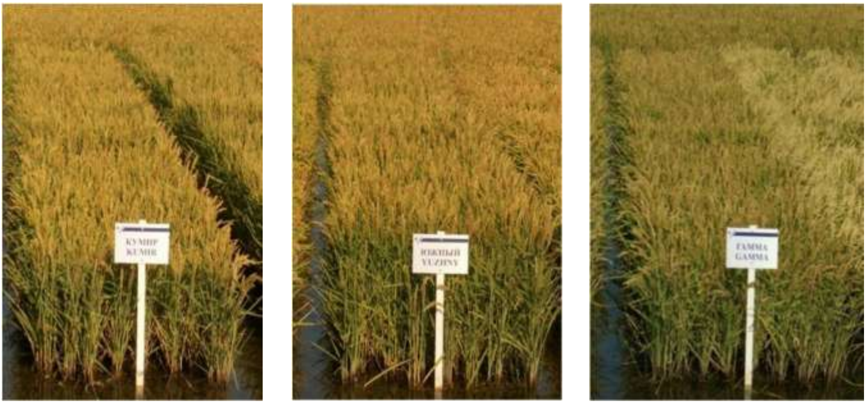


Figure 38 – High yielding varieties resistant to blast Kumir, Yuzhny, Gamma

The further development of breeding rice varieties resistant to blast are joint research of specialists in Biotechnology and rice breeders of the ARRRI on pyramiding resistance genes in native varieties [26, 81].

2.5 Rice Breeding for Resistance to the Rice Leaf Nematode

One of the most damaging rice diseases is white tip provoked by the rice leaf nematode *Aphelenchoides besseyi* Christie, 1942.

This pest is widely spread in many rice growing countries of Africa [146], America [127, 129, 138], Asia [131, 147], Australia and the Middle East [154]. In Europe, the rice leaf nematodes are recorded in Hungary, Bulgaria, on the territory of the former Yugoslavia, Italy [109]. In the former USSR, the rice leaf nematode was originally found in the Krasnodar Territory in 1939, and later in other rice growing areas – Astrakhan and Rostov Regions, Uzbekistan, Karakalpakia, Dagestan, the Chechen-Inguhetia, Ukraine, Azerbaijan, Tajikistan [108, 109] and in the southern part of Kazakhstan [1].

The disease is caused by the nematode, it periodically aquires the level of epiphytoty causing noticeable damage to the farms economy. The absence in Russia of effective chemicals and nematode-resistant rice varieties complicated struggle with this pest.

Knowledge of morphological and biological features of the parasite is necessary for organization of pest and disease control. The rice leaf nematode is a microscopic worm. The length of the adult nematode is 0,45–0,85 mm. Females have a straight form of the body, the tip carries a spinule with three or four sharp tips, arranged in a star; the male's tail is bent at 180 degrees. The main source of infestation is nematode infested rice seeds. Nematodes in hibernation are located under the rice seed scales. When infested seeds get into the moist soil, nematodes emerge from dormancy stage, migrate to seedling growth points and accumulate inside the sheath. They feed on the tissues of young growing leaves.

Vital functions of nematodes begin at the temperature of 13 °C. Optimal conditions are: temperature +25–30 °C and humidity of 70–100 %. The upper temperature limit for the nematodes is +42 °C. The life cycle from egg to adult at temperature ~ 21–23 °C is completed in 8–10 days. The female lays 40–50 eggs in several bouts within 35–40 days. One generation is superimposed on the other, the number of rice leaf nematodes grow rapidly and reaches maximum when the rice plants are at the phase of flowering and milky ripeness. As the plants are maturing and drying the nematodes' life slows and they fall into a state of rest. The number of nematodes in the panicles of rice can reach 1000 species. One grain can contain from 1 to 200 adult nematode species. In moist soil at a constant-temperature the nematodes do not survive longer than 4 months, even in infected rice seeds. In the dry seeds and straw, in hibernation state, the nematodes can remain viable from 3 to 6 years [10].

Symptoms of diseased plants with rice leaf nematodes appear as "white tip" of rice, i.e. whitening of the tips of the leaves (2–5 cm) at the tillering phase. Later, they become necrotic, yellow, turn brown, shrivel and curl. Leaf mosaic and shirring can also be observed. They are accompanied by a general inhibition of the plants, reduced shoot formation. The main stem is damaged most. The panicles become shorter, their ends atrophy. The grain of the infected panicle is frail, deformed and dark. The productivity of plants goes down drastically.

The harmfulness of nematode depends on many factors: resistance of the varieties, climatic conditions, agronomic practices, crop rotation, predecessors, etc. In this regard, the published data on the reduction of the crop yield vary greatly. For example, in the United States, the yield of susceptible varieties of rice went down 44.2–54.1 % [142]. In the USSR, the losses of rice crops from nematodes in some fields were 26.0–71,0 %. Thus, in infected plants of the susceptible variety Dubovsky 129 the height was reduced by 30 %, the number of grains per panicle – by 31 %, weight of panicle grain – 64.3 % [108]. It was just due to this susceptibility to the nematode that this early maturing variety with the excellent quality of grain was discontinued. In addition to direct reduction of yield the nematode infection leads to considerable economic damages to the seed producing farms due to lower yield of conditioned seeds. The affected crops of the elite are discarded or transferred to lower reproductions.

The rice leaf nematode affects not only rice; it is a parasite of several flowering plants (orchids, chrysanthemums, daffodils, and others), essential-oil plants (mint), and wild grasses (foxtail, bristle grass, millet) and sedge.

In addition, the nematode easily propagates on such fungi as *Puricularia, Alternaria, Culvularia, Helmin-thosporium, Fusarium* and others. With the ability to feed on fungus mycelium and not being narrow specializing parasite, the rice leaf nematode survives by feeding on wild cereals, the plants of other families, it can save on plant residues and for some time in the soil [109, 127].

The most effective way to solve the problem of the nematodes is to create and recognize the resistant and tolerant varieties of rice. They provide both a reliable nematode control and protection of the environment by eliminating the use of pesticides.

International experience shows the possibility of successful solution to this problem. For example, in the United States in the period from 1935 to 1955 the white tip disease was the most harmful among other rice diseases [59].

The United States began to produce enough rice for own needs since 1917, and since the beginning of the 1970-ies is one of the leading exporters [4]. There are three types of rice varieties grown there: with short, medium and long grain.

There are three historical stages in the rice breeding research in the United States. At the first stage, it was oriented at introduction of new varieties, while the second stage is characterized by wide application of analytical methods, and at the third, modern, stage the synthetic methods are used. The introduction of varieties from other countries is important even now in replenishing the funds of genetic resources.

Analytical selection was carried there since the beginning of the last century. Several varieties were created by the selection method; some of them are being sown up to date. They are widely accepted by farmers. For example, the variety Colusa has been cultivated since 1917, Fortuna – 1918, Coloro – 1921, Rexoro – 1928 [59]. And in the years that followed, the analytical selection was successfully used by the American breeders. This method helped to obtain the varieties Zenith (1936), Bluebonnet 50 (1951), Nova 66 (1966) and others.

In 1920-ies hybridization method in breeding was adopted. However, the varieties received by the synthetic breeding appeared in the production only in the 1940-ies. (Texas Patna, 1942; Bluebonnet, 1944; Magnolia, 1945, etc.).

The created rice varieties are not subject to registration and admission into production if grain has not been tested over the years. The varieties can be recognized as perspective if they possess the same quality as the ones registered earlier.

Of exceptional importance is breeding for resistance to diseases, among them the most harmful under conditions in the United States are rice blast and white tip caused by rice leaf nematode.

From 1935 to 1955 the damage caused by nematode in the United States was the deadliest among other plant diseases. However, after identification of the agent of this pathology, the research was started to breed resistant varieties [142].

Regular testing of varieties for resistance to nematode in the infection nursery was started in the USA in 1949. Among the studied varieties there were identified the immune ones: Fortuna, Rexoro, Nira, Bluebonnet. They became the ancestors of almost all nematode-resistant rice varieties created in the USA in the next 40 years [59].

Careful analysis of the origin of the nematode-resistant varieties of rice has allowed us to make their genealogical chart (Figure 39).

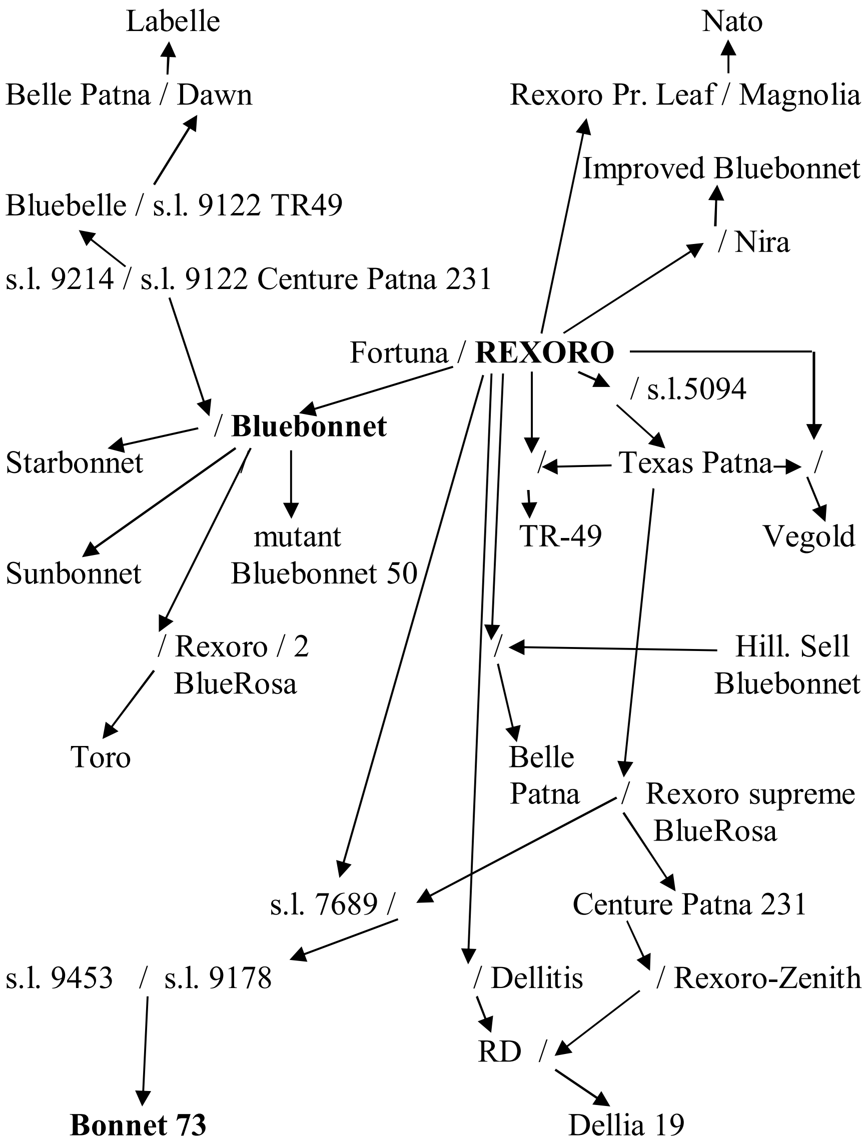


Figure 39 – Pedigree of US rice varieties, resistant to the nematode [59]

As can be seen from the pedigree of the varieties Bonnet 73, Dellia 19, Toro etc., the breeders conducted long purposeful step hybridization with wide use of the donor of stability Rexoro and received on its basis variety Bluebonnet [36]. Here is the list of the most nematode resistant rice varieties widely cultivated in the United States: Belle Patna, Bluebelle, Bluebonnet 50, Bluebonnet, Improved Bluebonnet, Century Patna 52, Century 53 Patna, Century 231, Dawn, Fortuna, Nato, Nira, Rexoro, Starbonnet, TP-49, Texas Patna, Toro, Vegold, Bonnet 73, Del Labelle and others. Most of them belong to a group of long-grain varieties, giving the milled rice of high-quality. Of note is the variety Bonnet 73 with integrated resistance to nematode, blast, leaf rot, brown spot disease.

Currently, due to the breeders' work, the nematode disease of rice in the USA has lost its economic importance [132]. However, until the present time evaluation for resistance to nematode it is a prerequisite in rice breeding programs. The potential harm of the nematodes still remains in connection with the cultivation of susceptible varieties: Saturn, Merluse, Nova 76, and others [129].

The positive experience of the US breeders in creation of rice varieties resistant to nematode turned out to be very useful in Russia.

Rice breeding research of nematode resistant rice varieties, given the high harmfulness of nematodes, was deployed in Russia since 1986 [43]. The program was implemented by specialists of ARRRI and the All Russian Institute of Helmintology named after Scriabin. The beginning of this research was accompanied with considerable difficulties associated with the complexity of creating a hard infection background in the field with a uniform distribution of invasion load on the nursery plots. Furthermore, there were no reliable donors of resistance to nematode among domestic varieties. Foreign rice samples did not mature under climatic conditions of Russia.

Following the development of methodology for assessing and creating invasion nursery in the field, a systematic verification of the resistance of varieties, collection patterns and breeding material for the selection of sources of resistance to the rice leaf nematode was started. The samples selected during field evaluation without signs of damage were tested in the second pot experiment in the greenhouse. Grown rice plants were analyzed at the laboratory. At the same time, the expression of infection and plant nematode invasion were checked. The stability of the samples to the nematode in the field was evaluated at the end of the growing season. When parsing a rice sheaf, the panicles were divided into two groups: 1) affected; 2) apparently healthy.

The following scale was used for evaluation of the panicles:

0 – no signs of nematode invasion;
1 – no damage, signs of invasion;
3 – damage and nematode invasion.

Resistance index (I_r) was defined per formula:

$$I_r = (1 - a - 3b/3n) \times 100,$$

where *a* – number of rice stems evaluated as grade 1;
b – number of rice stems evaluated as grade 3;
n – number of all rice stems per sample.

The evaluation results were classified:

Resistance Group	**Resistance index, %**
Highly resistant	99–100
Pactically resistant	86–98
Medium resistant	76–85
Susceptible	51–75
Highly susceptible	50 and less

During the study, it was determined that all rice varieties recognaized in Russia are susceptible to the nematode. However, the degree of susceptibility varies considerably. Thus, against the high invasion background the damage of panicles reached 100 % in the varieties Dubovsky 129, Uzros 59, Zhemchuzhny, Start, Kulon, it was 30–50 % in Liman and Yubileyny, and only 5–30 % in

Kuban 3 and Kuban 9. Not by chance only the rice varieties Liman and Kuban 3 are cultivated so far, and all others "retire from the scene" [43].

Weak susceptibility to nematode was observed in varieties of Arpa-Shaly, Krasnodarsky 424, Krasnodarsky 86, Prolog and Sadri Massalinsky. They manifested the degree of panicles injury on invasive background 0–10 %. However, it should be noted that their low damage is due to plants endurance to nematode infection. When tested on a hard-invasive background in the greenhouse, these varieties easily become infected, the nematodes multiply and increase in number. But at the same time the infected plants show no symptoms of disease, and only some of them show a weak degree of these symptoms.

Plants resistance to infestation by nematodes is a valuable feature of rice varieties. The grain weight per panicle of the infected plants of these varieties is 0–15 % lower compared to the control while the susceptible varieties with the manifestation of symptoms have it less 39–70 % [93, 94]. The effect of the use in the production of the rice varieties resistant of the nematode is reduced if they are grown near highly susceptible varieties. As carriers of infection, resistant varieties pose a real danger to recontamination of highly susceptible varieties. Thereby potential harm of nematode is constantly preserved in the rice fields.

Meanwhile, the conducted research shows that from 70 to 90 % of promising varieties and breeding samples are strongly susceptible to nematode. This suggests that in previous years, the breeders did not pay attention to resistance to nematode while selecting the parental forms for the breeding of new varieties. But this depends mostly not on unwillingness to create resistant varieties, but on the lack of reliable donors of resistance. Therefore, the search for sources and donors of rice nematode resistance appears an urgent task. To solve the problem the samples of the VIR world collection and the ARRRI working collection are evaluated [43].

Unfortunately, out of the tested 3,500 plus samples of the collection the clear majority turned out to be highly susceptible to nematode. Only seveal samples of the VIR world collection at all stages of the evaluation showed high resistance to Krasnodar nematodes population (Table 23).

Table 23 – Resistance of rice varieties of the world collection to the rice leaf nematode (VIGIS, 1988–1989)

Number in VIR catalog	Variety	Country of origin	Evaluated resistance		
			preliminary, grade	repeated, grade	field (Resistance Index), %
4772	Bluebonnet	USA	0	0	100
6620	Bluebonnet	USA	0	0	100
4773	Bluebonnet 50	USA	0	0	100
5741	Bella Patna	USA	0	0	100
4642	Century Patna	Cuba	1	1	98
6164	Century Patna	USA	1	1	98
5969	Bluebella	USA	1	1	99
6177	Bluebella	USA	1	1	95
4871	Vegold	USA	1	1	93
6165	Starbonnet	USA	0	0	100
Start – susceptible variety – control		USSR	5	–	0–30

Among them were varieties Bella Patna (K-5741), Bluebonnet (K-4772 and K-6620), Bluebonnet 50 (K-4773), Bluebella (K-969 and K-6177), Century Patna (K-4642 and K-6164), Starbonnet (K-6165).

These varieties are widely used as breeding donors of the resistance to nematode in the USA [13]. Of note are the varieties Bella Patna and Bluebella, which stand out among the other varieties with shorter period of vegetation. This fact is important when choosing a donor of the resistance to rice nematode for use in domestic breeding programs.

However, among the samples of the VIR world collection no rice varieties highly resistant to nematode of the domestic origin were detected. This confirmed the need to intensify breeding research in Russia to release nematode resistant varieties.

At the first stage of the evaluation work there were no samples immune to nematode found among the working collection. There were selected 30 samples with resistance index of 86–98 %. Of most interest for breeding programs are samples K-0584, K-0956, K-01494, K-02056, K-02214. Resistance index in their field experiment was 91-95 %, and in the pot trial 94–98 %.

In subsequent years, the working collection was replenished with new domestic and foreign samples. They were studied in detail for the economically valuable traits, including resistance to nematodes. Some samples were identified, their resistance index in the field was 95–100 %. They could be recommended for use in hybridization as sources of increased resistance to nematodes and study the nature of inheritance of this trait. Unfortunately, among the working collection of samples there are still not many samples of rice genotypes with high resistance and immune to the nematode: to date only two have been identified: 93–76 from Bulgaria and 98–35 from Japan (Table 24).

In assessing the collection of rice samples for resistance to nematodes a significant number of varieties were revealed that had no symptoms of infection, despite the presence of nematodes. We consider that such rice varieties and forms could be used in breeding programs for the rice varieties with field resistance to nematodes. Of course, these varieties can not fully solve the problem of combating nematode diseases, but at the first stage of the research they play a positive role in curbing the development of nematodes. The problem needs to be addressed through the involvement in the selection process of the sources and donors of rice resistance to nematodes in the plants of which the parasite does not multiply.

Important for breeding is the selection of rice samples with complex resistance to diseases such as rice blast disease and white tip. Evaluation of the samples of the world collection, resistant to blast, showed that most of them are susceptible to the nematode. However, varieties with effective resistance genes to *Piricularia oryzae*, such as Osenniy, Taichung Native-1, Dourado Precoce, Zenith, Hasi Kalmi, Taichung-sen-10 and the varieties with field resistance to blast Norin, Mochi 43-44, RT-29, Dwarf CH-1039, Badmase, Son Khorcha, Taluli Masino showed high resistance and tolerance to nematodes.

Table 24 – Resistance of the rice samples of the working collection to the rice leaf nematode (ARRRI, 2001–2003 гг.)

Number in ARRRI catalog	Country of origin	Resistance Index, %	Resistance degree
93-11	Hungary	98,0	PR*
93-13	Hungary	95,0	PR
93-17	Hungary	98,0	PR
93-76	Bulgaria	99,0	HR**
99-4	Japan	95,0	PR
99-17	Korea	98,0	PR
98-35	Japan	100,0	HR
0940	Russia	96,0	PR
0986	Russia	95,0	PR
01256	Russia	97,0	PR
02000	Russia	98,0	PR
02199	Russia	96,0	PR
02979	Russia	98,0	PR
03047	Russia	96,0	PR
03078	Russia	97,0	PR
03698	Russia	98,0	PR

* Practically resistant
** Highly resistant

When evaluated against hard invasive background they displayed very low invasive level and high resistance to nematode. Therefore, these samples can be used as source material for breeding varieties with comprehensive field resistance to blast and the rice leaf nematodes.

After selection from the world collection of some rice varieties resistant to thre Krasnodar population rice leaf nematode, their agrobiological traits were studied. It was revealed that most of these varieties were characterized by late maturing. The most suitable donor turned out to be Belle Patna from the USA, the growing period of which under the conditions of the Kuban Region was 145–150 days. In addition, the variety has a long grain and it is resistant to lodging. The donor was included in the hybridization program with some local recognaized early maturing varieties and collection samples. The result is a hybrid material under breeding elaboration.

Given that the genetics of rice resistance to the nematode in Russia had not been studied properly, we performed a genetic analysis of the hybrid population received after crossing the immune varieties Belle Patna with nematode susceptible variety Start. The research was carried out under controlled conditions as per the "Guidelines for the Evaluation of Rice Varieties and Hybrids for Resistance to the Rice Leaf Nematode" [96].

All plants of the first generation had no symptoms of nematode lesion, indicating the dominance of stability (R) over susceptibility (S). In F2 the splitting of this trait was observed. The plants of reaction type R are those that did not display symptoms of white tip and nematode infection (0 points), and the plants with lesions score 1–5 were referred to the plants of reaction type S.

The analysis of 178 plants showed that 99 had no nematode lesions (R), and 79 had lesions (S) of different degree: 54 plants – 1 point, 6 – 3 points, 19 – 5 points. The ratio of R : S was 9 : 7.

This splitting pattern indicates that in this population of hybrid varieties the immunity of Belle Patna to the rice leaf nematode is controlled by two pairs of dominant genes. It should be considered in studies of the original material obtained based on this donor.

The experience of cooperative work of the breeders and the helmintologists showed that already at this stage there was an opportunity to select from the selection material the rice samples and varieties with increased resistance and tolerance to the rice leaf nematode. In the plants of these samples the nematodes multiply with insignificant intensity, and the resistance of plants and loss of productivity are determined by the degree of tolerance to the infection. As is well known, even in case of the white tip epiphytoty the level of damage of the tolerant rice varieties is only 1–6 %, which practically does not reduce the yield [147]. Therefore, the selection in the severe conditions of the field artificial infestation background the nematode-tolerant rice breeding specimens allow creating the varieties with field resistance to white tip. Growing of these varieties will largely reduce the severity of the problem in areas suffereing from white tip caused by nematodes. Practice confirmed that this task could be resolved. After multiple assessments of the samples and their selection in infection nursery we were able to identify some varieties with high endurance of rice to the leaf nematodes, which were then studied in the nursery of the competitive trial (Table 25).

Most of these varieties slightly damaged by the leaf nematodes are based on the varieties Blastonik, Sprint, Kurchanka and donors of resistance to blast: Maratelli 5A, Zenith, Yerua P.A. Consequently, in these new varieties olerance to nematodes is combined with resistance to *Piricularia oryzae*.

Table 25 – Resistance of the rice samples of the competitive trial to the rice leaf nematode, ARRRI (2003–2004)

Variety	Resistance Index, %	Resistance degree
Liman (control)	65,0	MS*
KSI – 3-03	97,6	PR**
KSI – 9-03	100,0	HR***
KSI – 17-03	100,0	HR
KSI – 25-03	95,0	PR
KSI – 27-03	96,3	PR
KSI – 36-03	98,1	PR
KSI – 41-03	96,0	PR
KSI – 48-03	95,4	PR
KSI – 49-03	96,9	PR
KSI – 50-03	97,3	PR
KSI – 60-03	95,6	PR

* Mildly susceptible.
** Practically resistant.
*** Highly resistant.

The sources of tolerance to the leaf nematodes were the rice varieties Krasnodarsky 424, Kuban 3, and Kr-3-84. The last was obtained from the sample VNIIR8785 that stood out among the other collection samples by its high and stable tolerance to the nematode. As it is known, the variety Blastonik is characterized by race specific resistance to blast and tolerance to nematode (Resistance Index 74.2 %). It was handed over for State Variety Trials, but it was not included into the State Register as its yield did not exceed that of the standard varieties. However, Blastonik was used more tan once as a parent form in thehybridization process.

The rice variety Sprint, along with early maturity, stable productivity and tolerance to blast showed a rather high resistance to nematode (Resistance Index 92.5–96.0 %).

Of note is salt tolerant Kurchanka, derived from hybrid population Kulon / Raduga. This variety inherited from the first parent form long grains, high yield and resistance to lodging, and from the second – its middle maturity, short stem, resistance to salinity and resistance to the rice leaf nematode. Its parent form – the variety Raduga (VNIIR226) was isolated in the late 1970-ies as the least susceptible to the nematode. With invasion of 24.5 %, the symptoms are manifested only in 4.5 % of plants [94, 95]. Raduga for some reasons was not recognsized, but it was often used in hybridization process as a source different commercially valuable traits including resistance to rice leaf nematodes.

The varieties Sprint and Kurchanka were included into the State Register approved for use in the North Caucasus. They showed good results in the production conditions and are widely used in breeding programs for creating new varieties (Figure 40).

Thus, the initial material was isolated and some varieties resistant and tolerant to the rice leaf nematodes were created. They are under competitive and production trials. These varieties will help curbing the spead of the white tip disease and reduce its severity till the varieties immune to *Aphelenchoides besseyi* are selected.

Figure 40 – Rice breeding plots

However, since 2010 field evaluation of rice varieties and samples under artificial infection with the rice leaf nematode is not carried out at the ARRRI. This, of course, has a negative impact on future results of breeding of the Russian rice varieties resistant to nematodes.

Following the recommendations of the European Mediterranean Organization for Plant Protection (OERR), the leaf nematodes are included in the list A-2 in the European countries as a particularly dangerous factor of rice diseases based on their high and variable severity, absence of the resistant varieties. In these countries and in Italy in paticular strict quarantine control of rice seeds of the foreign origin is observed [59].

CHAPTER 3

Results of Rice Breeding Research

Rice breeding for resistance to blast has been carried at the ARRRI since 1982. The research program was theoretically substantiated and experimentally checked using infection background to select the unaffected plants and identify the resistance genotype.

The breeding methods were developed that allow creation of rice varieties resistant to blast and tolerant to the rice leaf nematode having also valuable economic traits. Currently, the breeding research of rice varieties tolerant to adverse environmental factors is ongoing at ARRRI (Figure 41).

Figure 41– Breeding Nursery at the ARRRI

These varieties are used for various agronomic practices including zero pesticides method.

3.1 Rice Varieties Released with the Author's Participation

The results of 33 years of research in rice breeding became 25 new varieties of rice, of which 14 were included in the State Register and admitted for use of the North Caucasus: Kulon (1987) [34], Slavyanetz (1991) [35], Pavlovsky (1995) [38], Sprint (1996) [39, 41], Kurchanka (1997), Leader (1999), Viola (2001), Snezhinka (2003), Atlant (2006) [46], Violetta (2007), Kumir (2009), Yuzny (2009) [48], Gamma (2010) [50], Olymp (2015) [60, 67, 68], Titan (2016). Eleven other varieties were submitted for State Variety Trials and production checks: Paritet (1990), Blastonik (1992), Vityaz (1993), Talisman (1995), Vodoley (1998), Jupiter (2000), Mars (2008), Avstral (2009), Vita (2012), Orion (2014), Zlata (2015). Moreover, varieties Talisman, Mars, Avstral and Vita are protected by the RF patents.

All the above-mentioned varieties are resistant to blast and do not require chemical protection from the disease.

In the last 8–10 years in response to the requests of the rice growing farmers we started a new direction of our research: creation of rice varieties for low energy consuming technologies (Leader, Atlant, Yuzhny, Gamma, Olymp, Titan). These varieties are cost effective and the savings can reach 6000–8000 rubles per ha (in prices of 2013) only due to refusal to use of anti-cereal herbicides and fungicides. This considerably improves the ecological situation in the rice-growing area [55].

For the first time in Russia we have created the glutinose rice varieties Viola, Violetta (with short grains) and Vita (with long grains) to produce dietary and baby food, as well as long grain variety Mars with colored husks for wholesome food [42, 45, 62].

Of course, the production life of varieties is limited. Some of the unique varieties have been "working" for decades (Krasnodarsky 424, Kuban 3, Spalchik, Liman), and the others much less. The rotation of varieties is never ending; it is a normal phenomenon. Frequent change of varieties is an indication of the high efficiency of breeding work, if, of course, at the same time the yields in the region increase. The increment of rice yield in Krasnodar Territory over the past five years to 7.1 t/ha indicates that rice breeding research is carried out effectively.

Currently in the State Register of breeding achievements of the Russian Federation out of 50 rice varieties approved for use, 30 are bred in the Kuban region and they occupy more than 75 % of sown areas under rice in the country. Of the varieties of the Kuban origin seven have been created with our participation (Atlant, Gamma, Kumir, Leader, Olymp, Snezhinka, Yuzhny). In addition, nine special purpose varieties including four of our breeding (Viola, Violet, Vita, Mars) have been registered [68].

Here is a brief agrobiological decription of the varieties used in rice production to date.

3.1.1 Rice Varieties for Low Cost Technologies

Leader

The variety was bred at the ARRRI by G.L. Zelensky, G.D. Los, Ye.P. Aleshin, N.G. Tumanyan, P.N. Naumenko, B.G. Fomenko.

The rice variety Leader is protected by the certificate of authorship and patent №0379 (Figure 42). In 1996 it was included in the State Register of Protected Selection Achievements and in 2000 in the State Register of *Breeding* Achievements Approved for Use in the North Caucasus [67, 68].

Leader was received by individual selection from the hybrid population of the third generation Kulon / Kuban 3 // Belozerny with repeated double selection in the breeding nursery (Figure 43). It refers to middle late maturing group. Its growing season is 120–125 days.

It belongs to the botanical var. *zeravshanica* Brasches. The variety is awnless. The lemmas are two-colored: the edges are of straw yellow color, the faces are brown-yellow, slightly pubescent.

Figure 42 – The rice variety Leader

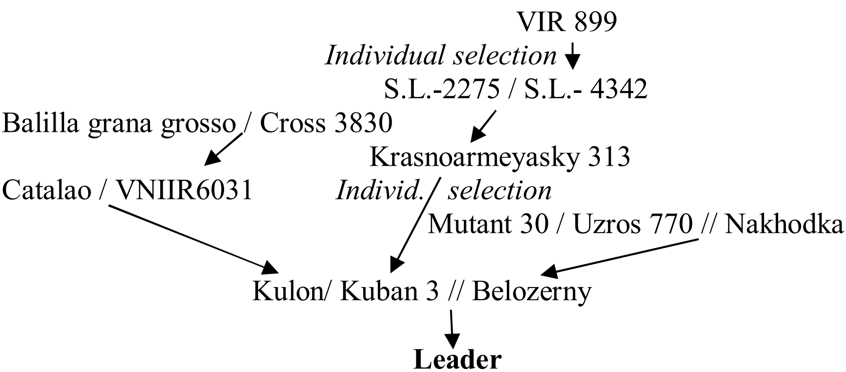


Figure 43 – The pedigree of the rice varity Leader

The plant is compact, with thick and very durable stem. The plant height is 90–95 cm. The panicle is compact, vertical, 13–15 cm long. The grain emptiness is low – 3–5 %.

The grain size is medium, its form is half round. The ratio of the grain length to width (l/b) is 2.3. Dehulling is easy, while the grain remains whole (has a lesser bond of the flowering films with the kernel). The weight of 1000 seeds is 30–31 g. The vitreousness is 86–90 %. The total yield of milled rice is 69–70 %, with 95 % head rice. The protein content of the caryopsis is 9.9 %, amylose content is 19.8 %. The milled rice is white and silvery, characterized by high watering-absorption degree (increase in volume). It maintains the form and crumbly texture when cooked. It can be cooking in an excess volume of water (soups, cereals). It is also recommended for cooking pilaf.

The variety has increased resistance to blast and the rice leaf nematode. It has high resistance to lodging and spikelets shattering from panicles.

A distinctive feature of the variety is its low demand to the growing conditions. The plants grow rapidly at the beginning of the growing season, they easily overcome the water layer during emergence, compete well with gramineous weeds. This makes it possible to avoid herbicides application.

Leader forms a power root system and therefore to produce yield it needs 40 % less fertilizer than the varieties of intensive type.

The quality of the grain of the variety Leader does not strongly depend on the environment. The variety is resistant to high temperature during the maturing without deterioration of the grain.

The variety has a wide ecological adaptivity, it is not highly demanding to the soil quality. It is recommended for energy saving technologies. Leader can generate a high yield when grown on adverse preceeding crops with low rates of mineral fertilizers. The yield potential of the variety is 10–11 t/ha.

The optimal sowing time is not later than May 5. The seeding rate is 5.0–6.0 million viable seeds per 1 ha.

Atlant

The variety was bred at the ARRRI by G.L. Zelensky, G.D. Los, A.R. Tretyakov, Ye.S. Kharchenko, T.N. Lotochnikova, V.V. Anoshenko.

The rice variety Atlant is protected by the certificate of authorship and patent №3174 (Figure 44). In 2007 it was included in the State Register of Protected Selection Achievements, and in 2008 in the State Register of Breeding Achievements Approved for Use in the North Caucasus [67, 68].


Федеральное государственное учреждение
«Государственная комиссия Российской Федерации
по испытанию и охране селекционных достижений»

АВТОРСКОЕ
СВИДЕТЕЛЬСТВО
№ 39170

Рис

АТЛАНТ

выдано в соответствии с решением Государственной комиссии Российской Федерации по испытанию и охране селекционных достижений от 11.09.2006

ПО ЗАЯВКЕ № 9705644 С ДАТОЙ ПРИОРИТЕТА 19.12.2002

Патентообладатель(и)

Автор(ы): ЗЕЛЕНСКИЙ ГРИГОРИЙ ЛЕОНИДОВИЧ

Зарегистрировано в Государственном реестре охраняемых селекционных достижений

Председатель *В.В. Шмаль*

Figure 44 – The rice variety Atlant

Atlant is received by individual selection from the hybrid population Leader / Sprint with the re-selection in the breeding nursery (Figure 45).

VIR 514
Individ. selection ↓
Balilla grana grosso // Krasnodarsky 3352 / Kendzo
↓
Spalchik / Кр-3-84
↓
Leader / Sprint
↓
Atlant

Figure 45 – The pedigree of the rice varity Atlant

The variety belongs to the middle maturing group. Vegetation period is 116–118 days, sometimes it slightly varies depending on the conditions of growing.

It belongs to the botanical variety *zeravshanica* Brasches. The edges are of straw yellow color; the faces are brown-yellow. The spikelets have no awns. Th plant height is 95–110 cm; it depends on the level of mineral nutrition.

The stem is of medium thickness – 6–8 mm, strong. The leaves are green, without anthocyan pigmentation, of average size. The curve of the leaf blade is insignificant. The panicle is compact, long (19–20 cm), slightly drooping, bears from 190 to 250 spikelets. The panicle sterility is low (8–10 %). The grain is of medium size, roundish.

The ratio of the grain length to width (l/b) is 1,7. The weight of 1000 seeds is 28–29 g. The vitreousness is 87–91 %. The total yield of milled rice is 71 %, with 65–71 % of head rice. The protein content of the caryopsis is 9.1 %, the amylose content is 18.7 %. The variety is recommended for canned food and soups.

The plants are resistant to blast, so the variety can be grown with zero perticide technology. It is highly resistant to lodging. Atlant does not shatter, even when it stays in the field longer than necessary but it I s easily thrashed.

The variety has a high growth rate at the period of receiving shoots. The plants easily overcome a layer of water up to 30 cm. Therefore, it is recommended for growng in environmentally protected areas where chemical means of weed and disease control are prohibited. At lower seeding rates the variety forms dense plant stand.

Atlant can form stable high yields with relatively low supply of mineral nutrition, especially nitrogen. The potential yield of the variety is 9–10 t/ha.

During ripening, the grain is unstable to high temperatures and low relative humidity of air. When grain moisture is 17 % and below, the intensity of fracture formation increases.

Atlanta is not demanding to soil quality. It can form stable yields even at low rates of mineral fertilizers.

The optimal sowing date is not later than May 10. The seeding rate is 5.0–6.0 million viable seeds per 1 ha.

Yuzhny

The variety was bred at the ARRRI by G.L. Zelensky, G.D. Los, A.R. Tretyakov, L.I. Seraya, T.N. Lotochnikova.

The rice variety Yuzhny is protected by the certificate of authorship and patent №4677 (Figure 46). In 2005 it was included in the State Register of Protected Selection Achievements, and in 2009 in the State Register of Breeding Achievements Approved for Use in the North Caucasus [68].

Федеральное государственное учреждение
«Государственная комиссия Российской Федерации
по испытанию и охране селекционных достижений»

АВТОРСКОЕ
СВИДЕТЕЛЬСТВО
№ 44264

Рис

ЮЖНЫЙ

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ПО ЗАЯВКЕ № 9464126 С ДАТОЙ ПРИОРИТЕТА 13.12.2005

Патентообладатель(и)
ГНУ ВНИИ РИСА

Автор(ы): ЗЕЛЕНСКИЙ ГРИГОРИЙ ЛЕОНИДОВИЧ

Зарегистрировано в Государственном реестре охраняемых селекционных достижений

Председатель

В.В. Шмаль

Figure 46 – The rice variety Yuzhny

Yuzhny was created by mass selection from the variety Jupiter; it belongs to middle maturing group. The growing season averages 120 days, with fluctuations from year to year from 116 to 122 days.

Yuzhny belongs to the botanical variety *italica* Alef. The plant height is 90–95 cm. The leaves are short, broad, with weak pubescence, form a 30–35º angle with the stem.

The leaves are green, with the medium intensity of color. The panicle is large, 17–18 cm long, with 150–170 spikelets, sterility is low (3–8 %). The form of the panicle is compact, with upright position, slightly inclined when ripe.

The grain is subrounded, of medium size. The ratio of length to width (l/b) is 1,9. The weight of 1000 seeds is 28–29 g, with the husk content of 16,5–17,5 % and the vitreousness of 90–96 %. The output of milled rice is high (69–70 %), including 85–90 % head rice.

The groat is white, of excellent quality, with high culinary indices. The protein content of the milled rice is 6.5 %. The amylose content is 17–18 %. When cooked, the kernels retain their shape with minimal transfer of solids to the cooking water.

The variety Yuzhny has increased resistance to the rice leaf nematode and blast, it is resistant to lodging. It does not shatter, even when it stays in the field longer than necessary but it is easily thrashed and can be harvested by direct combining.

The plants of this variety have intense growth during the emergence and easily overcome the water layer that kills gramineous weeds. This makes it possible to grow it without herbicides.

Yuzhny is a high-yielding variety. Under various conditions it yields 8–9 t/ha with high stability over the years. The potential yield of this variete is 10 t/ha.

The variety does not require special growing conditions. The cost of production is of the same level as the varieties grown without herbicides. The plants are prone to lodging when the plant stand is too dense and overfed with nitrogen.

Yuzhny possesses a wide ecological adaptivity, not demanding to soil quality, but responds well to increased applications of mineral fertilizers.

The optimal sowing dates are not later than May 5. The seeding rate is 5.0–6.0 million viable seeds per 1 ha.

3.1.2 Universal Rice Varieties

Gamma

The variety was bred jointly by the scientists of the ARRRI and KubGAU (G.L. Zelensky, G.D. Los, A.R. Tretyakov, N.N. Malysheva, N.G. Tumanyan, Ye.M. Kharitonov).

The rice variety Gamma is protected by the certificate of authorship and patent №5408 (Figure 47). In 2007 it was included in the State Register of Protected Selection Achievements, and in 2010 in the State Register of Breeding Achievements Approved for Use in the North Caucasus [68].

The variety is created by individual selection from a complex hybrid population of the second generation Kurchanka / VNIIR554-90 // Leader / Talisman (Figure 48) [51].

Gamma belongs to the middle maturing group. The average vegetation period is 115 days, varying over the years from 110 to 118 days.

Figure 47 – The rice variety Gamma

The variety is attributed to var. *italica* Alef. The height of the plants is 85–90 cm. The leaves are short, broad, with weak pubescence, set at 30–35° angle to the stem. The leaves are green; their color is of average intensity. The panicle length is 16–17 cm. The number of spikelets per panicle is 155–160. The spikelets sterility is low (5–7 %).

The form of the panicle is compact, its position vertical, slightly inclined when ripe. The grain is of roundish type (l/b) – 1.9, of medium size, the weight of 1000 seeds is 28–29 g. The vitreousness is high (94–95 %). The output of milled rice is high (70–71,5 %), including 90 % head rice.

The groat is white, of excellent quality, high culinary indices. The trait of the milled rice high quality is derived from Kurchanka.

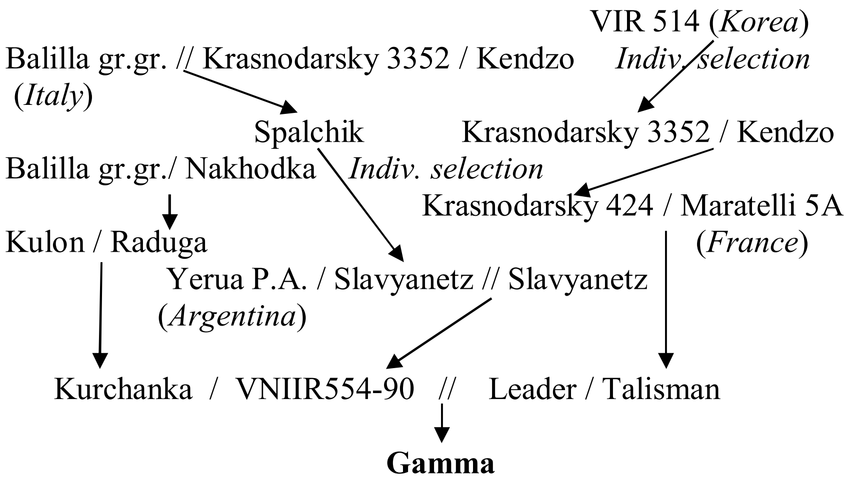

Figure 48 – The pedigree of the rice varity Gamma

The plants of the variety Gamma are characterized by intensive growth during emergence (this trait is inherited from the variety Leader). Therefore, they can easily overcome the water layer under which gramineous weeds are killed. Gamma is not affected by blast, the varieties VNIIR554-90 and Talisman being the sources of resistance. This allows growing this variety with zero pesticide technology and receiving ecologically sound and economically affordable product of high quality.

The variety is resistant to lodging. It does not shatter, even when it stays in the field longer than necessary but it is easily thrashed and can be harvested by direct or two-stage combine harvesting. Gamma is a highly productive variety: its yield is 8–9 t/ha with high stability over the years. The yield potential is 10–12 t/ha.

Gamma does not require special growing conditions. It can be grown both under intensive and low cost technologies.

The variety is not demanding to soil quality; a significant economic effect can be obtained by growing it on the soils with low fertility using energy saving technologies.

The optimal time of sowing is not not later than May 10. The seeding rate is 8.0–9.0 million viable seeds per 1 ha.

Kumir

The variety was bred at the ARRRI by G.L. Zelensky, G.D. Los, A.R. Tretyakov, S.V. Kizinek, Ye.S. Kharchenko.

The rice variety Kumir is protected by the certificate of authorship and patent № 4499 (Figure 49).

In 2005 it was included in the State Register of Protected Selection Achievements, and in 2009 in the State Register of Breeding Achievements Approved for Use in the North Caucasus [68].

The variety is created by individual selection from the sisterly line of the variety Jupiter (SPu 3161-92) in the period of it study in the competitive trial followed by repeated selection in the breeding nursery.

Kumir refers to the middle maturing group. Its vegetation period is 117–119 days.

The botanical variety is *italica* Alef. The floral scales are slightly pubescent, straw-yellow. The spikelets have no awns. The variety is of diminutive height (80–85 cm).

The stem is of average thickness (6–8 mm), durable, highly resistant to lodging. The leaves are green, no anthocyan pigmentation, short, the leaf blade curving is slight. The panicle is of medium length (14–15 cm), not drooping, with 150–200 spikelets. The panicle sterility is low (6–10 %).

Figure 49 – The rice variety Kumir

The grain size is average, half oblong. The weight of 1000 seeds is 28–29 g, the ratio of length to width (l / b) is 2,1. The vitreousness is high (94–95 %). The husk content is 16,8–17,4 %. The output of milled rice – 69,2–70,0 %, with 79,8–82,6 % head rice.

The variety gives even stands with good tillering. It has better resistance to blast compared to other cultivated varieties, so it can be grown without fungicides. The plants are highly resistant to lodging. Kumir does not shatter, even when it stays in the field longer than necessary but it is easily thrashed. The best results are displayed in the cultivation with the intensive technology on fallow predecessor and perennial grasses.

The potential yield of the varieties is 9–10 t/ha.

Kumir has average rates of growth during the emergence, so "soft" water regime is recommended [48].

The variety is recommended for growing on preceeding crops that provide high soil fertility, clean from weeds, using intensive technology.

Optimal planting dates are May 1–10. The seeding rate is 7.0 million viable seeds per 1 ha.

Olymp

The variety was bred at the ARRRI by G.L. Zelensky, N.G. Tumanyan, Ye.S. Kharchenko, A.G. Zelensky, A.R. Tretyakov, Ye.M. Kharitonov.

The rice variety Olymp is protected by the certificate of authorship and patent №7002 (Figure 50). In 2010 it was included in the State Register of Protected Selection Achievements, and in 2015 in the State Register of Breeding Achievements Approved for Use in the North Caucasus [68].

Figure 50 – The rice variety Olymp

Olymp was created by individual selection from the variety Jupiter, which, in turn, was derived from a complex hybrid population: K-5287 / VNIIR8356 // /// AzROS 1713 Bolshevik / Raduga //// L-5-80, with offspring check (Figure 51).

The botanical variety is *italica* Alef. The floral scales are straw-yellow, slightly pubescent, the awns are missing.

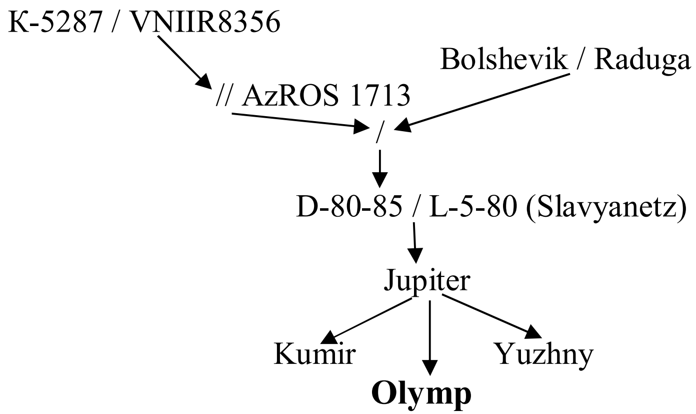

Figure 51 – The pedigree of the rice varity Olymp

The plants are with short stems, 85–90 cm high, with large erectoid panicles, semi-tight, by the end of the growing season slightly drooping, 17–18 cm long.

The number of spikelets per panicle is 155–175, the sterility is low (5–6 %).

The grain is semi oblong, of medium size. The ratio of length to width (1/b) – 2.2. The weight of 1000 seeds is 28–29 g. The milled rice output is high, average over three years 72.3 %, including 92.0 % head rice. The vitreousness is 95.0 %. The milled rice is of excellent quality, with high culinary traits.

The variety is resistant to blast and the rice leaf nematode. Its tolerance to soil salinity is average.

The potential yield of the variety Olymp is 11–12 t/ha.

The variety is resistant to lodging, not shattering even when it stays in the field longer than necessary but it is easily thrashed and it can be harvested directly.

The plants are characterized by intensive growth at emergence. Therefore, they easily overcome water layer under which the gramineous weeds die. Olymp can be grown without the use of chemical pesticides and provide wholesome and cost effective products of high quality [60].

The variety is not demanding to soil quality, the yields are equally good on the highly fertile and average soils.

The optimal time of sowing is from April 25 to May 10. The seeding rate is 7.0 million viable seeds per 1 ha.

3.1.3 Special Purpose Rice Varieties

Snezhinka (long grain rice)

The variety was bred at the ARRRI by G.L. Zelensky, G.D. Los, Ye.P. Aleshin, N.G. Tumanyan, T.M. Kolomietz, Ye.S. Kharchenko.

The rice variety Snezhinka is protected by the certificate of authorship and patent № 1733 (Figure 52).

Figure 52 – The rice variety Snezhinka

In 1995 it was included in the State Register of Protected Selection Achievements, and in 2004 in the State Register of Breeding Achievements Approved for Use in the North Caucasus [67, 68].

The variety Snezhinka was created by individual selection from the hybrid population obtained from late maturing long grain varietiy VNIIR7630 and short stem early maturing form NF-DZ-84. It belongs to middle late maturing group. The vegitation period with reduced flooding co-constitutes 120–122 days, and 122–125 days if the plants emerge through water layer.

Snezhinka belongs to the subspecies *indica* Kato, botanical var. *gilanica* Gust. Its grains are narrow, long. The bush is compact. The stem is thick, hollow, very durable, its height is 90–95 cm.

The leaves are green, with weak pubescence and wax coating, of medium size, with slightly curved leaf blade.

The panicle is long (18–19 cm), of medium density (6–7 spikelets/cm, loosely spreading, drooping, with 115125 spikelets. Grain emptiness is low (6–8 %). Floral scales are awnlesss, with weak pubescence, straw-yellow, by the phase of full maturity become whitish.

The ratio of thre kernel length to width (l/b) is 4.0–4.2. The weight of 1000 seeds is 28–29 g. The rice germ is easily separated by grinding; the kernel is characterized by an increased amylose content (26 %). The protein content of the grain is low (8.2 %). The husk content is 17–18 %. The vitreousness is up to 99 %, the fracture porosity is low (4.0 %); white rece yield is 64–65 %, with 80–85 % head rice. The milled rice is white, with high water-absorption capacity, significant increase in volume, of good cooking quality and preservation of the grain form when cooked. It is recommended for parboiling, cooking sweet pilaf, puddings.

The variety Snezhinka is highly resistant to blast. This makes it possible to grow rice without fungicide applications. It is highly resistant to lodging and shattering.

The yield reaches 7.0–7.5 t/ha with high stability over the years.

A special feature of the variety is its high-energy performance of seed germination and field germination during "soft" water regime. This should be considered to form dense plant stand at a relatively low seeding rate. The long-term monitoring of the development of the plants has shown that they react negatively to the overcrowding. The variety is cultivated using technologies adopted for short-stem varieties of rice, with no chemicals for crop protection as an option.

Snezhinka has a high resistance to grain splitting at dead-ripe stage. Given that the variety has a long narrow grain it is recommended to select sieves individually [64].

The variety does not require special growing conditions. The optimal time of sowing-flooding is the first decade of May. The seeding rate is 6.0–6.5 million viable seeds per 1 ha, or 180–200 kg of seeds per ha.

Avstral (long grain rice)

The variety was bred at the ARRRI by G.L. Zelensky, A.G. Zelensky, P.I. Kostylev, N.N. Malysheva, Ye.M. Kharitonov.

The rice variety Avstral is protected by the certificate of authorship and patent № 16835 (Figure 53). In 2013 it was included in the State Register of Protected Selection Achievements.

The variety Avstral belongs to middle late maturing group. Its average vegetation period is 120 days, varying over the years from 118 to 122 days.

The variety is awnless, belongs to the subspecies *indica*, botanical var. *gilanica* Gust.

Unlike all cultivated varieties of rice, the leaves of the plants of Avstral curl at temperatures above 28 °C. Thus, the evaporation area reduces, the plant wastes less energy for cooling. The shading of the leaves of the lower tiers decreases, so they maintain their viability longer.

The average plant height is 105 cm. The panicle is long (20–22 cm), drooping, with 90–100 spikelets. Sterility of spikelets is low (up to 5 %). The grain is narrow, long, spindle-shaped, the length to width ratio (*l/b*) is 3.5. The weight of 1000 seeds is 27.0–28.0 g.

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Федеральное государственное бюджетное учреждение
«Государственная комиссия Российской Федерации
по испытанию и охране селекционных достижений»

АВТОРСКОЕ СВИДЕТЕЛЬСТВО

№ 54095

Рис

АВСТРАЛ

... от 26.02.2013

по заявке № 9052435 с датой приоритета 19.11.2009

Автор(ы): ЗЕЛЕНСКИЙ ГРИГОРИЙ ЛЕОНИДОВИЧ

Зарегистрировано в Государственном реестре охраняемых селекционных достижений

Председатель В.В. Шмаль

Figure 53 – Сорт риса Австрал

The grain of Avstral has high technological indices and excellent culinary properties: the vitreousness is 96 %, the husk content is 18,5 %, the overall milled rice output is 64–69 %, including 87–90 % head rice.

Compared to the rice variety Snezhinka the grain of Avstral is more resistant to breaking when processed.

Avstral is not affected blast in the field and does not require pesticides. This provides wholesome and cost effective products of high quality.

Avstral does not shatter, even when at dead-ripe stage, but it is easily thrashed, so it can be harvested either directly or by two-stage combining [64].

The yield reaches 7.2–7.5 t/ha with high stability over the years.

The optimal time of sowing-flooding is the first decade of May. The seeding rate is 6.0–6.5 million of viable seeds per 1 ha.

Titan (large grain rice)

The variety was bred at the ARRRI by G.L. Zelensky, A.G. Zelensky, N.G. Tumanyan, Ye.M. Kharitonov, Ye.S. Kharchenko.

The rice variety Titan is protected by the certificate of authorship and patent № 6835 (Figure 54). In 2015 it was included in the State Register of Protected Selection Achievements and in 2016 in the State Register of Breeding Achievements Approved for Use in the North Caucasus.

Министерство сельского хозяйства Российской Федерации
Федеральное государственное бюджетное учреждение
«Государственная комиссия Российской Федерации
по испытанию и охране селекционных достижений»

АВТОРСКОЕ СВИДЕТЕЛЬСТВО

№ 57480

Рис

ТИТАН

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ПО ЗАЯВКЕ №8853963 С ДАТОЙ ПРИОРИТЕТА 29.11.2011

Патентообладатель(и)
ФГБНУ 'ВНИИ РИСА'

Автор(ы): ЗЕЛЕНСКИЙ ГРИГОРИЙ ЛЕОНИДОВИЧ

Зарегистрировано в Государственном реестре охраняемых селекционных достижений

Председатель *В.С. Волощенко*

Figure 54 – The rice variety Titan

The variety Titan was created by re-selection from the variety Pavlovsky. It belongs to the middle maturing group. The growing season is 114–116 days.

The botanical variety is *italica* Alef. The color of the floral scales is straw yellow color, the awns are missing. The plant height is 90–95 cm. The panicle is compact, 15–17 cm in length, carries 110–130 spikelets, drooping when ripe. The sterility is 6–8 %.

The kernel is large, elongated, the ratio of its length to width (l/b) is 2.5–2.6. Weight of 1000 seeds is 34–36 g, the husk content is 17–19 %. The milled rice is white, its vitreousness is high 95–98 %; the total output of the milled rice is 68–69 %, the head rice output is up to 90 %. The milled rice is recommended for the preparation of canned food, soups.

The variety is characterized by high rates of initial growth. The plants of Titan overcome the water layer at emergence well enough; they possess average tolerance to soil salinity. With the optimal nutrition, the plants of Titan are resistant to lodging and shattering of the spikelets. The resistance to blast is satisfactory.

The potential yield of the variety is 9–10 t/ha.

Titan responds well to the reduced seeding rates compensating it with high productive tillering, which is a varietal trait. Top-dressing is recommended to increase tillering. The existing practice of double top-dressing before and after tillering for intensive varieties is unacceptable with Titan, because it causes proliferation of the vegetative mass with increasing sterility of panicles.

Titan is responsive to the average rates of nitrogen fertilizers. The optimal time of sowing-flooding is not later than May 10. The seeding rate is 5.0–6.0 million viable seeds per 1 ha.

Viola (sticky rice)

The variety was bred at the ARRRI by G.L. Zelensky, A.G. Zelensky, G.D. Los, V.G. Krasnikov.

The rice variety Viola is protected by the certificate of authorship and patent № 09469 (Figure 55). In 1994 it was included in the State Register of Protected Selection Achievements [68].

The variety Viola was created by an individual selection from hybrid F1: Yerua P. / Slavyanetz // Slavyanetz /// Slavyanetz ////

Kr-3-84 / Maratelli 5A // Kr-3-84 ///// Maratelli 5A / Slavyanetz // Slavyanetz /// Liman / Kr-3-84 // Kr3-84.


РОССИЙСКАЯ ФЕДЕРАЦИЯ

Государственная комиссия Российской Федерации
по испытанию и охране селекционных достижений

АВТОРСКОЕ
СВИДЕТЕЛЬСТВО
№ 30524

Рис

ВИОЛА

ПО ЗАЯВКЕ № 9503277 С ДАТОЙ ПРИОРИТЕТА 18.12.1994

Заявитель(и)
ВНИИ РИСА

Автор(ы): ЗЕЛЕНСКИЙ ГРИГОРИЙ ЛЕОНИДОВИЧ

Зарегистрировано в Государственном реестре
охраняемых селекционных достижений

Председатель В.В. Шмаль

Figure 55 – Сорт риса Виола

Viola is the first domestic glutinous variety of rice. Its grain comprises starch and amylopectin and less than 5 % amylose (conventional varieties contain 8 to 37 % amylose). The grain of glutinous rice is intended for production of special wholesome products and baby food [42].

The variety Viola belongs to the middle maturinggroup. The growing season is 116–118 days.

The botanical variety is *minantica* Gust. The plants have violet veins on the stem. The lemmas are awnless, by the the phase of full ripeness they become brown-yellow. It makes Viola distinct from all other cultivated varieties. The plant is compact, erect, with strong stems.

The plant height is 80–85 cm. The panicle is compact, slightly droopinhg, 14–16 cm in length, carries up to 125 spikelets. The sterility is 6–8 %. The color of leaves is rich green.

The shape of the grain is rounded, the ratio of its length to width (l/b) is 1.6–1.7. Weight of 1000 seeds is 28–29 g. The milled rice is white, non-vitreous. The output of the milled rice is 66–68 %. When cooked, it turns into gluey mass, its taste is different from that typical of rice. Therefore, the milled rice of Viola should be used for grinding into flour for wholesome and baby food.

The variety has a high field resistance to blast and moderate resistance to the rice leaf nematode. It is resistant to lodging and shattering of the spikelets.

The yield of the variety Viola is 6.0–7.0 t/ha.

A distinctive feature of the variety is its very high energy performance during seed germination and field germination. The rice plants, despite their short stems, easily overcome a layer of water at emergence. The combination of this trait with the disease resistance allows cultivating it using energy-saving technologies.

Russian State Standard (GOST) does not allow the presence of glutinous rice in the grain mass of the harvested varieties, so Viola must be grown at specially allocated plots. Grain processing should be carried on the specially leased lines to prevent mixing with other varieties.

Viola does not shatter, even when dead-ripe but it is easily thrashed. Harvesting is recommended both as a two-stage process and direct harvesting.

The variety can form stable yield even at low supply of mineral nutrition, especially nitrogen.

The optimal planting time is in early May. The seeding rate is 4.5–5.0 million viable seeds per 1 ha.

Violetta (sticky variety)

The variety was bred at the ARRRI by G.L. Zelensky, G.D. Los, A.R. Tretyakov, T.N. Lotochnikova, Ye.S. Kharchenko.

The rice variety Violetta is protected by the certificate of authorship and patent № 3647 (Figure 56). In 2007 it was included in the State Register of Protected Selection Achievements [68].

The variety is created by individual selection from the hybrid population L-5-80 / Qn jung DO (IRRI 06,537).

Violetta belongs to glutinous varieties of rice; its grain contains amylopectin and at least 1.5 % amylose in starch. It belongs to the middle maturing group. The vegetation period is 120–122 days. The botanical variety is *nigropurpurea* Gust. The plants are with short violet awns, violet lemmas and stem veins. This makes them to be easily distinguished from all other cultivated varieties.

The plant height is 80–85 cm, the stem is of average thickness (4.5 mm), durable, highly resistant to lodging. The leaves are green, no anthocyan color, of medium size, the leaf blade is slightly curving.


Федеральное государственное учреждение
«Государственная комиссия Российской Федерации
по испытанию и охране селекционных достижений»

АВТОРСКОЕ
СВИДЕТЕЛЬСТВО
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Рис

ВИОЛЕТТА

выдано в соответствии с решением Государственной комиссии Российской Федерации по испытанию и охране селекционных достижений от 28.05.2007

ПО ЗАЯВКЕ №9811806 С ДАТОЙ ПРИОРИТЕТА 19.12.2001

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Зарегистрировано в Государственном реестре охраняемых селекционных достижений

Председатель В.В. Шмаль

Figure 56 – The rice variety Violetta

The panicle is short (14–16 cm), drooping, with 120–125 spikelets. The sterility of panicles is low (8–10 %).

The grain size is medium, weight of 1000 seeds is 28–29 g. Grain shape is rounded, the ratio of length to widthe (l/b) is 1.6.

The milled rice is white, non-vitreous. The output of milled rice is 68–69 %. When cooked, the grain turns into a gluey mass, which has a taste not typical of rice. Therefore, the milled rice of Violetta should be used for grinding into flour to be used for preparation of dietary and clinical nutrition.

The variety has a high field resistance to blast and moderate resistance to rice leaf nematode. It is resistant to lodging and spikelets shattering from the panicles.

The yield of the rice variety Violetta is 6.9–7.2 t/ha.

A distinctive feature of the variety is its high germination energy and field emergence. Despite the shortness of the plants, they easily overcome water layer while receiving shoots. The combination of this feature with the disease resistance allows to cultivate Violetta applying energy-saving technologies. The variety does not shatter, even when dead-ripe but it is easily thrashed. Harvesting is recommended both as a two-stage process and direct harvesting.

Violetta should be grown at specially allocated plots. Grain processing should be carried on the specially leased lines to prevent mixing with other varieties.

The variety can formg stable yield even at low supply of mineral nutrion, especially nitrogen.

The optimal planting time is in early May. The seeding rate is 4.5–5.0 million viable seeds per 1 ha.

Vita (sticky, log grain variety)

The variety was bred at the ARRRI by G.L. Zelensky, A.G. Zelensky, I.N. Chukhir, A.R. Tretyakov, L.I. Seraya, T.N. Lotochnikova, Ye.M. Kharitonov.

The rice variety Vita is protected by the certificate of authorship and patent № 09469 (Figure 57). In 2012 it was included in the State Register of Protected Selection Achievements [68].

The variety is created by individual selection from the hybrid Violetta / Metelitza.

Vita is a glutinous long grain variety. It belongs to the middle maturing group; its growing season is 112–119 days. It belongs to sub species *japonica*, botanical variety *minantica* Gust. The plants have no awns, with violet lemmas and stem veins. Unlike glutinous variety Viola, Vita has elongated grains.

The plant is short, its height is 80–85 cm, the stem is of average thickness (4.5 mm), durable, highly resistant to lodging.

The leaves are green, no anthocyan color, of medium size, the leaf blade is slightly curving. The panicle the average (17–19 cm), drooping, with 120–130 spikelets. The panicle sterility is low (5–7 %).


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«Государственная комиссия Российской Федерации
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Зарегистрировано в Государственном реестре охраняемых селекционных достижений

Председатель В.С. Волощенко

Figure 57 – The rice variety Vita

The grain size is medium, the weight of 1000 seeds is 28–29 g. The kernel is elongated, spindle-shaped, the ratio of length to width (l/b) is 3,0. The milled rice is white, non-vitreous, its yield is 68–69 %. When cooked, the grain turns into a gluey mass, which has a taste not typical of rice. Therefore, the milled rice of Violetta should be used for grinding into flour to be used for preparation of dietary and wholesome products.

The variety Vita belongs to the so-called glutinous varieties. Its grain contains amylopectin in starch and less than 5 % amylose. It is intended for production of special wholesome and baby food products.

Vita possesses a high field resistance to blast and medium resistance to the rice leaf nematode. The plants of this variety are resistant to lodging and shattering of spikelets from the panicles.

The yield is 6.0–7.0 t/ha.

A distinctive feature of the variety is its high germination energy and field emergence. Despite the shortness of the plants, they easily overcome water layer while receiving shoots. The combination of this feature with the disease resistance allows cultivation of Vita applying energy-saving technologies.

Vita should be grown at specially allocated plots.

The variety does not shatter, even when dead-ripe but it is easily thrashed. Harvesting is recommended both as a two-stage process and direct harvesting.

The optimal sowing time is the first decade of May. The seeding rate is 5.5–6.0 million viable seeds per 1 ha.

Mars (long red grain variety)

The variety was bred at the ARRRI by G.L. Zelensky, O.V. Zelenskaya, Ye.M. Kharitonov, N.G. Tumanyan, T.N. Lotochnikova.

The rice variety Mars is protected by the certificate of authorship and patent № 6525 (Figure 58). In 2011 it was included in the State Register of Protected Selection Achievements [68].

The variety is created by individual selection of a spontaneous hybrid in the production rice plant stand of the variety Izumrud.

Mars belongs to the middle maturing varieties. The vegetation period with reduiced flooding is 115 days, with fluctuations from year to year it is from 112 to 117 days.

Botanical and morphological parameters: the plants are awnless, but in some years, the awns rudiments can be found in some spikelets. Mars belongs to subspecies *indica* Kato, botanical variety *philippensis* Gust. The floral scales are straw yellow, beardless, slightly pubescent. The plant height is 100–105 cm, the panicles are long, drooping, 19–21 cm long. The number of spikelets per panicle is 140–160. The spikelets sterility is low (3–5 %).

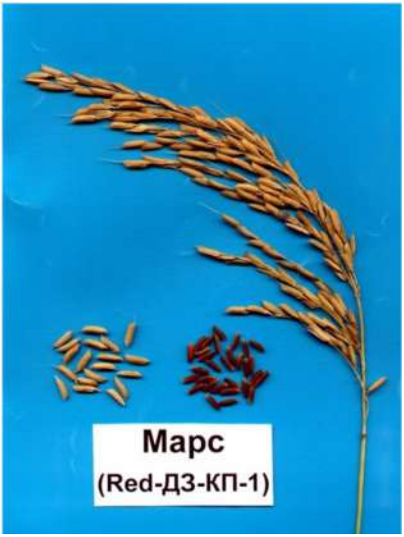

Figure 58 – The rice variety Mars

The grain is narrow, long, spindle-shaped, l/b is 3,5, the weight of 1000 seeds is 27–29 g. The vitreousness is high (96–97 %) The yield of milled rice is 66–68 %, including 90 % head rice. The milled rice has improved nutrition value, it is intended for special food and exotic dishes.

Mars is recommended for processing without polishing or with partial polishing.

The variety has average resistance to blast. The plants do not lodge, but are prone to topple, especially when overfed with nitrogen. It does not shatter, even when at dead-ripe stage, but easily thrashed, so it can be harvested either directly or at two-stage combining.

The yield of this variety reaches 7.0–7.5 t/ha with high stability over the years.

Mars does not require any special conditions for growing and therefore can be grown using the technologies accepted for the white grain varieties, in compliance with rules that do not allow mixing it with other varieties. A special feature of the variety is its high-energy performance at seed germination and field germination during "soft" water regime. This should be considered to form a dense plant stand at a relatively low seeding rate. The long-term monitoring of the development of the plants of this variety showed that it negatively responds to dense plant stand (more than 300 plants per 1 m^2).

Given that Mars has a long narrow grain, the sieves should be selected individually.

The variety is responsive to the average level of mineral nutrition. It is recommended for cultivation after clean predecessors to obtain high quality long grain rice.

The optimal sowing dates are the first decade of May. The seeding rate is 6.0–6.5 million viable seeds per 1 ha.

3.2 Perspectives of Breeding High Yielding Rice Varieties

Breeders of many rice-growing countries are working at creation of highly productive rice plants of the new type (New Plant Type). The purpose of this reaserch is implementation of the Super Rice Project. This calls for breeding rice varieties yielding 15–17 t/ha [139, 144 148]. For example, the rice variety with the growing season of 162 days was bred and tested in Australia and its yield is 16.5 t/ha. In China, there is ongoing research on the creation of highly productive rice hybrids by heterosis. The created rice hybrid has a potential productivity of 17 t/ha. The authors do not disclose the information on the length of the growing period. (It is known that the rice growing season in the south of China is 170–180 days).

The increased productivity of rice plants is one of the major breeding problems. At different stages of the breeding this could be achieved by improving the individual traits, such as productive tillering, resistance to disease and lodging, as well as high levels of the panicle productivity (number of grains, grain size and weight).

However, some scientists believe that breeding aimed at the above-mentioned traits has exhausted its reserves and there is need to look for new traits. A.I. Nosatovsky [89], A.A. Nichiporovich [86, 87, 88], S. Donald [24] think that the size and the position of the leaf blades can have a significant impact on rice productivity.

It is known that the yield depends on the plant density and their individual productivity, which is the product of the number of panicle and weight of grain per panicle. The number of plants and panicles per unit area is regulated by agricultural practices. These values have high modification variability and low heritability. Therefore, the main role in increasing the yield of the variety belongs to the panicle productivity [79].

Figure 59 – The rice sample BZ-600

Our experience in rice breeding has shown that even in Russia, where the climatic conditions restrict vegetation period of rice to 125 days, the biological potential of the rice plant significantly exceeds the productivity of the varieties cultivated in this country. The hybrid form of rice BZ-600 received as long ago as 1983 (Figure 59) in the thin crop produced 14 g of grain from the main panicle (while most the varieties this value is not above 2.5–3.5 g). But mealy endosperm of the grains deprived the form of the prospects of direct use to obtain milled rice, the other constraint was that with an increased plant density the yield dropped radically. Therefore, BZ-600 was used as a parent form in the numerous hybrid combinations of which a diverse breeding material was selected [31].

The value of BZ-600 is that while working with this form, we concluded that the rice yield in Russia can be considerably increased by breeding. But the existing morphological type of the cultivated varieties is one of the limiting factors for this task. Most of them have leaf blades located at an angle of 30º or more to the stem. In dense plant stand by the flowering time, the rice plants shade each other, so only the top 2–3 leaves are productive, and the rest gradually die. Consequently, it is necessary to change the morphological type of rice plants to significantly reduce competition for light in dense plant stand.

Analysis of the breeding results of the field crops [79] led to the conclusion that the yield of modern varieties increased mainly due to redistribution of the dry matter between the vegetative and generative parts of the plant. The total biomass yield of the plants remained at the level of the old varieties, only the harvest index increased, and the selection for its increase reached its limit. A further increase of the rice yield, as stated by A.G. Lyahovkin [79], is possible only by increasing the biomass. This view is shared by the Indian researchers. They believe that biomass of the rice varieties should be increased to 25 t/ha and yield index should increase from 0.5 to 0.6 [144].

Of importance is the improvement of the rate of photosynthesis. However, it is difficult to resolve this issue since the modern rice varieties do not actually exceed the photosynthetic activity of the wild rice forms [124]. In addition, there is a contradicting evidence that cenosis productivity and that of an individual plant is not directly linked to the leaf assimilation mechnism [85]. In addition, the increase of the leaf surface area is contrary to the basic feature of the highly productive cenosis where with the increase of the number of plants it is necessary to maintain high productivity of the individual plant. The increase in leaf surface of plants deteriorates light conditions of photosynthesis [84]. The shape of leaf blades plays an important role in shading. It is shown that the area of the photosynthetic surface of valleculate leaves by the projected leaf area is considerably higher than of the arrect ones [151].

Given that rice plants under shading compete for light, there is an optimal value of the leaf surface index for the cenosis productivity. When the index surpasses the optimal value, the leaves shade each other so that the dry matter spent for breathing exceeds the increase of the dry matter in the process of photosynthesis. However, the Japanese researcher Yoshida [6] showed that this concept applies to traditional varieties with drooping leaves and lodging stems. For the semi-dwarf varieties with straight leaves the optimal value of the leaf area index is not established and it is concluded that in such plants photosynthesis prevails over respiration process [6]. Perhaps under seedling rice practice the density of the plant stand did not reach the density of the direct sown rice.

Since in Russia the accepted practice of rice growing is by sowing and biomass is formed mainly due to the density of the plants, morphological type of the variety must be such as to significantly decrease the competition of the plants for light in case of dense plant stand. Many years of our experience in breeding work has shown that the existing morphological type of the cultivated rice varieties and collection samples is one of the limiting factors in breeding for the rice yield increase in Russia up to 15–17 t/ha. We believe that the plants of the Russian Super Rice should have erectoid leaves, the height of 90 cm, excellent grain quality and high resistance to lodging, diseases and pests. This is the type of plant that can support a large panicle with high number of spikelets that survive in dense crops. At that the panicle size of the new plant should reach 35–40 % of the total length of the stem (Figure 60).

As is known, the leaf is one of the important organs and the plant productivity depends on it. The dimensions of leaves and their arrangement in space affect the rice yield and other traits.

To most effectively catch the solar radiation, the assimilating surface should completely cover the soil throughout the growing season. Under full coverage is meant the plant density, at which the soil surface gets at least 5 % solar radiation reaching the crop. However, the majority of crops do not provide such coverage. So, the demse crop can achieve these values through the development of two or three tiers of horizontal leaves or, on the contrary, due to significantly greater leaf area when their position is tilting and almost vertical.

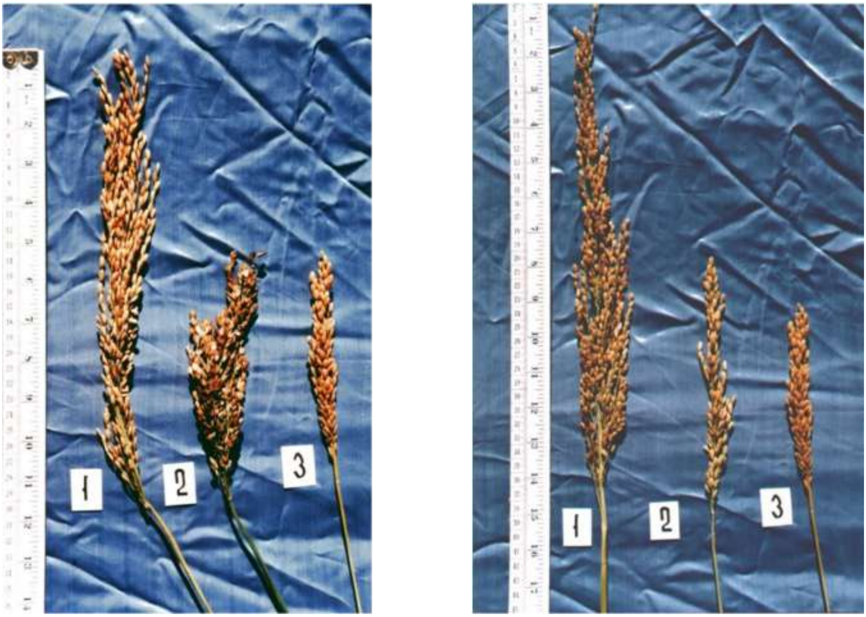

Figure 60 – High yeilding rice forms
compared to ordinary varieties

Some scientists have shown that with this (vertical) arrangement of leaves the light penetrates better into the crop stand and more evenly illuminates the leaves of different tiers and the stems. Thus, J. Roth, B. Roth [99, 100] state that the light transmittance into the crop in this case is increased 2.0–2.5 times.

In the morning and in the evening the plant with vertically located leaves are irradiated with direct and diffuse radiation flow. The leaves oriented almost perpendicular to the direct rays of the sun get highest intensity at low position of the sun, while the horizontal leaves of a single plant receive practically no radiation. The sun rays a kind of slide along them, and in the dense plant stand they just do no reach the leaves.

The plants with similar leaves orientation constitute the optimal type of geometric structure of the leaf mechanism, which allows a maximum use of radiation throughout the day. Total photosynthesis in such forms is the highest compared to the forms with normal arrangement of leaves.

This type of the plant, even in dense crop stand can have a large panicle with many spikelets. The panicle size in the new type of the rice plant should reach 35–40 % of the total length of the stem. An example is a dwarf rice plant “Mutant Alexeenko” with the plant height of 20 cm, the panicle length is 9 cm [5], i.e., the panicle share in the length of the stem is 45 %. With recognized varieties, this value is much lower: in Krasnodarsky 424 it is 15 %, Spalchik 20 %. Our breeding practice confirmed the possibility of implementation of the model of the new morphological type of rice plants [40].

After years of multi stage hybridization and repeated seletions we could identify several breeding lines, each with the traits needed to create plants of the new type. The samples were obtained with vertical erectoid leaves, good resistance to dense crops, as well as samples with large panicles and high number of spikelets. They had grain of excellent quality, had the usual arrangement of leaves and negatively reacted to dense plant stand. After hybridization by multiple selections we managed to produce plants combining the erectoid leaves with panicles having many spikelets (Table 26).

Among the studied samples the two rice forms Olin-1 and Olin-2 stand out. The productivity indices of these plants are significantly higher than in the varieties in production at that time: short stem Slavyanetz and tall Krasnodarsky 424. Of note is the indicator "percentage of panicles in the total length of the stem". In Olin-1 it is 43.5 %, and 40 % in Olin-2. Both forms have vitreous endosperm, they do not lodge, do not shatter. They are resistant to diseases. However, their growing season exceeds 130 days, which is unacceptable for climatic conditions of Russia.

Table 26 – Performance of high yielding rice forms compared to recognized varieties, 1997

Form, variety	Type of leaves	Plant height, cm	Main panicle		Panicle /stem length ratio, %
			length, cm	Number of grains, pcs.	
Olin-1	Erectoid	92	40	702	43,5
Olin-2	Erectoid	90	36	670	40,0
G-29-500	Common	125	29	500	23,2
BZL-97	Common	85	18	580	21,2
Slavyanetz	Common	85	18	186	21,1
Krasnodarsky 424	Common	115	22	125	12,0

Subsequent study of the offspring of these forms helped us to identify several biotypes of highly efficient plants (Olin-1-1, Olin, 2-1), which differ in panicle density and degree of its drooping. Numerous repeated selections among samples of these plants were done to continue their study. For expansion of the genetic diversity of breeding material with erectoid positioning of leaves a series of direct and reciprocal crosses of the isolated forms were performed with rice varieties that differ in a few morphological and biological traits. For each hybrid combination, there were received 150–180 seeds and that was sufficient for further breeding.

Based on the original material a series of various types of vertical samples with reduced vegetation period, large and quality grain, increased yield, resistant to diseases were bred (Figure 61).

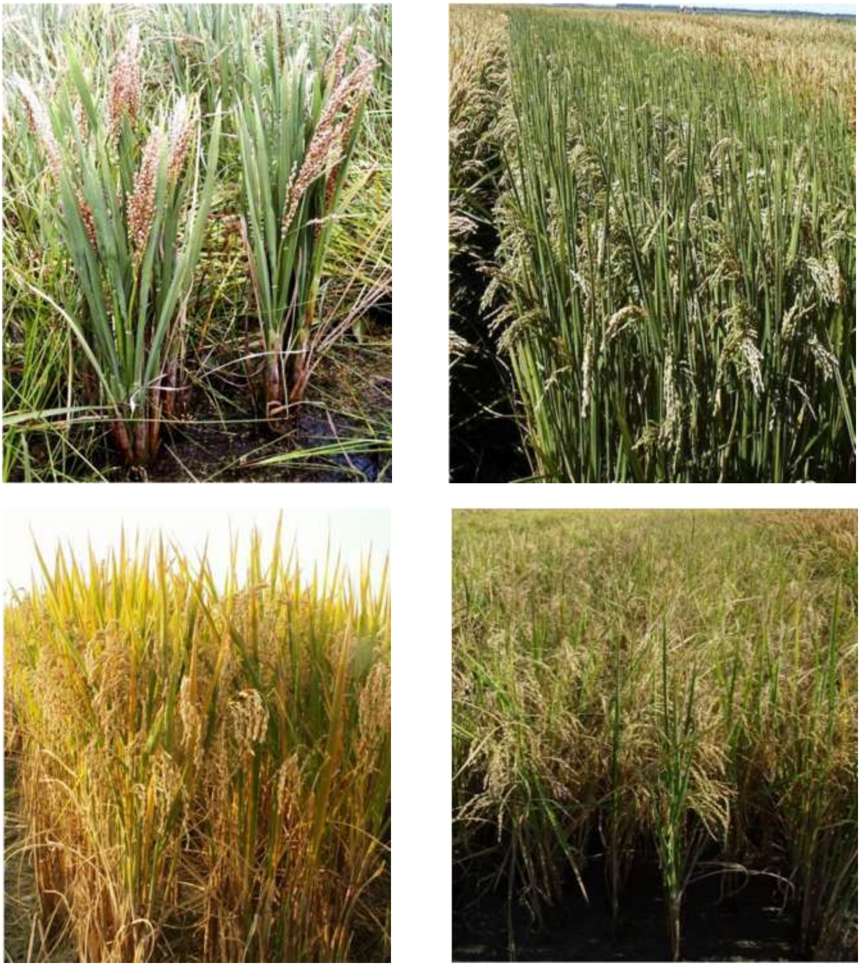

Figure 61 – New rice samples with the modified (vertical) type of leaves

Many years of breeding work resulted in creation of the rice form with a new morphological type of the rice plants. They have enhanced the understanding of the biological potential of this crop in the south of Russia, as well as became the basis for the creation of a new generation of the rice varieties [61].

CHAPTER 4

Elements of Rice Agronomic Practices

Agronomic practices of agricultural crops including rice should to be developed regarding their biology and especially in view of morphobiological features of each variety [57].

In the 1970–1980-ies Agriculture in Russia developed based on intensive agronomic practices. Its main task was a steady increase in grain production. For this purpose, the state allocated agricultural machinery, fertilizers and pesticides in the required amount. The intensive agronomic practices with wide application of chemicals spread among the farms of Krasnodar Territory and thus agriculture made some progress. However, this was accompanied by a large expenditure of labor, energy and money, and negative ecological consequences, deterioration of top soil [102]. A good example of this was the objective to produce 1 million tons of rice in the Kuban region in 1980. The task was accomplished, but with negative consequences that hit hard during the next few years. To gather the necessary amount of rice the acreage of rice crop was significantly increased violating the crop rotation sequence, fallow fields were sown with rice and alfalfa fields were taken to plow. Already next year this resulted in the considerable reduction in rice yields, with field infestation with red rice forms and, consequently, decrease in the gross rice grain yield in the years that followed.

In the 1990-ies during the "reforms" of the economy the downturn in the rice industry continued. The intensive agronomic practices with application of chemicals became unacceptable and unprofitable. It was only since the mid-2000-ies that the economic situation in the country improved, with a gradual rise in rice production in the Krasnodar Territory.

The transfer of the farming of the Kuban Region to the rational biological foundation does not mean rejection of the mineral fertilizers and pest control. It involves the creation of a flexible system of land use with the constant increase in the share of biological (low-cost) methods, a reasonable application of fertilizers and other chemical products. This fully applies to the rice farming.

4.1 On Rice Biological Traits and Agronomic Practices

Let us consider how the knowledge of the morphology and biology of the rice varieties can be used in their cultivation. First, with complete specifications of the varieties, we should define the rice production strategy and tactics.

1. Placement in the rotation. As is known, there are three types of rice crop rotation [44]:

a) with fallow;

b) with grasses;

c) with grasses and fallow.

The first type is a three-year rotation: rice during the first year; rice during the second year and the sown fallow during the third years. This rotation is used in the Primorsky Territory, where soybeans are plowed in the fallow field as green manure. In the Astrakhan region rice and vegetables three-year rotation is popular. Tomatoes, cabbage, cucumbers and watermelons are grown in the fallow fields. Rice plays the role of the land reclamation agent: the water layer reduces the level of soil salinity. Some farms alternate the crops: they grow vegetables for two years in the field and rice is sown during the third year.

In the Kuban Region, the eight-year crop rotation turned out to be the most effective with rice occupying 62.5 %: perennial grasses (alfalfa) are grown in the first and the second fields; rice is grown in the third, fourth and fifth fields; the sixth field is the sown fallow, the seventh and eighth fields are occupied by rice. Thus, most the rice irrigation systems are the engineering systems considering such rotation.

At present, the State Register of Breeding Achievements approved for use contains more than 30 rice varieties created in the ARRRI. Besides, some new varieties are under State Trial Program. Each of them has a set of different features and properties from the other varieties. They also have some advantages over the previously established varieties. The environmental testing and production verification of the rice varieties in the different rice growing areas helps identify these advantages.

It is very important not only to test the variety after the best predecessors, but also place them parallel in different crop rotation links. This allows rice growing farmers extending the term "crop rotation" with the concept "variety rotation", that is fill the impersonal term "rice" with varieties and their names (Table 27).

Table 27 – Rice Variety Rotation in the 8-year Rice Rotation (rice share is 62,5 %) [44]

Field	Crop	Rice variety	
		type	name
1	Alfalfa	–	–
2	Alfalfa	–	–
3	Rice	Middle maturing, intensive	Rapan, Khazar, Ametyst, Garant, Kumir, Victoria, Sonet, Gamma
4	Rice	Middle maturing, undemanding	Leader, Atlant, Flagman, Sonata, Severny, Yuzhny, Olymp
5	Rice+ winter wheat	Fast maturing – 50 % Middle maturing – 50 %	Novator Sonet, Gamma, Kumir
6	Amelioratory field – winter wheat: 50 % for fodder as shredded biomass + 50 % for grain production + winter rapeseed	–	–

Field	Crop	Rice variety	
		type	name
7	Rice after rapeseed	Middle maturing, half intensive	Regul, Yuzhny, Olymp, Yantar, Snezhinka
8	Rice+ winter wheat+ alfalfa sown in spring	Fast maturing – 50 % Middle maturing – 50 %	Novator Sonet, Gamma, Kumir

Thus, after alfalfa, the best rice predecessor in the crop rotation, it is necessary to place varieties of the intensive type using the soil fertility in the best way.

These varieties are: Rapan, Khazar, Amethyst, Garant, Kumir, Victoria, Sonet, Gamma. All of them, except Gamma have average growth rates at emergence and, therefore, require a "soft" water mode.

For optimal density of seedlings in this field it is advisable to apply modern herbicides complex action (Nominee, Segment, Citadel and others). This applies particularly to the variety Kumir that stands out by its short stature (70–80 cm), high resistance to lodging, enhanced productivity against the rich background. However, the deep layer of water makes the rice stand of both Kumir and Amethyst thin.

In the field with soil overturning it is advisable to sow less demanding varieties, such as Leader, Atlant, Flagman, Sonata, Severny, Yuzhny, Olymp.

These varieties are characterized by their ability to emerge through the water layer. Therefore, they can be grown both using herbicides against gramineous weeds and zero herbicide technology (in buffer zones). The mentioned varieties have a strong root system, especially the variety Leader, Atlant and Yuzny, so they are less demanding in terms of mineral nutrition. In the fifth field, which will be fallow, it is advisable to sow winter wheat after rice. To have time to prepare soil in autumn it is better to sow the varieties with a short growing season. To maintain the level of the yield, half of this field should be sown with early maturing variety (Novator), and the other half with the middle maturing (Kumir, Sonet or Gamma). After harvesting there is enough time to prepare the soil for sowing of winter crops (wheat, barley, rapeseed, peas, vetch, etc.).

Since the reclamation field is intended for thorough levelling of rice plots, some varieties of wheat can be harvested for fodder as shredded biomass and levelling can be started in early June. The second part of the wheat crop is harvested upon its full maturity and levelling is continued. Upon completion of levelling soil tillage shall be done (disking and nonmoldboard loosening) with subsequent sowing of winter rapeseed. This crop is a good forecrop for rice. This phytosanitary crop cleans soil from pathogens (i.e. *Fusarium*) and that leads to better rice germination, and hence the rice yield. Rapeseed is mowed in the spring for fodder and its vegetation residues are embedded by disking as green manure.

The following year, after the reclamation of the field it is advisable to sow the middle maturing half-intensive rice varieties. The choice of these varieties is sufficient: Yuzhny and Olymp with short grain, Regul and Yantar with middle size grain and long grain Snezhinka. Given field cleanliness after the fallow, it is possible to avoid or reduce to minimum the herbicides application. In the last field of the crop rotation it is recommended to sow winter wheat after rice to sow alfalfa under its cover. At this stage of the crop rotation, it is necessary to sow the variety with the shortened vegetation period: 50 % early maturing and 50 % middle maturing [57].

In saline plots the highest effect will be observed with salt tolerant varieties (Sonata, Sonet).

Of course, our proposal for placing rice varieties and other crops in the rotation are just recommendations. In each farm the specialists should choose the rice varieties by their biological traits, soil conditions, meliorative state of the rice irrigation system, and the farm state of business. But anyway, the farm should not focus on the cultivation of the crop rotation with one or even two varieties. The winner is the farm with 4–5 sown rice varieties on the main areas, and 3–4 new varieties being tested in the "Agronomist’s field". The optimal variety rotation will lead to significant improvement of the efficiency of crop rotations in each of rice farm.

2. Determination of the areas, especially in the buffer zones where rice is grown without antigramineous herbicides. The rice irrigation systems should be prepared in advance and the rice varieties that easily overcome the water layer should be chosen. These varieties are Leader, Atlant, Olymp, they can be grown without chemical crop protection products.

3. Consideration of the main limiting factor for rice growing in the Kuban Region. This is the number of days with effective temperature (above 15 °C). The long-term data the transfer to average daily temperature of 15 °C is observed here in spring on May 8, and in autumn on September 29. Between these dates there 142 days. This is the limit allotted to rice crop in the region. However, over the years there are deviations from these dates, sometimes quite substantial. So, in 1997, already on September 5 the registered temperature was 7 °C. And in 2000, the spring transition of average daily temperature of 15 °C was observed on May 21. Based on this information the varieties with growing season up to 125 days can be grown in the Kuban Region. This is supported by more than 30-years of experience of growing the rice variety Krasnodarsky 424 with this duration of the vegetation period. But it is known that this period is getting longer with shoots growing through the water layer, with high rates of nitrogen fertilizers, and especially when the plants are treated with herbicides. Therefore, the breeders strive to create varieties with growing period of 112–120 days. However, there is positively correlation between yields and vegetation period: the more days the plant grows under the sun, the more biomass is accumulated. Therefore, late maturing varieties produce higher yields than the early maturing ones. The breeder is obliged to look for “the golden mean”.

The next factor that exerts considerable impact on the development of rice, is the length of the daylight. The longest day in the Kubsn region is about 16 hours, it is June 22. This date should be considered for the following reason. While the days are getting longer, the rice plant is at the stage of its vegetative development. Reduction of the light day is a stimulant for the switching on the transition mechanism in the rice plant to generative development (panicle formation). This means that by the date of June 22 the rice plants should have 6–7 leaves, and have productive tillering completed. Lateral shoots formed after July 7–10 do not significantly affect the increase of the plants productivity. Hence the conclusion: the sowing of rice should be started early (in the third decade of April), so that to finish flooding of the entire area should be finished before May 10. On the one hand the rice plants can fully use the effective temperature to obtain seedlings, and on the other hand, they get the maximum of tillering before the length of the light day begins reducing. The rice plant needs on average about 30 days for tillering. Timely nitrogen top dressing stimulates tillering. For early maturing varieties, it is necessary to do it at the phase of 2–2.5 leaves, and for the middle maturing at the phase of 3–3.5 leaves.

When growing rice with zero herbicide technology (buffer zones), the agronomist has an opportunity to accelerate the development of plants while obtaining seedlings though the water layer by increasing water temperature. For that a two-stage flooding is recommended. At first the level of flooding water is 5–7 cm, and after 4–5 days, as water warms over 20 °C, water level can be increased to 15–20 cm. For example, in 1999 we observed the water temperature in the Slavyansky region. In the irrigation canal it was 11 °C, in the first field with 25 cm water layer is was 14 °C, in the second field where the water layer was 20 cm the water temperature was 16 °C. The height of rice plant (variety Leader) was 6–8 cm in the first field, while in the second it was 12–15 cm, though both fileds were flooded on the same date. The further development of the rice plants confirmed the feasibility of the maintaining the layer of water up to 20 cm.

A deeper layer of water not only reduces its tempera-ture, but also accelerates leaf dying-off. As noted, the lateral shoots are formed at the tillering phase only from axils of the living leaves. After booting and heading photosynthesis in leaves covered with water ceases and they gradually die. Therefore, for growing rice the water layer on the flooded fields should not exceed 15–20 cm.

The rates of growth of the rice varieties vary considerably during obtaining seedlings (Table 28). This is biological trait to be considered when choosing a method of controlling millet weeds (water layer or herbicides). The highest growth rates characterize Sprint, Leader and Atlant (9 points). These are the rice varieties that should be sown in the areas where the application of herbicides and more over yheir aerial application, is forbidden.

An important element of agricultural practice, related to the biology of the varieties, is a timely discharge of water from the fields. Maintaining a layer of water depends on the traits of the varieties according to the type of grain filling. The significant differences in this trait between varieties have been determined. In some varieties, the filling of grain is mainly due to the ongoing photosynthesis, and in others at the expense of re-utilization, i.e. the outflow of plastic substances from the stems and leaves. The most striking example of the former is the rice variety Spalchik, and the latter is Kuban 3. For this reason, to maintain photosynthesis and normal grain filling in the rice variety Spalchik and other varieties with short stem (Kumir, Sonet) the layer of water is required almost to the end of the vegetation period.

Table 28 – Morphological and Biological Traits of Rice Varieties

Variety	Vegetation pariod, day	Plant height, cm	Growth rate, pount	Grain type, *l/b*	Milled rice, %	Resistance to blast
Rapan	116–120	90–55	7	1,8	72	MR
Flagman	117–120	90–95	7	1,8	71	MR
Atlant	112–116	85–90	9	1,7	71	R
Leader	120–122	90–95	9	1,7	71	R
Yuzhny	120–125	85–90	8	1,9	70	R
Olymp	118–122	85–90	8	1,9	70	R
Snezhinka	120–122	85–90	6	4,0	69	R
Gamma	116–118	80–85	8	1,7	71	R
MR – medium resistance; R – resistant.						

In addition, in case of early lodging the photosynthesis is disturbed in the short stem varieties, thus the grain is hollow. This is not observed in the variety Kuban 3 that forms the normal yield even if water is discharged and the plants are lodging in 18–20 days after flowering. This is a valuable quality we could pass to the variety Leader, Kuban 3 being one of its is parental forms. Already three weeks after flowering the plants of Leader do not need water layer. A vigorous root system supplies the plant with water from the soil, providing a normal filling like in the variety Kuban 3. However, in contrast to the Kuban 3, Leader does not lodge and it is not affected by balst. These same qualities are found in Atlant, the variety bred by crossing varieties Leader and Sprint. Water discharge from the rice fields should be carried out based on the biological traits of the varieties and the types of grain filling.

It should be noted that the knowledge of morphological and biological traits of the varieties also allows determining the harvesting strategy of the crop. The degree of resistance to shattering, especially to the lodging of plants, the time of their maturation determines the choice of the method and harvesting sequence of the varieties, their threshing and post-harvest treatment. The terms and methods of harvesting are subject to weather conditions and traits of every variety. It should be borne in mind that, as the grain is drying its fracture porosity increases. The dedicted trial [71] showed that the timing of rice harvesting significantly influences the grain quality (Figure 62).

At dead-ripe stage and rice grain humidity reaching 14,5 %, the fracture porosity went up to 28,3 %. During processing, such grain produces a significantly reduced output of the head rice.

The comparison of seven rice varieties with different types of grain and growing season shows varietal differences in reaction to the overmaturing of the plant after the onset of full ripeness (Figure 63).

The diagram above proves that on the 35-th day after flowering the differences in fracture porosity between varieties were small. Further, every five days these differences increased. At that on the 65-th day the maximum fracture porosity (50 %) would be observed in the fast maturing short stem varieties Sprint and Liman, and the minimum – (less than 20 %) of the long-grain varieties Izumrud and Snezhinka.

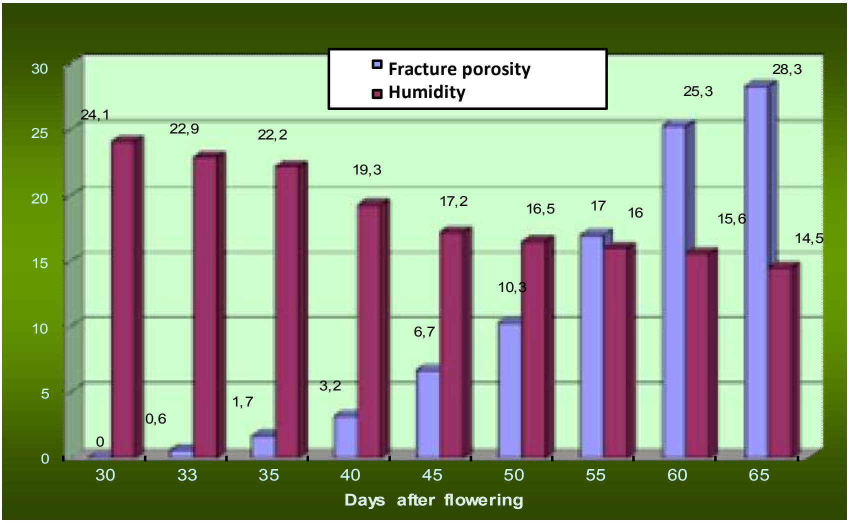

Figure 62 – Impact of rice harvesting dates on grain fracture porosity [71]

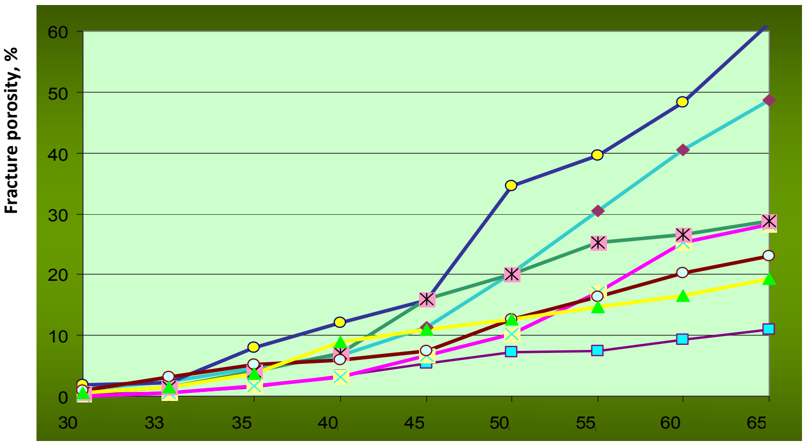

Figure 63 – The differences of rice varieties according to fracture porosity [71]:

Izumrud Sprint Liman Rapan
Amethyst Kurchanka Snezhinka

The middle maturing long grain varieties Amethyst, Kurchanka and Rapan showed intermediate values of fracture porosity (22–28 %).

The obtained data are of interest for the rice farmers of the Kuban region in determining the harvesting strategy for the cultivated rice varieties.

In conclusion, it should be emphasized once again that to obtain a high yield of rice all biological traits of the cultivated varieties should be considered. This includes crop rotation, the level of mineral nutrition, and water regime during the growing season, especially during maturing, when the water must be discharged from the fields.

4.2 Mechanized Rice Growing and Harvesting Practices in Russia

The main operations of the rice production in Russia are carried out by machines. Rice irrigation systems (RIS) are of engineering types and include: fields (checks) of 4–6 hectares (sometimes 10–20 ha), limited along the perimeter by bunks and dams; main irrigation canals for the supply of large volumes of water from catchment basins (rivers, reservoirs) to RIS (Figure 64); smaller channels for fields irrigation/water discharge; escape canals intended for water removal into natural receiving waters (e.g., the Azov Sea) (Figure 65); hydraulic engineering installations to control the amount of irrigation water supplied to the fields or discharged from them; roads and bridges for self-propelled units and vehicles during rice cultivation and other crops and during the execution of repair or restoration works of the engineering systems (Figure 66).

In such engineering systems, highly efficient machines and machine tractor aggregates (MTA) are used for tillage, sowing, diseases, pests and weeds control and havesting.

Figure 64 – Main Irrigation Channel

Figure 65 – The field irrigation canal with hydraulic engineering installations

The bunks separating rice field from each other, are impassable, i.e. the machine units cannot move across them from one field to the other (previously in Russia some rice systems were with bunks that could be passed over). The ditches of 0.8 m deep are on the perimeter of the fields.

Figure 66 – The roads of the Rice Irrigation System (RIS)

The area of the fields is formed with the possibility of providing horizontal levelling of their surface to a level of ±50 mm, and the need for operations control of the water regime under growing rice crop.

Depending on the type of the field their areas vary from 4–6 ha to 10–20 ha. This makes it possible to efficiently use agricultural machinery to perform all operations of the rice production practices. Compact and autonomous location of RIS at a sufficient distance from the populated areas allows the aerial application for some operations, such as weed control, and in the critical years even sowing.

In Russia, in most cases, in the existing rice irrigation systems it is difficult or economically impractical to use different wide-cut machines and assemblies (above 5 m) or echelon units.

It should be emphasized that the production of rice in Russia is organized on soils declared unfit for cultivation of crops. Many RIS were built on the places of former swamps, floodplains, water logged fields. This is a significant factor to be considered when designing and chosing agronomic practices for rice growing and harvesting.

Creation and development of modern technologies has been simultaneous with the development and adoption of new rice varieties. The ARRRI has been and continues to be involved in the development of rice production practices. The scientists of the Kuban State Agrarian University also take an active part in this research.

At present, different options and technologies of rice cultivation and harvesting have been developed and used and they consider the following:

– State of RIS;

– Specific traits of the cultivated varieties;

– The soil and climatic conditions of the rice growing ares;

– The level of material and technical equipment of agricultural enterprises, especially their technical support;

– Staffing levels – the availability of qiualified specialists;

– Economic status of the rice farms.

The variants of the technologies differ in the amount the operations or saturation thereof; basic parameters – yield potential of rice, economic indicators, with priority given to the cost efficiency and the market competitiveness of the products.

Common to all options are the practices of soil tillage, rice nutrition, weed control, crop protection from pests and diseases, agromeliorative measures.

The tillage system includes deep main tillage 0.2 – 0.22 m performed in autumn after rice harvesting or in agromeliorative field after the restoration work (Figure 67) and secondary tillage in spring before sowing.

The main soil tillage is by moldboard, either share plough or boardless plough, the last is preferred since they distort the levelled relief of the rice field to the minimum degree. Deep plowing is not recommended, since the gleic soil horizon of the underlying layers can be put on top.

Figure 67 – The agromeliorative field

During main tillage crop residues and shredded rice straw are incorporated into the tilled soil layer as an organic fertilizer. To accelerate straw decomposition in the soil before its incorporation nitrogen fertilizers at the rate of 5 kg a.i. / ha are applied on the field surface.

The fall-plowed fields remain for 110–120 days in this state until the tillage units can get into the field.

In autumn – winter and early spring seasons frost penetration of the fall-plowed fields helps disintegrate large clumps of soil, destroys seeds and rhizomes of weeds. Soil oxidation processes complete and water-air regime is restored. However, in the low fields in case of heavy rainfall and poor collecting and discharge network water can accumulate and this leads to delay the onset of pre-sowing activities. In such cases, special land improvement activities are performed, the discharge canals should not overflow so that the water drainage from the checks is provided.

The complex of pre-sowing activities in rice fields provides for the following requirements:

– Ensuring early drying of the topsoil;

– The destruction of weeds seedlings and those already growing;

– Incorporation and uniform distribution of applied mineral fertilizers in the root zone;

– The creation of fine lumpy soil structure of 1–10 mm in a layer up to 50 mm deep;

– Restoration the levelled relief of rice fields.

When the soil reaches physical maturity in the fall-plowed fields the breaking up is performed to the depth of 0,14–0,16 m to destroy the remaining large lumps and to ensure the active aeration and drying of the tilled layer. This operation is carried out by special chisel culivators with spring struts, reinforcing the effect of soil loosening and ensuring their self-cleaning of adhering soil and crop residues. Tractors with special treads for swamps are recommended for this type of soil tillage.

After this tillage, phosphorous and potash fertilizers are applied as the main treatment, they are embedded to the depth of 0.12 m by chisel cultivators with sweeps or rotary rippers removing weeds at the same time.

To bring the topsoil to fine state and levelling the fields the surface levelling is performed with long-base levelers and smoothers.

Rice sowing is by drilling at a depth of 20 mm and after that drainage grooves are arranged with furrow plows. The same day the sown fields are flooded.

During the growing season, mineral fertilizers are applied as top dressing (on condition) and the complex herbicides are applied for weed control.

These works are carried out by the ground machines – fertilizer spreaders and sprayers mounted on the special tractors MTZ-82R to be used in the field during rice vegetative stage in the presence of a layer of water on the field or by aircraft.

Water discharge from the fields is carried out in such a way that by the time of full rice maturity the soil should be dried up so that reapers and harvesters could work in the field. It is necessary to consider several factors: the biological traits of the varieties and their reaction to the water discharge; RIS hydrologic and meliorative state, which allows to control water discharge, type of soil and weather conditions during this period. Reducing the water layer in the fields should be gradual so as not to provoke rice lodging (Figure 68).

Figure 68 – Rice Field General View before Harvest

Harvesting rice in Russia is one- or two-stage operation with special combine harvesters and reapers. With single-phase method involving direct harvesting, rice is harvested in a single pass. Grain in this case has high humidity – 20–25 % and requires a speedy drying.

When the two-phase method of the rice plants is applied, the rice plants are first cut by the reaper and put swathes and then after drying (the grain moisture content reaches 18–20 %), usually in 4–5 days, they are thrashed by combine equipped with a pick-platform (Figure 69).

The rice straw is cut and scattered over the surface of the field using the mounted shredder or collected in rolls, and compressed into bales (Figure 70).

Figure 69 – Rice mowing and thrashing

Figure 70 – Rice straw shredded, rolled and bailed

The shreddded straw is embedded in the soil as an organic fertilizer, the straw rolled up into rolls and pressed into bales is removed from the field as feedstuffs.

4.3 Challenges in Rice Growing and the Ways to Resolve them

Rice growing in the Kuban Region has been effectively developing in the last 5–7 years. In 2012, the rice sown area was 133,000 ha and the yield of paddy rice was 7.11 t/ha, in 2014 the yield reached 7.13 t/ha, and in 2015 is was 7.04 t/ha with the sown area of 134,000 ha. These high yields were due to several factors.

The first is the variety: the contribution of the variety to the harvest is no less than 50 %. In second place is the agronomic practices with the contribution of 30 %. Remaining 20 % (and sometimes more) belongs to rice harvesting equipment (harvesters). The discussions between engineers and rice growers are still ongoing as to the type of rice harvesters – with wheel or tracks [56].

Currently there are enough good varieties of rice in the Kuban Region. The breeders of the ARRRI have created a range of different types of high-yielding varieties. The State Register of Selection Achievements admitted for use in our area includes more than 20 varieties of rice. The varieties Rapan, Khazar, Leader, Kumir, Yuzhny, Victoria, Gamma, Olymp and others under optimal conditions can produce up to 10 t/ha. This is confirmed by the rice yield received in 2012 by the rice growers of the farm "Kubris" in Krasnoarmeyskiy District: the 1-st place in the region was awarded to D. V. Rybakov who received rice yield 11.74 t/ha, the 2-nd place was won by S. R. Basiev with 11,27 t/ha, and A.A. Predatko took the 3-rd place with 11,05 t/ha. Each of them was assigned more than 100 hectares of rice fields. The results received by these rice growers show that far from all potential soil and climatic conditions in the Kuban Region have been used up to date.

The following conditions are required for the full realization of the potential of the rice varieties. First, it is necessary to ensure that each farm has the the optimal set of varieties: 4–5 main varieties, of different genotypes and 3–4 new varieties. This selection should be regularly carried out based on the results of special tests for environmental trials in the "Agronomist's field." This painstaking research shall be conducted jointly by scientists and agronomists of the farms.

Thus, the work of the scientists of Krasnodar Research Institute of Agriculture named after P.P. Lukyanenko (KNIISH) aimed at breeding winter wheat varieties mosaic (when each variety occupies at a farm not more than 15 %), solved the problem of brown rust epiphytoties. [13] This is a vivid example for rice farmers, because the blast disease is significant factor reducing the yiels of many rice varieties.

Regarding rice agronomic practices aimed at achieving the planned increase of the yield, it is necessary solve several problems at once. First, the mineral nutrition should be optimized and balanced, considering the rice varieties, the predecessor and soil fertility.

Optimal nutrition of rice is the basis of high yield. Back in 2010 at the regional meeting of the rice growers of the Kuban Region it was noted that since 2004 the application of mineral fertilizers for rice was constantly increasing, but this increase is mainly due to nitrogen. So, in 2009 there were applied mineral fertilizers in the amount of 178 kg/ha a.i. Over the past 16 years, it was the highest rate, but it was the worst as to ration of the main. In 2011, this negative trend was repeated. The amount of applied fertilizers increased, but again due to nitrogen. This led to excessive growth of the rice plants and the appearance of blast, its mass development was facilitated also by the weather conditions. Warm, wet weather in June – July caused epiphytotic spreading of blast. The first signs of the disease were manifested as never too early – in late June. The first to suffer were dense rice plant stands overfed with nitrogen. And to safe the future yield some farms had to apply fungicides two, and even three times. The cost of each treatment was 1300–1500 Rubles/ha. The measures taken by the farmers and dry weather stopped progression of the disease. However, the negative impact of blast led to a considerable reduction of the the rice yield in the affected areas, and a sharp deterioration of the grain quality. After epiphytoty the crops overfed with nitrogen went down and it resulted in additional expenses during harvest.

Obviously, the agronomists of the farms should have adjusted the mineral nutrition of rice and balance NPK, apply not only nitrogen but also phosphorus and potassium. However, it was not so.

In 2011 and in 2012 only nitrogen was applied, so blast epiphytoty continued to “burn” the rice fields, regardless of fungicide treatment. And in 2013, it "took" in Krasnodar Territory more than 20 % of the rice yield [3].

Next equally important task is to improve the state of the RIS. It is necessary to perform a huge amount of excavation and cleaning of irrigation and discharge canals and the drainage networks inside rice fields, restore systematic capi-tal levelling of the fields’ surfaces. To do this, modern laser type levelling units MARA are used. The farm "KubanAgroPriazovye" of Kalinisky district can serve as an example. There are 8 such levelling units at the farm. In the old rice systems where no capital levelling activities were performed in 43 years, the maximum rice yield reached 5.6 t/ha. After the complex reclamation works (cleaning canals, rehabilitation of drainage and levelling the fields with new MARA to the level of ± 2 cm the yield obtained at the same field in 2011 was 8.6 t/ha. The increase of grain yield was 3 tons with the same variety, the same forecrop and fertilizer rates. The additional yield obtained per 1 ha gave 30 000 Rubles gain while the costs of levelling was 6000–8000 rubles/ha.

The final stage of any agronomic practice is harvesting. The result of the rice farmers’ work depends on the quality of its implementation. In recent years, the rice fields are harvested by a new generation of equipment – rotary combine harvesters produced both in Russia and abroad. Among them stands out the rice combine harvester TORUM 740 produced in Russia (Rostselmash). This powerful machine has an output of 15 kg/s, whereas previous generations of harvesters like CKR-7 "Kuban" – only 10.7 kg/s, and "Yenissei 1200 RM" – only 3 kg/s.

Compared with all previous harvesting machines TORUM 740 has a cabin with climate control. The combine harvester TORUM 740 is available in two versions: the one with wheels and the other with half-tracks (Figure 71). Its performance is significantly higher compared to harvesters of other modifications, the grain losses are less.

Figure 71 –Combine Harvester TORUM 740

So, when threshing rice in 2010 in the experimental field of the ARRRI with estimated yield of 8.0 t/ha, the combine harvester TORUM 740 collected 8.0 – 8.2 t/ha, and the harvester SKR-7 "Kuban" only 6,4–6 6 t/ha. At the same time speed of TORUM

740 was nearly 2 times higher than that of CKR-7 "Kuban". But it is so only when the rice is harvested in dry fields, but if the soil is wet (low-lands and after rains) it is a big problem for semi-tracked harvester, and crop losses increase drastically (wheel harvesters can not get into such fields at all). The machines sink in moist soil and deep tracks with a highly-compacted bottom remain after their passage (Figure 72).

Figure 72 – The rice field harvested after rain by the harvester with semi-tracks

The accumulated water remains in tracks till spring. In these fields, it is impossible to till the soil in autumn or early spring: their surface gets so much deformed, that major levelling is required again. It is known that the strong deformation of the rice field surface leads to significant reduction of rice yield [56].

Given that rice harvesting often takes place in the "moist" conditions, in the late 1970-ies Russia started producing crawler combine harvesters: SKD-3, then ACS-5p, "Yenisei-1200 RM" (in Krasnoyarsk) and SCR-7 "Kuban" (in Krasnodar). In the 1990-ies the production of "Kuban" combines was stopped. Some farms still have some of them for rice harvesting in low, poorly drained fields (Figure 73).

Figure 73 – The Combine Harvester SCR-7 "Kuban"

Unfortunately, TORUM 740 is not supplied with crawler tracks. This limits its capabilities of harvesting rice.

It is known that heavy rainfalls in September and October are registered in the Kuban region with periodicity of 4–5 years. In such conditions without crawler combine harvesters the losses during rice harvesting will be very high. Even in normal years the rice harvest starts when the soils are still moist, so the rice reapers working in difficult conditions (moist soil) should have good cross-country ability (i.e. supplied with crawler tracks, Figure 74).

By the way, in the advanced rice-producing countries (Japan, Korea) harvesters are produced only with crawler tracks (Figure 75). Experts and leaders of many rice farms believe that rice farmers of the Krasnodar Territory should have 20–25 % of crawler harvesters. Professor Mikhail Chebotarev, one of designers of the combine harvester SKR-7 "Kuban", states that the effectiveness of the annual rice harvest can be provided by the fleet of the combine harvesters at least 60 % of which shall be tracked [56].

Figure 74 – The Crawler Harvester ZhRK-5

Figure 75 – Korean Rice Harvester

Optimally, these can be TORUM 740 harvesters. When this harvester or its equivalent are the main harvesting machines in the rice fields of the Kuban Region, the stable annual average rice yield of 7.0 t/ha will be a reality.

CONCLUSION

Rice breeding is a specific branch of Agriculture. The morphological characteristics and biological traits of the rice plants make them different from other cereal crops in their ability to grow in water, moist soil and on dry land. The presence of the special tissue – aerenchyma – provides the rice root system with oxygen and allows its growth and development in the water layer. Having orginated from the tropical climate of India with abundant rainfall, the rice plants spread far beyond their historical homeland due to their high adaptability. Dozens of thousands of varieties of rice are cultivated in 114 countries on more than 155 million hectares.

For the population of Asia, rice is the staple food, and for the people of many other countries it is a valuable dietary and medicinal product. In the Russian Federation, the share of rice is 40 % of the total consumed cereals. The main area of rice growing is Russia is the Krasnodar Territory where over 80 % of rice produced in Russia is concentrated. Therefore, the success of the rice farmers of the Kuban Region largely ensures the supply of population of Russia with rice. In recent years, rice growing in the Kuban Region is successfully developing. Crop yields exceeded 7.0 t/ha, and the gross paddy yield is approaching 1 million tonnes.

In most rice growing countries of the world rice breeding and seed production is carried out to create, reproduce and select the varieties most adapted to local conditions. Knowledge of the rice plant biology, its ability to adapt to growing conditions form the foundation of the success of the breeding process and development of the farming practices.

The main research center for this crop is the All-Russian Rice Research Institute (the ARRRI) of the Kuban region. Here new rice varieties are bred and their agronomic practices are developed. Over 85 years of the research carried out by the ARRRI there have been more than 80 varieties of rice released and accepted into the State Register of Breeding Achievements approved for use in different rice growing regions of Russia. The Russian-bred rice varieties are cultivated in Ukraine and Kazakhstan, where they occupy more than 60 % of rice growing areas.

Over 30 years the scientists of the ARRI have been conducting the research in the sphere of rice breeding for resistance to diseases and other biotic stresses. Based on the study of biological traits of rice and genetic reserves of the crop over 20 resistant varieties have been created during these years.

This book is an attempt to summarize information on the biological traits of rice, the experience of its use in breeding of new rice varieties and development of some elements of agronomic practices. The description of the varieties created earlier and the ones used in production now is provided and the author's point on the prospects for further breeding research is given.

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– 85th anniversary of the All Russian Rice Research Institute;
– 90th anniversary of the Department of Genetics, Plant Breeding and Seed Production of the Kuban State Agrarian University

Grigory L. Zelensky, Dr. Sci. (Agric.), Professor, Honored Science Worker of the Kuban Region

The year of 2016 is also a landmark or the author of this monograph who successfully combines educational work at the Kuban State Agrarian University and rice breeding research at All Russian Rice Research Institute. G.L. Zelensky graduated from the Faculty of Agronomy of the Kuban Agricultural Institute 40 years ago. He has been Head of the Department of Genetics, Plant Breeding and Seed Production of the Kuban State Agrarian University for 20 years (the first Head of this Department was V.S. Pustovoit).