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Rice quality breeding efforts in the US

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Abstract

The US rice industry is known for production of high quality rice, both for domestic and international markets. Long, medium, and short grain classes of rice are produced. Long grains are grown mainly in the southern US, and the largest concentration of medium and short grains is in California. Long grains are tropical japonicas, and the medium and short grains are temperate japonicas. Breeding for superior grain quality and high yield are among the highest priority objectives of US programs.

For rice breeders, assessment of grain quality begins with physical characters such as kernel shape and translucency, proceeds to chemical composition, especially amylose content and gelatinization temperature, then milling yields, and finally taste testing of cooked rice.

Breeding strategies generally involve pedigree breeding and backcrossing, with a few cases of mutation breeding where it is possible to change characters such as height, maturity, or endosperm type in otherwise desirable varieties. Because of the complex balance of characters constituting superior grain quality, most programs utilize somewhat narrow germplasm pools. Emerging molecular techniques are expected to permit access to broader germplasm sources.

Several aromatic varieties have been developed in the US, but it has been difficult to match the quality attributes of imported jasmine and basmati rices. Hence US breeding programs now include components for development of speciality varieties such as aromatics, mochis, premium quality medium and short grains, and large-seeded Mediterranean types.

Keywords

- Grain shape, composition, milling yield
- USA

Introduction

The US has long enjoyed a reputation for production of high quality rice, which helps keep its industry competitive in the global economy. There are two main production areas, Arkansas, Louisiana, Mississippi, Missouri and Texas in the southern US and California in the western US. Superior grain quality and high yield are the highest priority objectives of US rice breeding programs, although disease resistance often is a major goal as well. Rice is classified into three grain types, long, medium, and short (Table 1). Standard long grain varieties have intermediate amylose content of 21-24%, cook dry and flaky, and are grown principally in the southern states. Standard medium and short grains have low amylose contents of 14-19%, and cook moist and sticky. Currently there is very little short grain production in the US; medium grain production is concentrated in California (96% of the state production), Arkansas (17% of state production), and Louisiana (24% of state production). Current area, yield and distribution of grain types by states are shown in Table 2. The high yields of the US are typical of high-latitude rice areas of the world, and result from a combination of improved varieties, intensive cultural practices including permanent flooding, high fertility, and good weed control, as well as much less pest pressure than in the tropics. Production is totally mechanized, with all of the crop being direct seeded, either sown into water as in California and parts of the southern US, or drilled into soil as in most southern states. About half of the US crop is exported, with long grains going to Central America, Europe, Middle East and Africa, and the medium and short grains going to Turkey, Puerto Rico, Pacific island markets, and various Asian countries in times of rice shortages. Per capita consumption of rice in the US has nearly doubled in the last decade, and now is about 10 kg. Part of the increase is due to growth in ethnic groups preferring rice, but most of the increase probably is due to the recognition by a generally diet-conscious society that rice is a healthful food.

Somewhat separate germplasm pools have been in use within the two main regions, as California varieties are susceptible to blast disease when grown in the southern US (blast was unknown in California until 1996), and southern varieties are susceptible to cool temperatures when grown in California. However, both pools are japonica types. Mackill (1995), using RAPD analysis, showed that most medium and short grain varieties are temperate japonicas while most long grain varieties are tropical japonicas. To date, the main indica rice grown in the US is a small area of Jasmine 85, which is an aromatic rice introduced from IRRI where it is known as IR 841 (Bollich, 1989).

Germplasm sources of US grain quality

The germplasm source for superior long-grain cooking quality was Carolina Gold which may have come in as a mixture in Carolina White, a line introduced in 1694, probably from Madagascar (Jones, 1937). Although grain shape of Carolina Gold is too broad to be acceptable for present markets, it has the cooking quality of current US long grain varieties (Rutger & Bollich, 1991). Carolina Gold has gold hull color, as the name implies. Since gold hull color is a recurring mutant in induced mutation studies (Rutger, 1992), it is tempting to speculate that Carolina Gold may have arisen as a spontaneous mutation in Carolina White.

The California short-grain industry was based on two early 20th-century introductions : Early Wataribune, introduced from Japan into California in 1913, from which Caloro was selected; and Chinese which came to the US from Italy (surely it must have originally come from China!), from which Colusa was selected (Johnston, 1958). Caloro and Colusa were grown in California for fifty years, from 1920 to 1970. Medium grain rices, a US market class, subsequently were developed by hybridization of short grains and long grains. The first of the medium grain varieties was Calady, from a cross between Caloro and the long-grain variety Lady Wright (Jones, 1937). Subsequent crossing and backcrossing of Calady to Caloro led to the medium grain variety Calrose, which became a mainstay of the California rice industry for some twenty-five years after its 1948 release. Although Calrose itself is no longer grown, the "Calrose" name persists in marketing of California rice.

In recent years, several speciality type varieties have been developed to fit market niches. These include a unique quality long grain type with high amylose of 25-30%, characterized by the varieties Newrex and Rexmont (Bollich et al., 1979), and Dixiebelle (McClung, 1997), which have been developed to satisfy the US industry's need for a rice with improved canning properties (Webb et al., 1985). In California several waxy endosperm varieties have been developed for mochi rice markets. Currently the most popular variety is Calmochi-101 (Carnahan et al., 1986).

Aromatic varieties have become of increasing interest in the US in the last decade especially since 11% of the rice being eaten today in the US is imported, primarily Thai jasmine and basmati (USDA, 1994). The aromatic imports have risen from zero in 1980 to more than 400,000 metric tons of milled rice today (USDA, 1997). In the last twenty-five years, US rice breeders have developed several aromatic varieties, but these varieties apparently are not acceptable to the ethnic groups preferring aromatic rice. The first aromatic variety developed in the US was Della, developed in Louisiana (Jodon and Sonnier, 1973). Recent aromatic releases include Dellmont (Bollich et al., 1993), Dellrose (Jodari et al., 1996), and A-201 (Tseng et al., 1997b). Virtually all rice breeding programs in the US are continuing efforts to develop aromatic varieties which fully match the taste and quality of the imports.

Several premium quality medium-grain varieties, originally based on the proprietary variety Kokuhorose, of uncertain parentage, have become popular in California. "Premium quality" is a term used to identify the California medium-grain varieties like M-401 that have unique cooking characteristics preferred by Japanese and Korean customers (McKenzie, 1994). These types are similar to the high quality short-grain Japanese varieties like Koshihikari although they are generally rated at a somewhat lower quality level. Premium quality rice is very glossy after cooking, sticky with a smooth texture, and remains soft after cooling. Aroma and taste are also cited as important features. The physicochemical characteristics that produce these quality characteristics are not clearly defined or well understood (Webb et al., 1985). Studies are underway to determine analytical measurements which can be used to predict "premium quality" and can be used by breeders as a selection tool (Champagne et al., 1996). Intensive efforts are underway to develop additional premium quality rices in California (CCRRF, 1997) and Arkansas (Moldenhauer et al., 1995), using Koshihikari as a donor parent. This effort is driven in part by opportunities to increase US rice exports to Japan and Korea that materialize as a result of the General Agreement on Trades and Tariff.

Assessment of grain quality in breeding programs

Laboratory Evaluations

Assessment of grain quality in rice breeding programs begins with physical characters, proceeds into chemical attributes, then milling yields, and finally to cooked rice taste and flavor. Kernel shape and grain translucency are noted as early as the F2 generation. Chemical tests begin by the F4 or F5 generation. Near infrared reflectance is used to predict amylose and protein content and alkali spreading value is used to predict gelatinization temperature. These quality parameters, coupled with grain shape and dimension evaluations, allow the breeder to identify which selections will fit into the established market classes of long, medium, or short grains and which should be considered as speciality rices. A simple qualitative test for aroma can be performed at any generation by placing leaf tissue or brown rice in a closed container in a solution of potassium hydroxide and heating slightly. After a few minutes the aroma which is due to the presence of 2-acetyl-1-pyrroline, the main compound responsible for the aroma of scented rices (Buttery et al., 1986), becomes evident. After additional generations of selection, other quality tests may be performed including : amylographs to determine the starch pasting viscosity under varying temperatures; gas chromatography to quantify the amount of 2-acetyl-1-pyrroline; taste tests to evaluate attributes such as firmness, cohesiveness, chewiness, starchiness, and other measures (Kohlwey, 1994); texture analysis of cooked rice, cooking time, cooked kernel elongation for basmati types, and whiteness meter readings of milled rice. Microcooking tests may be conducted by the breeders in early generations and may involve thousands of lines annually. Advanced materials may be distributed to marketing organizations and experts for cooking and processing analyses. This is especially true for speciality rices such as aromatics, mochis, and premium quality medium and short grains for which chemical composition tests do not fully define the desired characteristics.

Concurrent with yield tests, milling data for head rice or whole grain percentage are obtained, as well as agronomic performance and disease resistance. As Gravois et al. (1991) have shown, it is important to study both genotype and environment effects on head rice yield. Much of the variability is due to genotype by year variation and in most cases heritability for head rice yields increases with additional years of testing.

Molecular techniques are coming into use for accelerating progress in breeding for quality, particularly when wide crosses are needed for attributes such as yield and pest resistance. RFLP markers have been found that are associated with aroma and the cooked kernel elongation trait that is typical of basmati rices (Ahn et al., 1992; 1993). Microsatellite markers have been developed which can be used to distinguish classes of amylose, a major component of rice quality, and thus can be used as a selection tool in early generations and in narrow crosses (Ayers et al., 1997).

Breeding Strategies

Introduction of diverse germplasm into crossing programs usually upsets the balance of desired quality traits. Therefore most rice breeders prefer to work within somewhat narrow germplasm pools. However, rice breeders are not alone in this practice. Rasmusson and Phillips (1997) recently noted that incremental improvements continue to be made in malting barley breeding in the US even though it appears to involve a narrow gene pool. They postulate that continued progress is possible because of de novo variation and elevated epistasis, as well as from the original diversity in the parent lines. Continued progress in the long-term selection studies for modified oil and protein in maize is another example involving a narrow germplasm pool. After more than 90 generations of selection variability is still present (Dudley and Lambert, 1992). Nevertheless US rice breeders generally are broadening the quality base in their programs, particularly in development of disease resistant or speciality and premium types.

The array of breeding methods being used in quality improvement include pedigree breeding, backcrossing, modified single seed descent, bulk breeding, and mutation breeding with pedigree breeding being the method in universal use. Almost all breeding programs utilize a winter nursery to accelerate progress. Breeders in the southern US have a winter nursery in Puerto Rico, while California breeders have a nursery in Hawaii.

In recent years a major quality attribute that has been improved through pedigree breeding in several different US programs is head rice yield. Thus improved head rice yield potential has been recovered in Cypress (Linscombe et al., 1993), Millie (Moldenhauer et al., 1991), and L-204 (Tseng et al., 1997a) in long-grain varieties. The medium grain M-103 (Johnson et al., 1990) gave significant increases in head rice over previous very early maturing California varieties. Selection for this improved milling characteristic was achieved by selection for resistance to kernel breakage and kernel shape and uniformity tied with laboratory milling tests on advancing lines. These improvements have come in conjunction with high grain yield potential which characteristically is at odds with high milling yield.

Modifications of backcross breeding are commonly used to introduce improved agronomic characters and disease resistance into otherwise high quality lines. Examples include utilization of semidwarfism from tropical germplasm to develop adapted semidwarf varieties in California, Texas, and Louisiana. Similarily, resistance to blast disease is usually introduced by modified backcrossing in order to preserve the grain quality parameters of US varieties.

Several speciality varieties have resulted from mutation breeding. These include : Calmochi 201, an induced waxy endosperm mutant from S6 (Carnahan et al., 1979); M-401, an induced semidwarf mutant from the premium quality medium grain variety Terso (Carnahan et al., 1981); and M-203, an induced mutant for early maturity from M-401 (Carnahan et al., 1989). In Arkansas a current attempt to produce semidwarf mutants in basmati varieties is underway (Rutger, unpublished), and semidwarf and early maturing mutants of Koshihikari and Arborio are also in testing in California (CCRRF, 1997).

Over 90% of the US rice hectarage is planted with publicly-developed varieties (McKenzie, 1997). These have come from experiment stations in Arkansas, California, Louisiana, Mississippi and Texas. Interest in private-sector breeding is increasing, as can be determined from the recent survey reported in the National Plant Breeding Study - I, which showed that 22 of the 42 rice breeding scientist - years in the US are employed in the private sector (Frey 1996). The private programs include development of speciality types and hybrid rice breeding. Private programs include Busch Agricultural Resources, Inc., Pleasant Grove, California and Jonesboro, Arkansas; RiceTec, Inc., Alvin, Texas; Farmers Rice Cooperative, Sacramento, California; and Rice Researchers, Inc., Glenn, California.

Table 1. Grain dimensions and amylose content of long, medium, and short grains.

Grain type & amylose content (%)	Brown rice length (mm)	Length/Width ratio		
		Rough	Brown	Milled
Long (21-24)	6.61—7.5	3.4:1 and more	3.1:1 and more	3.0:1 and more
Medium (14-19)	5.51—6.6	2.3:1—3.3:1	2.1:1—3.0:1	2.0:1—2.9:1
Short (14-19)	≤5.5	2.2:1 and less	2.0:1 and less	1.9:1 and less

Source : FGIS (1990) and Webb et al., (1985).

Table 2. Average annual rice production in the US, 1994-1996.

State	Area (ha x 1000)	Percent	Yield (kg/ha)	Percent Grain Type		
				Long	Medium	Short
Arkansas	536	43	6,459	83	17	<1
Louisiana	234	19	5,309	76	24	—
California	196	15	8,807	2	96	2
Texas	132	10	6,645	96	4	—
Mississippi	110	9	6,459	100		—
Missouri	46	4	5,992	100	<1	—
Total (Avg.)	1,254	100	6,610	72	27	1

Source : McKenzie (1997).

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