Rice: Latin America's Food Grain of Choice

The Importance of Rice

In the 20th century, rice (*Oryza sativa*) has gradually become the most important food grain in Latin America and the Caribbean, supplying consumers with more calories than staples such as wheat, maize, cassava, and potatoes. It is surpassed only by sugar as a source of energy in the diet.

Over the last 70 years, the region's per capita consumption of rice has increased threefold, rising from 10 kilograms in the 1920s to 30 kilograms in the 1990s. Rice has become particularly important in the diets of the poor, who constitute about 40 percent of Latin America's total population.

The displacement by rice of traditional staples, such as cassava and plantains, which are bulkier and more perishable, has its roots in rapid urbanization throughout the region. Because of its convenience, rice has found sizable markets in recent decades in the cities, where nearly three-quarters of all Latin Americans currently reside. Rice has many other dietary virtues as well, being rich in vitamins and minerals, low in fat and salt, and free of cholesterol.

Rice is a versatile crop, with varieties adapted to a wide range of climates, soils, and moisture conditions. In Latin America about 55 percent of the crop (3.7 million hectares) is concentrated in wetlands, and roughly two-thirds of that area is irrigated. The other 45 percent (3.0 million hectares), referred to as "upland" rice, is grown under rainfed conditions.

Most upland rice in Latin America is mechanized; about a third is cultivated manually. Upland rice has served as a pioneer crop during this century, with mechanized production spreading into Latin America's vast tropical savannas and manual cultivation penetrating the margins of its tropical forests.

Irrigation provides the best conditions for rice production, so naturally irrigated areas have registered the most gains in recent decades. Irrigated rice is grown mainly on a commercial basis in Latin America, involving almost universal adoption of modern varieties and widespread use of agrochemicals for fertilization and pest control.

Research for Development

Challenge

Given continued rapid growth of Latin America's metropolitan areas, and of its population generally, more efficient rice production is a matter of considerable urgency. Unless marked progress is achieved in the lowland and upland areas already under rice cultivation, production will undoubtedly spread further into the tropical savannas and forests, increasing the pressure on natural resources in these fragile agroecosystems.

One of the major obstacles to rice improvement in Latin America and other regions is that the crop's yield potential has reached a plateau, which conventional breeding has been unable to surpass. Other barriers to higher, more stable yields include several major diseases and pests in both lowland and upland environments and the prevalence of infertile acid soils in the latter. Disease and pest problems often prompt farmers to use excessive applications of agrochemicals, which pose a threat to human health and the environment.

To help overcome these problems, rice scientists at CIAT are engaged in a well-focused program of research that integrates advanced techniques with conventional plant breeding and related research. A central aim of this work is to broaden the genetic base of rice production, providing genes for useful traits that have not previously been available to the region's rice growers.

Though most of the gains in Latin America's rice production so far have been registered in irrigated lowlands, rice in the rainfed uplands—especially the vast savannas of Brazil, Colombia, Venezuela, and Bolivia—continues to occupy an important place in the region's agriculture. A central challenge of research for this environment is to make rice production more competitive and profitable by providing technology that increases productivity and reduces costs.

In the sections that follow, we briefly describe the main lines of rice research at the Center, with emphasis on recent outcomes.

Conventional population improvement

CIAT's current rice breeding strategy is focused on the development and improvement of populations, or gene pools, through recurrent selection. Our aim is to offer national rice programs diverse sources of potential parents for crossing, as opposed to finished lines for release as varieties. Breeding populations of both lowland and upland rice are widely distributed in Latin America for evaluation and selection.

In connection with this work, rice scientists at CIAT have identified various characteristics of the "new plant type" developed at the International Rice Research Institute (IRRI) in the Philippines that could enhance rice germplasm in Latin America. Among the desirable traits are heavier grains, a longer grain-filling period, and sturdier stems. To incorporate these traits into rice gene pools for the region, selected IRRI lines are being crossed with locally adapted genotypes.

Germplasm development for the uplands

In population improvement CIAT researchers work closely with numerous national programs and with several international centers, as described below in "Partnerships." Under an agreement with France's Center for International Cooperation in Agricultural Research for Development (CIRAD), two CIRAD rice breeders are based at CIAT headquarters, where they are engaged in improvement of upland rice populations through recurrent selection.

These researchers are placing particular emphasis on tolerance to soil acidity, resistance to pests and diseases, good grain quality, and early maturity. A large number of lines have been selected for recombination and multilocation evaluation in several countries, and new populations are being developed. Lines developed jointly by CIRAD and CIAT are in high demand among national programs in Latin America and Asia.

During recent years CIRAD scientists have expanded their work for the uplands to include germplasm development for the midaltitude hillsides of the Andean zone. This is in response to the demand for new alternatives from coffee growers and other farmers who want to diversify their agricultural production and create new sources of income. Lines derived from recurrent selection at CIAT and introduced from Madagascar are currently being evaluated in Colombian farmers' fields.

Exotic genes for rice improvement

One of the brightest hopes for breaking the yield barrier in rice lies with some 20 wild *Oryza* species. Using techniques developed by colleagues at Cornell University in the USA, CIAT researchers are exploring the potential of these species for improving rice yield and other traits, with the aid of molecular markers.

While showing some undesirable characteristics, the wild species have much potential as sources of genes for improved yield as well as better grain quality and stress resistance in the cultivated crop. To introduce such genes into improved cultivars, Center scientists have made crosses between wild species and improved varieties. In the resulting populations, they have applied an advanced backcross QTL (quantitative trait loci) method, featuring molecular marker-assisted selection. Families resulting from a cross between the variety Bg 90-2 and *O. rufipogon* yield 5 to 25 percent more than the variety. Families from a cross between the variety Lemont and *O. barthii* yield up to 30 percent more than Lemont. Several new interspecific populations are being developed and evaluated, using *O. glaberrima*.

There is thus clear evidence that crossing improved cultivars with wild species can produce offspring whose yields are superior to those of the cultivated parent. Moreover, molecular markers can be used to locate the genes responsible for higher yield, with a view to speeding germplasm improvement. Rice lines derived from interspecific crosses are also being evaluated for traits other than yield, such as plant architecture, grain type, and disease resistance.

Anther culture to speed the breeding

Another technique that CIAT is applying and improving to quicken the pace and lower the cost of rice improvement is anther culture. With this method homozygous, or true-breeding, lines are developed from segregating populations by doubling the chromosomes of the haploid pollen and regenerating double haploid plants, all in a single cycle of tissue culture. In contrast, with the standard pedigree method, it normally takes six generations of selfing to produce completely homozygous rice lines. By thus accelerating the development of breeding populations, anther culture can cut several years off the approximately 15-year process of developing and releasing a new commercial rice variety.

CIAT scientists are currently employing this technique in gene pool improvement, with particular emphasis on identifying genes for cold tolerance and disease resistance. The technique is also being used to fix enhanced traits in the backcrossed populations resulting from crosses between cultivated rice and wild species. Anther culture should prove useful as well for accelerating the introgression of QTLs for higher yield from wild species into cultivated rice varieties.

In addition to using anther culture in its own rice improvement research, the Center has transferred this technology to national programs throughout Latin America by means of workshops, training, and instructional materials.

Durable resistance to rice blast

In a further effort to make rice improvement more efficient, CIAT scientists have integrated molecular marker techniques into pathology research and breeding aimed at developing durable resistance to rice blast.

Blast is the most widespread and damaging disease of the crop worldwide. In Latin America alone, it causes losses estimated at US$200 million annually. The disease attacks the crop at all stages of development, prompting frequent fungicide applications, which are expensive and pose an environmental hazard.

Developing durable blast resistance is complicated by extreme diversity among the large number of races, or pathotypes, produced by the disease's fungal pathogen (*Pyricularia grisea*). Most resistant varieties released so far have contained single resistance genes, which are effective only against certain pathotypes. After 2 or 3 years, this resistance breaks down as a result of shifts in the frequency of pathotypes or the emergence of new ones through mutation or other mechanisms.

Thus, a key requirement for finding sources of durable resistance is to gain a better understanding of the genetic structure and population dynamics of the blast pathogen. Toward this end an interdisciplinary team of CIAT researchers has carried out virulence diversity studies and characterized the genetic structure of the pathogen, with the aid of DNA "fingerprinting." These studies have shown that a large and diverse population of pathotypes can be grouped into a relatively small number of families, or lineages.

This knowledge has better enabled scientists to identify combinations of genes with resistance to various lineages. Under screen house and field evaluation, 15 rice lines containing two resistance genes have held up against all the lineages that encompass the highly diverse blast pathogen population in Colombia. These genes are now being incorporated into commercially available cultivars in Latin America and the Caribbean.

In search of further resistance sources, CIAT scientists are using molecular markers to identify genes in the cultivar Oryzica Llanos 5, which has shown stable blast resistance since its release in Colombia during 1989. They are also starting to identify resistance genes in the wild species *O. rufipogum* and *O. glaberrima*.

Novel resistance to rice "hoja blanca" virus

Another major disease of rice, one that attacks the crop only in tropical America, is caused by the rice *hoja blanca* virus (RHBV). Recurring epidemics of the disease have taken place in the Andean zone, Central America, and Caribbean over the last 30 years, often causing severe damage. The virus is transmitted by a planthopper insect (*Tagosodes oryzicolus*), referred to in Latin America as *sogata*, which can also cause serious damage by feeding on rice. Control of the planthopper with pesticides is generally self-defeating, because it eliminates the predators that help keep the pest in check.

Efforts to break the cycle of recurring epidemics date back to the 1950s, when the Rockefeller Foundation created a rice improvement project in the Colombian Institute of Agriculture (ICA), which was the predecessor of CIAT's rice program begun in 1967. Since then a series of disease-resistant varieties has been developed, but these depend on a single source of resistance, which offers protection only to plants that are more than 25 days old and also tends to break down over time. CIAT scientists and their national partners continue the search for lines resistant both to the disease and insect. In Colombia current control strategies depend heavily on new varieties that are resistant to the insect and show an intermediate reaction to the virus.

To further reduce the risk of disease epidemics, CIAT scientists have created an entirely novel resistance source through genetic transformation of rice. This has involved incorporating the nuclear protein gene of RHBV into CICA-8, a disease-susceptible rice variety that is widely grown in Latin America. The nuclear protein protects the rice crop by impeding replication of the virus in the plants. The results of crossing transgenic plants with highly resistant, intermediate resistant, and susceptible rice lines suggest that the transgene can be used effectively to complement natural disease resistance.

Partnerships

Partnerships between national and international as well as public and private organizations are absolutely critical for the successful development and delivery of new rice technology.

International centers

Within the Consultative Group on International Agricultural Research (CGIAR), CIAT has a regional responsibility for rice research in Latin America and the Caribbean. In fulfilling this role, the Center works closely with IRRI in the Philippines, which has a global mandate for the crop within the CG. The CG's West Africa Rice Development Association (WARDA) in Cote d'Ivoire is also a valued collaborator in rice research, serving as a source of germplasm and of feedback on materials received from tropical America.

Over the years a key vehicle for cooperation in rice improvement has been the International Network for Genetic Evaluation of Rice (INGER), which is operated by IRRI and circulates new germplasm and evaluation results among national programs worldwide. For Latin America and the Caribbean, the network is coordinated by the

Fund for Latin American Irrigated Rice (FLAR), of which both CIAT and IRRI are members (see discussion below).

CIRAD, another international center with a major commitment to rice research, has become an especially close partner in recent years. As mentioned previously, CIRAD scientists have focused mainly on the development and improvement of rice populations and on promoting this breeding approach in Latin America and other regions through workshops, training, and information exchange.

Industrialized country universities

To further the integration of new techniques into conventional breeding, CIAT has established partnerships with various advanced laboratories. For example, as mentioned earlier, our work with rice wild relatives involves close collaboration with Cornell University in the USA. In our research on the genetic structure and population dynamics of the blast pathogen, Purdue University in the USA has been a key partner.

National and regional institutions

National institutions have been central partners in rice research at CIAT from its inception. Just how much they value this collaboration has become especially evident in the last 5 years.

Starting in 1995, public and private organizations in 13 countries have joined forces with CIAT, CIRAD, and IRRI in support of an innovative model for financing and guiding rice research. This is FLAR, a regional consortium that has taken responsibility for ensuring that irrigated rice production in the region continues to benefit from new technology, despite a decline in public-sector support for international and national rice research during recent years. Each national member of the consortium contributes a yearly quota, based on the country's annual rice production. Members also define the agenda of the research they are financing.

By thus consolidating rice research for the region, FLAR reduces duplication of effort, promotes sharing of knowledge and experience, and achieves economies of scale in key areas of research, such as germplasm development and exchange and integrated crop management.

Impact

One of CIAT's initial objectives was to develop high-yielding semidwarf rice varieties and production technologies that would largely replace Latin America's low-yielding traditional rices. In the late 1960s, the first high-yielding rice variety developed by IRRI, IR8, was introduced in Latin America. IR8 received mixed reviews, primarily because it was susceptible to local pests and diseases. Farmers needed high-yielding lines that were better adapted to conditions in the region.

In response a joint breeding project was set up in Colombia involving CIAT and ICA. The new rice varieties and production practices they developed spread quickly through the efforts of the Colombian Rice Growers Federation (FEDEARROZ). This was the beginning of Latin America's Green Revolution in rice.

In the 1970s farmers throughout Latin America rapidly adopted new rice varieties developed by CIAT, IRRI, and national programs. By 1981 annual production in the region had reached 15.7 million tons, an increase of 50 percent from 1966. According to a major study on the economic impact of rice varieties, carried out recently by CIAT and the International Food Policy Research Institute (IFPRI), the new varieties made flooded and irrigated rice systems more competitive. Higher yields resulted in lower costs to farmers and lower rice prices for consumers.

Over the last three decades, national rice research programs across the region have released, on average, a total of 10 new wetland rice varieties a year. Of the approximately 300 improved rice varieties released to the region's growers, about 90 percent have been targeted to flooded conditions. Today these varieties account for more than 70 percent of the region's total rice production.

Many of the improved rice varieties (242 released in 23 countries) were developed from germplasm provided by CIAT. The rest have come from crosses made at IRRI or have been derived from germplasm identified by national programs in Latin America, Africa, and Asia. In general, each new variety represents significant improvement for at least one key trait, on top of the gains already achieved.

The new varieties, along with new crop management techniques, increased the average rice yield in wetland areas from 3.3 tons per hectare in the mid 1960s to 4.6 tons (5 tons for irrigated rice) in 1995. As a result of these yield gains, total rice production doubled during the 30-year period to 20.6 million tons, making Latin America about 90 percent self-sufficient in rice. The area planted to rice, meanwhile, rose modestly, from 5.8 million hectares in 1966 to 6.7 million in 1995.

Currently, more than 3.2 million hectares of the region's rice land is sown to CIAT-related varieties. In many countries these account for a large percentage of the total rice area: e.g., 94 percent in Brazil, 86 percent in Ecuador, and 84 percent in Peru.

The large increase in rice output has brought down its price by about half over the last three decades. According to the above-mentioned CIAT/IFPRI study, consumers have saved US$518 million in rice purchases annually since 1966. Despite lower prices, producers in irrigated areas have also captured large benefits, amounting to $437 million per year.

More recent analysis carried out by CIAT economists estimated the cumulative value of production increases made possible by Center-related varieties since 1970 at about $5.5 billion in 1990 dollars. The internal rate of return to rice improvement at CIAT was estimated to be an impressive 57 percent.

Large gains in irrigated rice have been offset somewhat by losses in other production environments. Mechanized upland rice, for example, registered net annual losses of $70 million between 1966 and 1995. The losses in manual upland rice amounted to $5 million annually over the same period.

These were the result of falling rice prices—due to productivity gains in irrigated rice—combined with the inability of manual and mechanized upland rice growers to match the technical progress of their counterparts in irrigated environments. In other words rice production in irrigated areas simply proved more competitive than that in the uplands.

Bad news for upland rice producers meant good news for the environment. The discouraging economics of upland rice reduced growers' financial incentive to spread production further into the savannas and tropical forest margins. Irrigated rice thus acted as a kind of safety valve, removing some of the pressure on these ecologically fragile areas.

Were it not for the dramatic increase in yields of irrigated rice, Latin American farmers would have had to at least double the area planted in order for production to reach its current annual level of 20.6 million tons. Most of the area expansion would have occurred in the savannas and forest margins, at a huge cost in terms of biodiversity loss, deforestation, and contamination of water from overuse of agrochemicals.