

Rice: How the Most Genetically
Versatile Grain Conquered the World

by

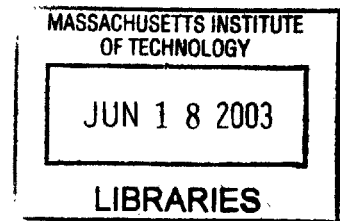
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Submitted to the Program in Writing and Humanistic Studies
On June 9, 2003 in Partial Fulfillment of the
Requirements for the Degree of Master of Science in
Science Writing

ABSTRACT

In a low-wet valley in southern China some 9,000 years ago a handful nomadic farmers saved the seeds of a wild grain they normally gathered as food. The next year they planted the seeds in the ground on purpose; from that day forth rice has been an essential part of human subsistence. In a mutually beneficially relationship with man, rice has enjoyed the genetic diversification of centuries of farmers' artificial selection while man has thrived on the nutrition packed in its starchy innards.

The ancient science of agriculture—proto genetic engineering—has given rise to over 80,000 different varieties of rice around the world, and now modern science is plumbing the depths of the rice genome for insight into the evolutionary history of the other grass species.

In between the first deliberate planting of rice and the 2002 announcement of a completed genetic sequence, rice has slowly spread across the planet, accompanying human populations wherever they settled. And while new rice varieties were constantly being bred to thrive in new environments, rice bred a new type of man—one who created elaborate political structures and social hierarchies, and as a result, was free to turn his energies from farm labor to exercises of the intellect.

For almost half of the worlds' people, rice is necessary part of life, providing most of the calories they need to survive. In much of Asia, this longtime dependence on rice has led to the deification of rice and in many instances, elaborate rituals, celebrations, and folklore involving rice. For all of humanity, however, rice is a quiet champion, the unrecognized catalyst of civilization, and now, an exciting keyhole into genetics, the organization of life at the molecular level.

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RICE

HOW THE MOST GENETICALLY VERSATILE
GRAIN CONQUERED THE WORLD

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—INTRODUCTION—

On an overcast day in late January the rice fields in Crowley, Louisiana are chocolate-brown and barren. Except for a few remnants of rice stubble and tractor trails, there is little to suggest that anything more than earthworms grow here. In a matter of weeks, however, this landscape will begin to transform. The first brilliant green leaves of rice will poke their heads through the soil, speckling the dark earth with the promise of the harvest. Throughout the early months of summer, the plants will grow taller and fuller, and will sprout multiple branch-like tillers. The tips of each of these will blossom into a head of small white flowers, giving the fields, from a distance, the look of a sugar coating. As the flowers mature, seeds will form and begin to fill with starch. The rice plants—now top-heavy with the weight of the grain—will bend forward in a graceful bow. Soon the rice grains will harden and the stalks will dry out, turning the fields a rich golden brown. Some ninety days after the first hardy spikelets emerged, the rice will be ripe and ready for harvest.

Not that the rice in these fields will ever make it to the supermarket shelves. Here at the Louisiana State University Rice Research Station just outside Crowley, the rice fields are giant petri dishes and *Oryza sativa L*—better known as rice—is the experimental organism. On small one- to two-acre plots, scientists plant seeds from a stockroom containing thousands of different rice varieties—from strains that tolerate being sprayed with herbicides to types that smell like popcorn. And the researchers probe many aspects of rice production, from fertilization, soil, and water management to breeding of new varieties and, nowadays, genetic engineering. Founded in

1909, to improve rice production through “varietal improvement and the development of agronomic practices that increase production and maintain profitability”, the LSU Rice Research Station claims the oldest, and yet still one of the most prolific rice breeding programs in the country. Over forty percent of rice acreage in all southern states, and seventy percent in Louisiana, is planted with *Cypress* a long-grain variety born and bred at the LSU Rice Station. The leading medium grain rice in the United States, a variety known as *Bengal*, also comes out of the Crowley cradle. The Rice Research Station brings together a colorful array of rice experts—from lab scientists and plant breeders to farmers and policy-makers. And each group brings to the station its own unique

brand of rice knowledge.

Plant pathologists

examine the diseases and

viruses that afflict rice,

while entomologists

tackle the pestilential

bugs. Rice breeders make

careful crosses between

different rice varieties,

while geneticists

decipher what it is at

the molecular level that

determines a “variety”



Fallow fields at the Louisiana Rice Research Station await the planting season. These experimental plots enable the scientists to field-test newly developed varieties of rice and to methodically assess the numerous variables that can affect crop growth—factors ranging from the quantity, timing, and proportion of fertilizer application to pH of the soil to graded slope of the land.

in the first place. Farmers contribute by “field-testing” experimental rice and innovative farming methods; more importantly, they contribute something less tangible—a familiarity with rice that comes from decades of working the land.

Looking much like farmers themselves, the rice researchers are no goggle-masked scientists in latex gloves and lab coats. Bluejeans and cowboy boots are standard lab attire in Crowley, along with button-down plaid shirts and kelly-green John Deere caps. And while the research conducted at the LSU station is some of the most sophisticated in agricultural science, the scientists are only secondarily concerned with publication for academia. Or as Dr. Qi Ren Chu, a plant geneticist and rice-breeder at the Research Station puts it, “here we try to reach the rice community rather go to international symposia to present fancy papers.”

Instead, the focus in Crowley is on production: from determining optimal planting time to testing methods for weed management—the goal is always how to coax more grain from the soil per unit of time, energy, and money. This, indeed, is the holy grail of any rice farmer, and it is a preoccupation whose success determines the welfare of more than half of humanity.



Rice for Breakfast?

For many Asians, rice is not only eaten everyday, it is eaten at *every meal*. Lunch and dinner generally feature rice in a familiar form—steamed— with an accompaniment of vegetables and/or meat. For breakfast, however, rice is eaten as a porridge, something like runny oatmeal. Called *juk* China, *guinataan* in the Philippines, *bubur* in India, or more generally *congee* (from the Indian word for ‘boilings’), this simple rice soup is often served unseasoned so that people may add flavorings as they wish. Thinly sliced strips of beef or chicken, chopped scallions, soy sauce, and freshly ground pepper are some of the more popular stir-ins.

The global rice harvest is by far the largest agricultural production of food in the world. In 2001 this amounted to 585 million metric tons worldwide, compared with 580 million tons for the runner-up grain, wheat. Corn actually tied with rice on the '01 production list, but about two-thirds of the corn supply—and about twenty percent of wheat—goes to feed livestock. What is reaped from the rice fields, on the other hand, goes almost entirely to feed people. Rice is the main dietary staple for some 2.7 billion Asians—roughly 60 percent of the global population. And for these people, rice is a part of almost every meal, accounting for between 50 and 80 percent of their daily caloric intake. But rice's influence goes far beyond Asia: eaten on six continents and in over 200 countries, rice is a catholic cultivar—one that has worked its way into the cultures and cuisines of people the world over.



At *Shalimar Indian Restaurant* in Cambridge, Massachusetts, the chef stirs a giant vat of basmati rice—the variety most popular in northern India. Literally, “queen of fragrance”, basmati is renowned for its nutty aroma and its needle-thin grains that grow longer, but not wider when cooked.

Today it stars in a seemingly endless variety of dishes, from Japanese sushi rolls and rice crackers to Indonesian *nasi goreng* (fried rice) and a vast assortment of Turkish rice *pulaos* (pilafs). Spanish-influenced Caribbean cuisine features *Moros y Cristianos* (literally, “Moors and Christians” or black beans and rice), and Thailand specializes in sweet sticky-rice balls. Ground

into a fine white powder, rice can be fashioned into sweet cakes, biscuits, and crackers, or as on the Indonesian Island of Bali, molded into ceremonial food art. Across Asia it is rolled into rice flakes, pressure-popped into rice puffs, and pressed into long, thin rice noodles. In Europe rice is steamed into English puddings, stirred into Italian risottos, and baked into Spanish paellas. Rice appears



300lbs of rice flour go into making this ceremonial Hindu tapestry. After being colored with natural dyes and the flour is shaped into various religious figurines before being deep fried. Once dry, the pieces are assembled on the pedestal to tell a story. This particular cake took 7 women in Bali one week to make. Photo by Robb Kendrick, Washington Post Photo Voyage. <http://wpni01.auroraquanta.com/pv/rice>

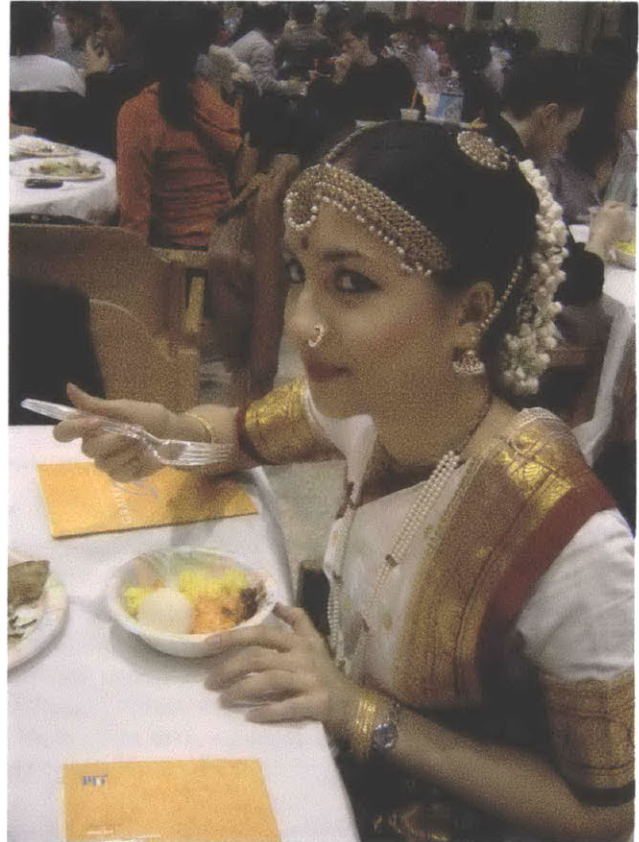
in fermented form as rice wine, rice vinegar, and the renowned Japanese *saké*. Ground up and boiled, rice gives the “refreshing taste and lighter color” to America’s Anheuser-Busch beer, as well as a texture-enhancing boost to many of our processed foods. Still, the most common rice dish is the plainest of all: a steaming bowl of white rice—no salt, no fat, no nothing. It is the quintessential rice dish, and the single dish eaten by more people in the world than any other.

As rice was finding its way into kitchens the world over, it also crept into languages, religions, and folklore—especially in Asia, where the grain was first cultivated. For many Asians, the words for “food” and for “rice” are one and the same—*shi fan* in Chinese and *kin khao* in Thai—reflecting a deep-seated appreciation of rice as *the* provider of life. In the southern parts of India, rice is called *Anna Lakshmi*—where “Anna” means food and “Lakshmi” is the Goddess of prosperity. Colloquial expressions also hint of rice’s deep influence: in Thailand, the traditional way to call a family to a meal is to say “eat rice”, and in China and Bangladesh, the polite way of

greeting a visitor translates literally as, “Have you eaten rice today?” To have a steady job in China is to “have an iron rice bowl” while to be unemployed is to “have a broken rice bowl.” Even today, when symbols of wealth and status go far beyond the size of one’s rice pantry, the grain carries connotations of success. Before entering her new home, a Hindu bride in India kicks a pile of rice across the floor. The bigger the spray of grains the better, for rice is a symbol of prosperity and good fortune.

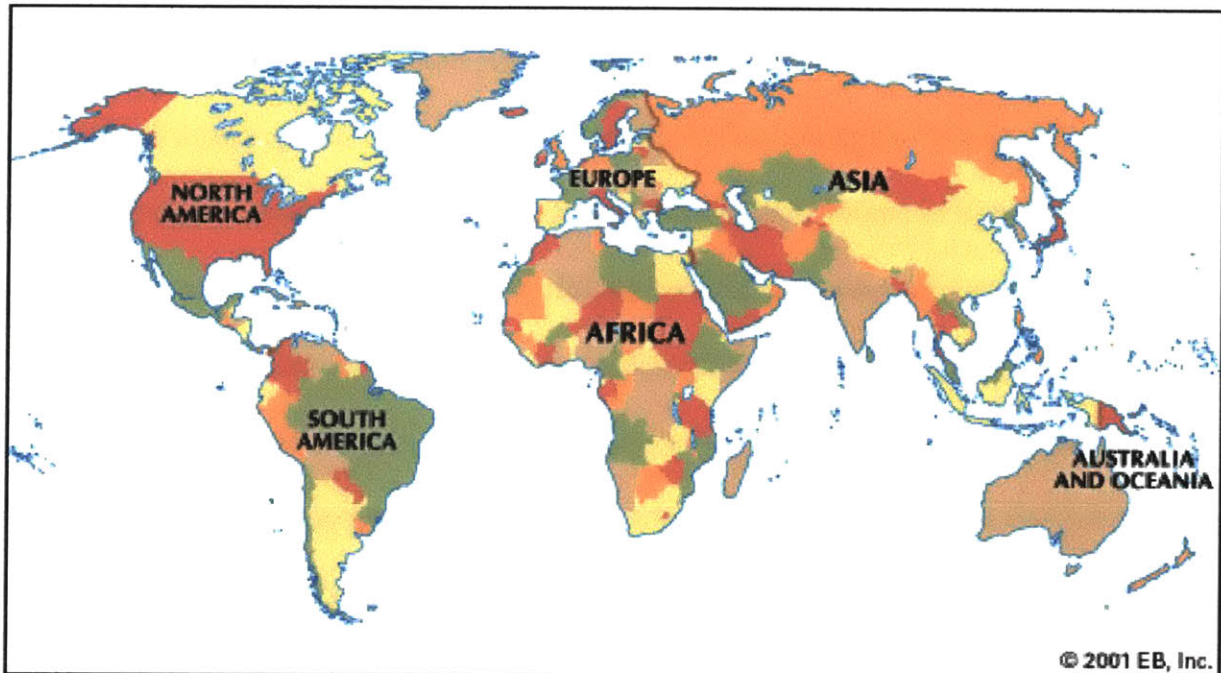
1 AROUND THE WORLD IN 3 MILLION DAYS

Rice cultivation is so ancient and its traces so perishable that no one knows for certain where it was first domesticated or who was responsible for that epochal achievement. Ancient pottery shards bear dateable rice grain imprints, for example, but it is almost impossible to tell whether these grains had been gathered wild or were planted. Most scholars seem to agree, however, that by 7,000 B.C. rice was being cultivated inside the Southeast Asian “monsoon belt”—a region that stretches from southern China across northern Vietnam, Thailand, and Burma to the province of Assam in northern India.



Dressed in traditional Indian garb, a student at the Massachusetts Institute of Technology takes part in the first annual *Grains of Rice*, a celebration of the rich diversity of Asian cultures and cuisines. Rice—the common sustenance for almost 4 billion Asians—is the unifying theme of the evening and, of course, the star of the menu.

Archaeologists have unearthed pottery fragments bearing the imprints of rice grains in China as well as in India and Thailand; the oldest among these—from Shen-hsi, China—have been dated to 6,000 B.C. The first written records of rice also come from China and date back to around 3,000 B.C. Pinpointing exactly when rice farming began has proven slippery, however, and it may be



First planted some 9,000 years ago by farmers in China and northern Thailand, rice and the knowledge of its cultivation had spread throughout most of Asia by the dawn of the Christian calendar. Arriving in the Middle East sometime in the fourth century, rice accompanied the Arab Moors as they swept through northern Africa and the Iberian Peninsula in the seventh and eighth centuries. By 1492—when both the Moors and Christopher Columbus departed from Spain, rice had been a staple in the Mediterranean diet for almost 700 years. Brought by the European Conquistadors, rice colonized much of Central and Latin America during the 17th century. And it arrived in North America in 1685 in the cargo of slave ships arriving from Western Africa, where the native people had been growing rice since ancient times.

that no such point even exists. Early humans had been hunting and gathering for several millennia, and probably would not have abandoned their collecting baskets one day and picked up hoes the next. According to David Thompson, author of Thai Food, it is likely that early rice farmers continued to gather wild rices (as well as other wild grains, nuts, and fruits) for years after they had already begun planting rice. Indeed, the full conversion from gathering to cultivation may have taken several thousand years.

Agricultural historians believe that from its origins in northern Thailand or the Yangtze

basin of China, rice made its way southward to Vietnam and the Malay Peninsula, westward to India, and eastward to Korea. Migrant peoples from the Chinese mainland carried rice and the knowledge of its propagation across the seas to the Philippines during the second millennium B.C., to Indonesia around 1500 B.C., and to the southern Japanese island of Kyushu no later than 100 B.C. Most archaeologists think it likely that the earliest rice cultivators grew both a long-grain tropical variety today called *indica*, and a shorter-grained temperate variety known as *japonica*. *Japonica* could tolerate the cooler climates and shorter days of Korea and Japan, so it became the dominant variety in these northern countries, while *indica* types flourished on the mainland. Gradually—over generations of being carefully selected by farmers—both *indica* and *japonica* split into multiple subtypes, each suited to its local environment.

By the time rice arrived in Japan in 100 B.C., it had already long established itself in western Asia. Indeed, archaeologists have found evidence that rice was an important food in the Indus valley city of *Mohenjo-Daro* as early as 2500 B.C. Via friendly bartering and not-so-friendly conquest, rice and its cultivation spread to present-day Bengal and further into Persia. Areas of present-day Iran and Azerbaijan became important rice-growing centers, a development reflected in the opulent rice dishes that emerged at the time in Persian cuisine. Traveling in the cargo of traders along what later became known as the Silk Route, rice made its way even further westward—into the fertile Tigris-Euphrates River valley and the Turkish lands of the Mediterranean. It was Alexander the Great, many believe, who introduced rice to Greece and her neighbors after his expedition to India in 344-324 B.C. The Greeks and the Romans came to value rice as a medicine instead of a food; according to Sri Owen's definitive text, *The Rice Book*, they locked the expensive import away in cupboards and even recorded it in household accounts.

Rice's next big break came in the seventh and eighth centuries, with the Moorish invasion of northern Africa and Europe. Rice cooked in clarified butter is said to have been the favorite food of the Muslim prophet Muhammad. As his followers swept through Northern Africa, Sicily, and finally, the Iberian Peninsula—which they occupied for the next eight hundred years—they brought with them both a love of rice and the knowledge of its cultivation. The Moors were eventually driven out during the *reconquista* of 1492, but rice was there to stay. Called *ar-roz* in Arabic, rice still retains this relic of its Moorish heritage in the Spanish word for rice, *arroz*.

Much of the rice growing expertise in the Mediterranean region departed along with the expelled Moors; not surprisingly, rice crop yields shrank dramatically. Even more damaging to its popularity was the sudden rise in “marsh malaria,” a condition that was believed to be spread by the bad air (“mal-air”) of swampy areas. The sixteenth and seventeenth centuries saw major drainage projects throughout the low-lying regions of Europe; wetland rice cultivation was strongly discouraged and in some cases, outlawed. For some time rumors even circulated that rice, if consumed, would poison a person's the digestive system. And yet through it all—the low yields, the fear of marsh malaria, and doubts about its physiological effects—rice in Western Europe survived.

By the end of the seventeenth century, however, rice had gone from being feared to being prized. In Elizabethan England, for example, it was common practice among the wealthy to give nursing mothers a mixture consisting of rice steeped in cow's milk, breadcrumbs, sugar, and powdered fennel seeds. In Charles I's time, rice boiled in milk with sugar and cinnamon was regarded as a potent aphrodisiac. With time, rice became less expensive and easier for the common folk to obtain; the seventeenth century gave rise to an abundance of English rice

puddings still popular today, and the traditional Christmas rice porridge of Norway. Old prejudices against the grain died slowly, however. As eighteenth century culinary historian Brillat-Savarin declared, “rice softens a man’s fibres, and even robs him of courage...[those] who live almost exclusively on rice have never resisted any attempt to subjugate them.” And it was not until the late 1800’s that rice farming was officially legalized in countries such as Spain and Italy where marsh malaria had run most rampant.

If the post-Moor years were difficult for rice on the European continent, they were adventurous times for rice abroad. Exploration and colonization ruled the day, and the Spanish, the Portuguese, the Dutch, and the English criss-crossed oceans in search of spices, gold, and land to conquer. Rice, meanwhile—stowed as food for the trip in the underbellies of these ships—resumed its quiet global conquest. Aboard Portuguese galleons, it traveled to Brazil; sailing beneath the Spanish flag, it put down roots in Central and South America.

Rice first landed in North America in 1685, when a slave-bearing ship from Madagascar—blown off course by a raging storm—hobbled into Charleston harbor. While the boat docked for repairs, its captain, John Thurber, ventured ashore to meet the locals. Upon leaving, Thurber gave his newfound friend—a Dr. Henry Woodward—a small sack of “golde rice seeds”. Curious as to how they would perform in South Carolina’s soft, sandy soils Woodward, an amateur botanist, planted the seeds. “From this he had a very good crop, but was ignorant for some Years how to clean it,” wrote A.S. Salley in an article in the *1919 Bulletin of the Historical Commission of South Carolina*, “It was soon dispersed over the Province: and by frequent Experiments and Observations they found out Ways of producing and manufacturing it to so great Perfection that it is thought it exceeds any other in value.” Indeed, rice became the favorite cultivar of the Carolina

landowning elite, and rice plantation owners grew to be some of the wealthiest men in the colonies. In 1700, some three hundred tons of “Carolina Golde Rice” were shipped to England; by 1728 that number had climbed to 4,500 tons—the colonists were churning out more rice than the ships could carry. In less than fifty years, rice had become the southern colonies’ main cash crop, and Carolina rice was widely regarded as a symbol of wealth and prosperity in the New World.

Although rice had come to North America from Madagascar, the slaves who became its chief cultivators in the America came not from that Indian Ocean island, but from West Africa, where *Oryza glaberrima* (a completely distinct species of rice from *O. sativa*) has been grown since pre-Hellenic times. Put to work on the colonial plantations of Georgia and South Carolina, as well as on the haciendas of Brazil and Argentina, African slaves were largely responsible for the success of rice in the Americas. In fact, as Judith Carney writes in Black Rice, plantation owners often bought slaves based upon their rice farming skills. Africans brought over from the rice-growing regions of the Niger River and the Gambian coast were renowned as the most brilliant rice cultivators. In the hands of these captive farmers, the name “Carolina Golde” became synonymous with high quality rice.

The Civil War and the Emancipation Proclamation brought dramatic changes to rice farming in the American south. As freed slaves abandoned the plantations, the white owners were left with plenty of seed, but neither the labor nor the know-how to grow it. Rice itself, however, did not suffer such a setback. While it lost the gifted touch of the Africans, it now gained the efficiency of mechanized farming equipment. The Machine Age of the 1800’s brought rice from the freshwater tidal swamps around South Carolina’s Cape Fear to the lowlands of Southwestern

Louisiana and Southeastern Texas, where the heavier soils could better bear the weight of the new machinery. While rice production dwindled to naught in South Carolina and Georgia, it sprang up and flourished in the Mississippi valley in the latter part of the 19th century. Meanwhile, rice became one of the biggest winners in the 1849 California Gold Rush. The Rush lured fortune seekers from all over the world, including an estimated 40,000 Chinese who, until landing in America, had scarcely gone a day without eating rice. Enterprising farmers quickly moved to fill this demand by developing rice varieties amenable to Asian tastes, but tolerant of California's heavy clay soils. Ever since, the Sacramento Valley has been a prime producer of rice in America.

2 SOWING THE SEEDS OF DIVERSITY

Today, at the outset of the twenty-first century, rice has rooted itself almost pan-globally. As it spread from Southeast Asia, to the Middle East, Africa, Europe, and finally the Americas and Australia, it adapted to an enormous range of climates, day lengths, and altitudes. Today it can be found growing as high as 2,200 meters (7,218 feet) in southwest China and practically at sea level in southern Louisiana. It thrives in the cool, dry foothills of the Nepalese Himalayas as well as in hot dry deserts of Egypt and India. Only Antarctica—frozen and off limits to all but the most rugged of species—has proved inhospitable to rice. The range of places *O. sativa* currently inhabits is one indicator of rice’s genetic versatility; another is the dazzling variety of *O. sativa* subspecies that have sprung up over the millennia. Although estimates vary, somewhere between 80,000 and 100,000 different rice varieties are thought to be living on Earth today.

Generally, scientists divide *O. sativa* into three subspecies: *indica* (usually tropical and longer grained), *japonica* (usually temperate and shorter grained), and *javanica* (tropical to subtropical and medium- to long-grain). But, as scientists at the LSU Rice Research Station note, classification beyond this level can present quite a conundrum, as it can be done in so many different ways: according to botanical variety (such as *basmati* or *arborio*), by size and shape of the grain, by degree of “stickiness”, by aroma, by extent of processing, or by any combination of the above.

Of all the ways to categorize rice, perhaps the simplest is by color. Most familiar is plain white rice, but hues range from almost pitch-black to red to yellow and everything in-between.

White is the color of “naked” rice—the creamy white endosperm left behind after the grain has been husked, milled, and polished. Husking removes the outermost sheath and the germ (the part that is the embryo of the new plant), while milling strips of the colored bran layer. The remaining starchy capsule—which would have provided food for the sprouting embryo—is what is usually recognized and consumed as “rice.” Colored rices, therefore, are simply white rices still clad in their tinted jackets of bran. This three-layer bran coating—rich in Vitamin B and oils—is generally brown, but may be red, black, or mahogany colored. If milled by hand, rice will retain bits of the bran layer, creating colorful dappled varieties such as the pinkish Bhutanese red and Italian *rosehatta*.

So Many Ways to Sort Rice

According to accepted standards, a long-grained rice is one that is at least three times as long as it is wide, a medium-grain rice is two to three times as long as it is wide, and short-grain rices are anything shorter than twice their width. Well known long-grain varieties include Indian Basmati, Thai jasmine, and American ‘Carolina’ rices (now actually grown in Texas). Most Japanese rice falls into the medium category, as do Italian *arborio* and Spanish *bomba* rices. Short-grain types include the mildly sweet Japanese sticky and Chinese sticky rices.

How sticky or “waxy” a rice is depends on its proportion of two kinds of starch—amylopectin and amylose. The less amylose a grain has, the less water it absorbs during cooking, and the stickier the product. (Sticky rices are sometimes called “glutinous”, but this is a misnomer as there is no gluten in any type of rice). Two very low-amylose varieties, for example are Japanese sushi rice and Thai sticky rice.

Rice can also be typed according to its scent and flavor. Numerous so-called “aromatic varieties” exist—the result of their having a higher proportion of 2-acetyl-1-pyrroline, a naturally occurring compound found in all rice. With its pronounced nutty smell and flavor, American-grown Della sells under names like “Louisiana Popcorn” and “Wild Pecan.” Worldwide, the most famous aromatic rices are undoubtedly Thai jasmine and Indian basmati—literally “queen of fragrance”—both of which boast a delicate floral scent.

That such a rainbow assortment of rices exists today is certainly testament to its genetic adaptability. But seeding the planet was not a feat rice could have accomplished alone. It relied on centuries of help from human beings—migrant groups, traders, conquerors, farmers, and cooks. In fact, the spread of rice over the globe can be seen as a travelogue of human journeys; whether in the bowels of ships, the seed bags of merchants, or even hitchhiking in the fur of pack animals,

rice seed traveled wherever man—and beast—could carry it.

If the history of rice is a reflection of human migration, it is equally a story of agricultural innovation. Crop-breeding, however informal, long predates the rise of research centers like the LSU Rice Research Station. It was up to the farmer—selecting the choicest plants from one year's harvest and planting their seeds the next—to “genetically engineer” the best rice. In short, travel and trade could introduce rice to new locations, but it was up to the farmer to make the grain happy in its foreign home. The earliest rice cultivation was almost certainly done “dryland”—perhaps along a damp riverbank or on a soggy valley floor, but without the aid of irrigation or flooding. Then, either by accident or by insightful experimentation, early rice

Terraces

Mention the word ‘rice field’ and the image that first springs to mind is an irrigated rice paddy—or more likely a mountainside staircase of such paddies: a rice terrace. At once water-logged farm fields and hypnotizing eye candy, rice terraces blanket the landscape in China, Bali, Vietnam, and the Philippines. Rice terraces may fascinate the spectator, but more importantly, they churn out over 9.5 million pounds of rice per year—a good 75% of the total rice harvest. As rain and river water run down the mountain, strategically placed canals channel the flow onto the rice fields. These flat paddies—actually built up onto the mountainside, not carved into it, as is usually imagined—retain the water up to about 20 centimeters. The most brilliant part about terracing, however, is that gravity does the dirty work. Using floodgates and channel controls, farmers allow water from the upper terraces to spill over onto the terraces below. Since rice needs less moisture as it matures, the scheme is perfect—the first seeds are always planted on the lowest terrace so that the oldest rice is always at the bottom!



farmers discovered that intentional flooding dramatically increased their crop's yield. Bathing the growing rice plants in deep water, they found, kept down the weeds, deterred insects, and stabilized temperatures. As rice cultivation spread alternately to upland hillsides and low-lying plains, it became intimately tied to human systems for water and land maintenance. Rain-fed rice farming gave way to the less precarious, higher-yielding method of irrigation farming. Rice, it seems, was happy to serve as food for the masses. But in return it demanded no less than an agricultural revolution.

People in the world today practice four main methods of rice cultivation: traditional “slash-and-burn” upland, rain-fed lowland, irrigated lowland, and deep-water or “floating.” Slash-and-burn cultivation—sometimes called “shifting” or “dryland”—is the oldest and the most primitive method of rice agriculture. It is still practiced by hill tribes in northern Thailand, the natives of Borneo, and small clans in South America and Africa. In shifting cultivation, the land is cleared of all vegetation, and the rice is grown with little in the way of fertilizers or irrigation.

After several back-to-back seasons of supporting a rice crop, however, the soil is nutrient-



Slash-and-burn clearing is the traditional way of preparing rice fields in Laos, but is nowadays giving way to more ecologically friendly farming practices. (Photo by Bruce Linquist, *Rice Today*)

depleted and the people are forced to move on. Although slash-and-burn is the least labor-intensive way grow rice, it is by far the lowest yielding. It also raises a number of environmental concerns, most visibly the fact that the forest rarely has time to recuperate before being cleared again. Just as damaging are the landslides and concomitant soil

erosion that occurs when barren hillsides are left in the wake of slash-and-burn planting.

“Paddy”—the Malay word for rice in the field—also refers to the most common method of rice cultivation. Paddy rice fields resemble a giant patchwork quilt, each patch a small reservoir surrounded by low earthen walls to prevent water from escaping. Before planting, farmers first till the ground—either by hand or by letting water buffalo run loose in the fields—then thoroughly wet or “puddle” it (again, this is done either by hand, or if the farmer is lucky, by rain). With broadcast sowing, the rice seeds are simply strewn on the ground to grow to maturity where they fall. This type of farming was once the norm in places like Thailand, where land was cheap and natural rainfall could be relied upon. As the population of Southeast Asia ballooned and land grew scarcer, broadcast seeding gradually gave way to transplanting. With transplanting, the rice seeds are first soaked to encourage germination, and then are planted in small “nursery beds.” After about 40 days, the seedlings are gently pulled from the soil and transplanted into the main paddies, which have meanwhile been plowed and puddled.

Nearly 2,000 years ago, Chinese farmers in the Yangtze River valley revolutionized rice farming forever when they developed the practice of irrigation. By carving canals to divert river water into the fields, they no longer had to rely on the whims of Mother Nature to water their thirsty seedlings. Sophisticated irrigation systems soon developed in Thailand, Burma, and Vietnam, and later on, in Indonesia and the Philippines. Jacqueline Piper, author of Rice in South-east Asia, describes how the ninth century Khmer kingdom in Cambodia boasted one of the more intricate of such systems. Water from the *Tonle Sap* Lake in the middle of the country was routed through a myriad of interconnected canals and pools which all converged at the great temple complex in Angkor. Within the complex, gravity pulled the water from level to level, as if the

entire temple were a multi-tiered waterfall. Finally, the water left the complex and branched out again to irrigate a vast network of low-lying rice paddies. At its height in A.D. 1100, the Khmer Kingdom was producing an estimated annual total of 126,000 tons of rice for its population of 600,000. That comes to an astonishing 420 pounds of rice per person, whereas even China—the undisputed rice champ of today—produces only 280 pounds per person.



www.cambodiaportal.com

Records from the twelfth century indicate that a Chinese diplomat named Chou-Ta-Kuan visited the Khmer capital specifically to examine its irrigation system. In his journal, Ta-Kuan wrote that up to three crops of rice were being harvested each year at Angkor, whereas in China at the time, the norm was one crop per year. He also described an unusual kind of rice he had seen—one that grew in deep river water and seemed to magically keep pace with the flood level. Ta-Kuan's eyes had not been deceiving him; this unique “floating

rice” is still grown today in deltas of large rivers such as China’s Mekong and Thailand’s Chao Phraya. Sown in the floodplain of the river, deep-water rices have been known to grow up to eight inches taller in a single day.

“Upon rice, great kingdoms were built,” writes chef and culinary historian David Thompson in Thai Food. And this statement is true at more than one level: as the “staff of life” rice nourished the early populations of Asia; on another level, it served as a powerful social organizer. In advanced rice-growing cultures, upholding the state and fostering wealth meant developing paddies and maintaining irrigation systems. Rice, according to historians, was the centerpiece around which the Chinese empire built itself. According to the culinary writer and historian Felipe Fernández-Armesto: “...rice became a symbol of abundance and a mainstay of the menu in a process important from the making of China....The rice grower’s world was the seductive frontier of the second millennium B.C., sucking settlers southward to the expanding limits of civilization, luring barbarians in, melding the natives and the newcomers into Chinese.” If rice could build empires, it could also, it seems, destroy them. Some scholars have suggested that neglected and silt-clogged irrigation canals contributed greatly to the weakening of the mighty Khmer Kingdom, making it vulnerable to conquest from Siam warlords in the mid-fifteenth century.

Irrigated rice farming—with its demands for sophisticated infrastructure and cooperative labor—catalyzed the expansion of complex, highly organized civilizations—the only ones that could manage a crop which grew this way. But even slash-and-burn cultivation, while primitive, unified people around an intrinsic understanding of the land, the crop and the weather. According

to Thompson, shifting cultivation led to “*an intricate pattern of beliefs and rituals, to explain and propitiate the caprice of the gods and nature. Society became organized around these concerns to ensure the success of the crop and the survival of the community.*”

Today rice continues to shape the political and social lives of the people who cultivate it. On the Indonesian island of Bali, for example, the irrigation systems are cared for by the local *subak*, farming cooperatives made up of all the landowners in a particular district. The *subak* maintain the multiple channels, dams, and weirs necessary to keep the irrigation network running. These duties, in turn, grant the *subak* the authority to distribute property and to allocate water rights—a task Westerners generally associate with government responsibility. The communal nature of rice production lives on in modern-day Japan as well. The renowned Japanese ethos of industriousness and endurance, many believe, is the happy result of centuries of “rice production lines”—generation after generation of farmers cultivating the same rice fields.

From early slash-and-burn practices to sophisticated irrigated cropping, rice cultivation has always been closely linked to the political and social structures of rice-growing communities. Long ago, the development of grain cultivation tied people more strictly to the land, forcing them to abandon the nomadic way of life. At the same time, anthropologists have long understood that an increasing dependence on settled farming liberated new kinds of intellectual and cultural potential. Nearly two centuries ago, the German culinary authority Baron von Rumohr noted that once people depended on grains, they were able to settle for longer periods in one place. This, in turn, gave them the opportunity to preserve the experiences of their lives in buildings, works of art and books—and also, he said, to develop abstract ideas. Echoing a similar sentiment, agricultural historian Jacqueline Piper writes in Rice in South-East Asia, “*Where yields were*

good, some people could be spared from the rice-fields for the manufacture of arts and handicrafts. As societies developed, with elite groups of royalty, administrators, and religious persons, the arts flourished and eventually attracted contact with a wider world.”

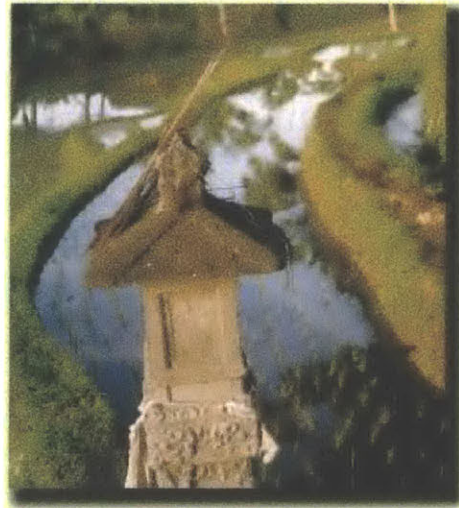
Continuously shaping, and being shaped by the societies in which it was cultivated, rice eventually opened the door for Neolithic peoples to move beyond the mode of sustenance-only to a richer world of arts, literature, philosophy, and science. Increasingly efficient methods of farming allowed more and more members of society to turn to other activities. The centuries of obsession with the success of the rice harvest had a lasting impact, however. By the time people were free to turn their attentions elsewhere, rice had long since worked itself into the collective subconscious. It had come to transcend the realm of everyday experience, finding a comfortable second home in the supernatural realm of the religion, folklore, and myth.



IRRI 2002 Rice Calendar

3 THE SPIRIT OF RICE

Perhaps only viruses and bacteria have traveled as far and wide on the human ticket as has rice. Continually evolving so as to outwit the human immune system, infectious organisms are, like rice, molded by their human hosts. But whereas people revile disease and attack infections, humanity's relationship with rice is mutually beneficial, symbiotic. People plant and nurture rice, helping it to evolve and spread over the Earth, and in return, rice nourishes people. In today's urbanized culture of grocery stores and restaurants, the link between farm and food has become almost invisible—many of us would probably recognize rice as a box of Uncle Ben's before we would recognize it as a plant with stalk and leaves. But for the millions who both grow rice and eat it, the reciprocal relationship between cultivar and consumer is intrinsically and profoundly felt. Across Asia and the Oceanic islands, it comes to life in a rich tradition of religious rites and festivals that pay homage to the grain and its harvest. The sacred nature of rice is embodied the Hindu rice goddess,



www.alamsari.com/request/html

Animal Origins

Across much of Southeast Asia and Japan, rice is ascribed religious origins, considered a gift of the gods. In China, by contrast, rice has a more earthly heritage. Chinese myth tells of time when the land was inundated by severe floods. When the land finally drained and the people came down from the hills where they had taken refuge, they found that all the plants had been destroyed and there was nothing to eat. The people scraped by for a period, hunting and gathering what they could, but continued to hover close to starvation. Then one day a dog came over the fields, carrying in his tail bunches of long yellow seeds. The people planted these seeds, the rice grew, and hunger disappeared. Ever since that time, the saying goes that "the precious things are not pearls and jade, but the five grains", of which rice is first.

Dewi Sri, who appears with different names and specific characteristics from country to country. The Angkabau of Sumatra, for instance, pay homage to *Indoea Padi*, the Rice Mother, while farmers of the Malay Peninsula and Indochina worship a rice spirit called *Mae Phosop*. Even the Sundanese of West Java, who consider themselves Muslims, believe rice is the personification of the rice goddess *Dewi Sri*, revealing her ability to traverse religious as well as national boundaries. In fact Hindus, Buddhists, Shinto, and Muslims alike honor *Dewi Sri* in one of various forms—a potent indicator that for billions of Asians, rice nourishes the spirit as well as the body.

On Bali, a small Indonesian island covered with rice paddies, an elaborate series of ceremonies accompanies the yearly planting and harvesting of rice. Journalist and traveler Peter White writes, “The making of offering in Bali never stops—at shrines in the family compound, at clan temples, *subak* temples, and hundreds of village temples, at full moon, at new moon, on auspicious days, on every 15th day when possibly harmful spirits are especially prevalent.” Placed in small mounds on banana leaves, rice is set down each day where spirits are most likely to be. As a young Balinese girl told White, “The spirits must be fed so they’ll be happy and not bother us.” It didn’t seem to matter to the girl that her dog, traipsing along behind, thankfully gobbled up the offering—the “essence” of the rice had been recognized; the gods had been appeased.

In Japan rice no longer dictates the pace of life as it does in Bali, but in spiritual significance, it ranks just as highly. Beginning around 300 B.C., during the so-called Yayoi period, a new approach to agriculture—highly organized and cooperative—sprang up in southern Japan. The new farming villages were perfectly suited to rice cultivation, and the Japanese soon raised the practice to an art. Tending the fields of rice became viewed as a religious act, a worshipful invocation to *Ta no Kami*, the god of the rice paddies. More than two thousand years later, rice

continues to be an essential spiritual staple in Japan. At the Grand Shrines of Ise, one hundred and ninety miles north of Tokyo, white-robed Shinto priests cook rice twice daily and present it to the sun goddess, *Ameratsu*, thought to be the ancestor of the imperial family. *Ameratsu*, it is said, brought the first handful of rice from the heavens so that the people could grow it and prosper. In the first ceremony performed by every new Japanese emperor, he steps behind a curtain to meet *Ameratsu* and emerges as *Ninigi no Mikoto*, the god of the ripened rice plant. And then—much as the U.S. president tosses up the first baseball of the major league season—the new emperor plants the first seeds of the year’s harvest on the imperial palace grounds. But rice worship is not confined to the realm of priests and emperors. In the ultra-modern Tokyo of today, children are often taught to scoop a small amount of white rice from the *suihanki* (electric rice cooker) to offer to the spirits of deceased ancestors in the family’s home altar.

In Thailand, the rice goddess is called *Jao Mae Phosop* (Mother Deity *Phosop*), also

The Lure of Jasmine

Just inside the entranceway of Boston’s Super 88 Asian Market, towers of 100-kilo bags of rice reach halfway to the ceiling. Here one can find varieties to suit all tastes and purposes, from the luxurious Indian *Dehra Dhun* to the no-nonsense California CalRose. In one corner sit smaller bags of purplish sticky rice and Bhutanese red rice, as well as special blends of wild, organic, and brown rices. But the majority of the burlap sacs are packed with one very unique rice: *Khaaw Dok Mali*, or Thai jasmine rice. A long-grain semi-sticky rice, the grains just barely cling together when cooked, and they are soft—almost satiny—on the palate. The signature of this rice, however, is undoubtedly its subtle, persistent aroma—like fresh jasmine flowers. True jasmine rice is grown only in Thailand, and it has become as much a symbol of Thai national identity as a fixture in their diets. It is not only the Thais, however, that prize this aromatic rice; bolstered by international commerce, jasmine has come to be loved by rice eaters all across Asia and, more recently, Europe and the U.S. Many Chinese, who consume by far the most rice in the world, actually prefer jasmine rice over their native non-aromatic varieties. Not surprisingly, immigration of Asians to the U.S. has fueled a growing market demand for the Thai import.

At the *Bangkok Express* in downtown Boston’s Quincy Market, a young Thai chef says that his restaurant uses only jasmine rice. “And when we run out,” he says grinning, “we just borrow from the Chinese place. They cook our jasmine too.”

In recent years, jasmine rice has come into a political cross-fire of sorts, as American rice growers attempt to create spin-offs from the popular Thai variety. The U.S. is Thailand’s biggest market for rice exports, so farmers are understandably concerned that U.S.-produced “jasmine-style” rices will put a deep gash in demand for their native crop.

recognized as goddess of fertility. All across the rice-blanketed countryside, wood and bamboo shrines can be seen—places where farmers leave offerings of unhusked rice, candles, flowers, incense, and cups of tea curry the favor of *Mae Phosop*. An elaborate ritual marks the beginning of the rice-growing season: rice grains saved from the last harvest ceremony are mixed in with new grains while the farmers pray for an abundant harvest. Later, when the first fruits of the plant appear, *Mae Phosop* is said to be pregnant. Accordingly, the villagers make special offerings of foods a pregnant woman would like—fruits such as bananas, tamarinds, coconut and even chewing tobacco. Sometimes a young woman from the village makes a contribution of a hair comb, fragrant oils, or a small vanity mirror to aid *Mae Phosop* in her pregnancy. The harvest time brings with it yet another ritual ceremony. En masse, all the farmers of the community head to fields to cut the grain; this is done entirely by hand, using a small sickle-shaped knife hidden in the palm so as not to offend *Mae Phosop*. Meanwhile, the old men of the village stay home to



Photo by Robb Kendrick/Aurora/Aurora & Quanta

prepare the threshing ground with buffalo dung and water (this mixture, ironically, is thought to prevent the rice from being soiled by dirt or mud). The farmers then lay out a fresh set of clothing and an offering of food—usually red and white rice dumplings, bananas, a sliced duck egg, and cooked rice—all for the health and pleasure of *Mae Phosop*.

In the past, the rural Thai who cultivated rice took these ceremonies very seriously; those who neglected their obligations could be severely punished, even expelled from the community. Today several of these practices are falling by the wayside, or at least, are considered more an act of tradition than of religion. Nonetheless, rice continues to be central to Thailand's cultural identity—and now, increasingly, to its economic well-being. *Mae Phosop* (aided no doubt, by market demand) has blessed Thailand with status as the world's number one rice exporter. In 2002, the nation shipped some 7.5 million metric tons of rice abroad—more than the next two largest exporters, India (4.5 million tons) and the United States (2.95 million tons) combined.

4 RICE TO THE RESCUE

None of today's abundance, however, was predicted back in the 1950's and 60's, when the underdeveloped world faced a dilemma of dire proportions. Thomas Malthus' predictions—that population growth would outpace food production—appeared to be materializing. As vice-president of the Ford Foundation, Forest F. Hill, said to his board of trustees in 1959, “At best, the world food outlook for the decades ahead is grave; at worst it is frightening.”

Since 1943, another large endowment—the Rockefeller Foundation—had been working on the hunger problem. In Mexico, Colombia, Chile, and India, programs that combined basic scientific research with on-site training of farmers had proven remarkably successful. The approach was problem-oriented, emphasizing basic indigenous food crops and livestock, and also promoting the involvement of promising young scientists. In less than a decade, the Rockefeller programs had transformed Mexico—a food-deficit country—into to a country with food to spare. But rice was not included in any of these early programs, and Rockefeller officers were growing increasingly aware that—as the major food crop in most of Asia—rice merited special attention. Deputy-director of the Rockefeller Foundation, J. George Harrar, envisioned a kind of international research center dedicated wholly to rice. On its own, however, the foundation lacked the financial means to attempt such an ambitious project.

For its part, the Ford Foundation had until the 1950's been largely been dedicated to

programs in education, economic planning, public administration, population control, and rural development. Its rural development work, initiated in India in 1951, had both humanitarian and geopolitical motivations—humanitarian because it focused on alleviation of poverty and hunger and geopolitical because it spoke to a growing fear in the west that widespread famine in South and Southeast Asia would cause those areas to fall under Communist control. Visiting India in the mid-50's, Hill saw that the agricultural extension programs were floundering, and he concluded that with regards to these programs, the Ford Foundation had, in his words, “got the cart before the horse.” What was needed before a self-help community development initiative could possibly work was an improvement in agricultural technology. Basic research and intensive training in the techniques of crop production were the essential building blocks they had overlooked.

Then in August of 1958, the two pieces to the International Rice Research Institute puzzle—the research-experienced Rockefellers and the wealthier, public-service Fords—found one another. As Robert F. Chandler Jr. —the soon-to-be first director of IRRI— recalls: “Harrar and I were invited to join a group of Ford Foundation officers for lunch to discuss the possibility of a joint venture to strengthen the Lyallpur agricultural college in Pakistan.” Towards the close of the meeting, Forest F. Hill, Ford vice-president of overseas development, turned to Harrar and said, “You know, George, someone should undertake to work with rice the way you Rockefeller Foundation people have with corn and wheat.” Harrar replied that he had already been toying with the idea, and was keenly interested in rice. “We have some money,” Hill responded, “You have experience in conducting agricultural research in the developing countries. We both are interested in doing what we can to help solve the world's food problem. Why don't we get together and see what we can do?”

Thus was born the partnership that would in 1959 establish the International Rice Research Institute (IRRI) just outside the Philippine capital of Manila. Composed of rice breeders, geneticists, plant pathologists, agronomists, social scientists, and engineers from around the world, IRRI would bring science to bear on rice—to combat the imminent threat of widespread famine. The task at hand was not a simple one, however. Raising grain yields would demand a complete transformation of rice—taking a crop shaped by thousands of years of farmers’ choices in the field, and re-engineering it in the laboratory to meet the world’s escalating food demands.

The First Green Revolution: “Miracle” and Hybrid Rice

Under the direction of Dr. Gurdev S. Khush, the Indian scientist widely recognized as the world’s foremost rice breeder, IRRI workers in the early 1970’s created the first generation of so-called “miracle rices.” These had shorter stems than ordinary rice and had a significantly shorter growing season. Petite stalks—three feet tall instead of five—ensured that when more fertilizers

bolstered the quantity of grain, the stalks would not bend and break under the added weight. And a growing season cut from 160 to 110 days opened up time for an additional crop each year. These sturdy little plants also boasted resistance to a number of rice pests—such as stem borers

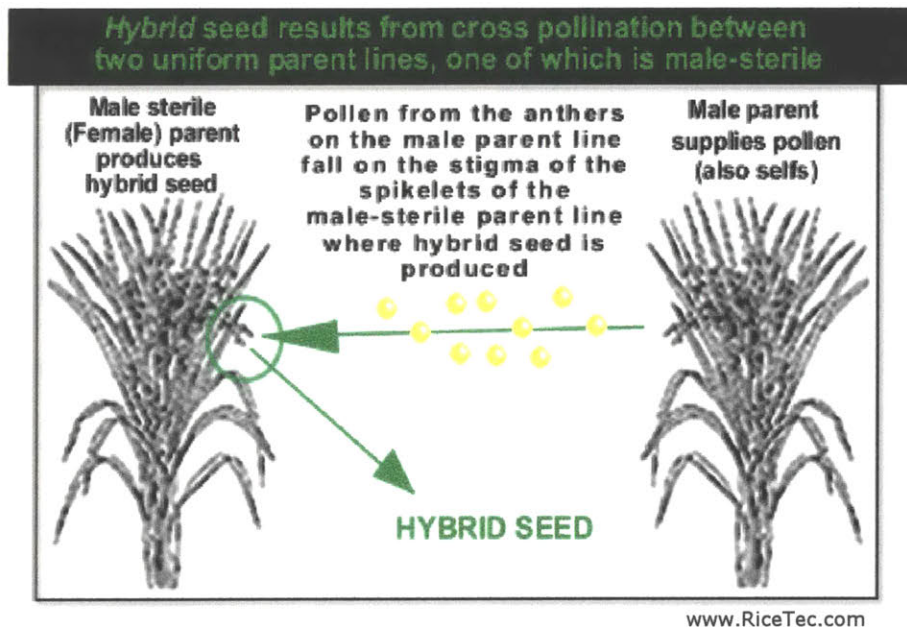
What was that Miracle Rice anyway?

In 2002—more than forty years after miracle rice was released—scientists announced new insight into the grain behind the green revolution. Researchers at Nagoya University in Japan reported in April 18 issue of *Nature*, that miracle rice’s ‘semi-dwarf’ stature is due to a mutation in the *sd1* gene. *Sd1* encodes an oxidase enzyme involved in the synthesis of the gibberellin plant growth hormone. Gibberellin is one of the main determinants of plant height, so a glitch in the biochemical pathway that produces it results in shorter, stockier plants. Surprisingly, although gibberellin also influences flower formation and fertilization, miracle rice shows no defects in either of these critical functions.

and plant hoppers—and to diseases, such as rice blast and bacterial blight. Packed with an arsenal of carefully selected genetic features, the new plants were designed to churn out grain as never before.

The miracle rice experiment was a stunning success. In the thirty-two years from 1967 to 1999, global rice production more than doubled, from 277 million tons to 609 million tons per year. The green revolution grain raised the theoretical maximum amount of rice harvestable per acre of land—the yield ceiling—by one hundred to two hundred percent.

Meanwhile, across the South China Sea from IRRI headquarters, the Chinese were developing a “miracle rice” of their own. Under the direction of head plant breeder, Dr. Yuan Long Ping, scientists at the China National Rice Research Institute crafted the world’s first hybrid rice. Hybrid rice, according to plant geneticist Dr. Qi Ren Chu, is just what the name suggests: the offspring of a cross between two genetically dissimilar parent varieties. “No one really knows why,” says Chu, “but the hybrid ‘baby’ turns out to be stronger, more productive, and in many cases, more resistant to pests, than either parent plant.” One theory, at least, is that this “hybrid vigor” comes about because the new plant displays only the dominant—and none of the recessive—characteristics of the parents. While the physiological mechanisms underlying hybrid vigor remain unclear, the phenomenon itself is nothing new. Hybrid vigor is what a farmer who breeds mules counts on when mates a mare with a male donkey. A cross between two different “varieties” of equine mammal, the baby mule—though sterile—inherits the most desirable traits of both. For a beast of burden, this means the strength of a horse and stamina of a donkey. For the purposes of rice cultivation, hybrid vigor generally refers to disease and pest resistance, and even more importantly, grain yield. The average yield for a good hybrid rice is 1.5-2.0 tons more grain



per acre than the parental varieties. The trick to making hybrid rice is the extra step of producing hybrid seeds. And creating a batch of these seeds requires the scientist—or farmer—to outwit rice’s normal reproductive mechanisms.

In its natural state, rice is a self-pollinating organism with both male and female plant parts. “Rice sex” occurs when the male pollen— produced at the top of the plant in structures called anthers—falls on the sticky tip of the female stigma below. The pollen, which contains one half of the full complement of chromosomes, then burrows its way to egg cell, which contains the other half, at the base of the stigma. The fertilized egg, now with a full complement of chromosomes, then begins to mature into an embryo, or “germ” cell. Every mature rice seed is composed of this gnat-sized germ cell and the giant endosperm to which it is attached. Packed with starches for the growing plant, the endosperm is what we normally recognize as “rice,” and it

is what is left behind after the germ is removed during the milling process. (The small divot at the tip of a polished rice grain reveals where the germ used to be). If not milled, the seed can be planted the following year, resulting in a varietal or “inbred” plant genetically identical to its parent.

Rice’s predilection to self-pollinate presented Chinese rice-breeders of the 1960’s with a conundrum. To make hybrid rice they needed to prevent the plant from mating with itself. In the lab, this was simple: they emasculated one rice plant by clipping off its anthers and then manually dusted its female parts with the pollen of a different rice variety. Magnified to the scale of a farm—where millions, if not billions, of anthers exist—removing each and every one was clearly impossible.

In 1968, Ping found a clever way around this problem. In research that later earned him the title, “Father of hybrid rice,” Dr. Ping discovered a “male-sterile line”, a natural variant of rice with *no* pollen-producing anthers. When a row of these male-sterile, or “female”, plants of one

Anther Culture: Paternity in a Petri Dish

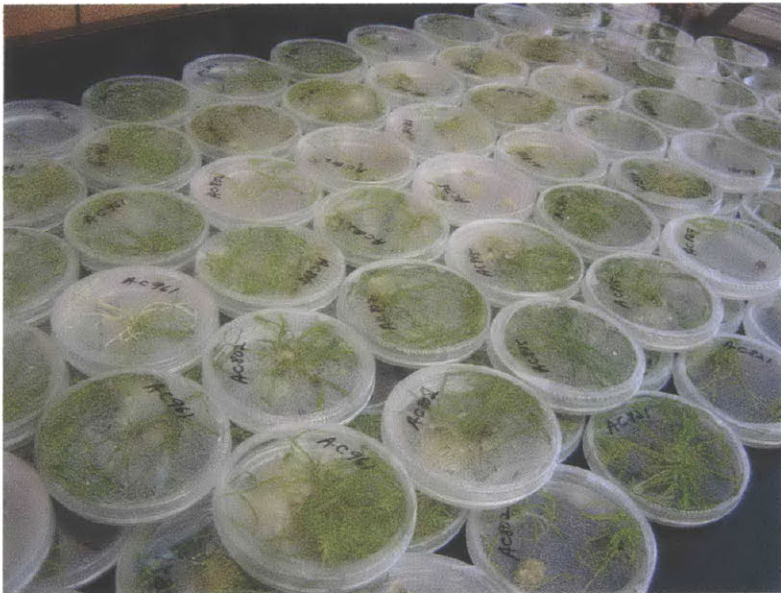
Few appreciate the finicky nature of hybrid rice better than the professional rice breeder. In his lab at the Louisiana State University Rice Research Station, Dr. Qi Ren Chu, is working to streamline the complex three-line method of hybrid rice production into a more efficient two-line method. Using a technique known as anther culture, he can grow a full-fledged rice plant from a single microspore, or pollen grain precursor. Chu treats the microspores with colchicine—a chemical that doubles the number of chromosomes in the spore, enabling it to all the tissues that are normally produced by a fertilized egg. In rows after row of hormone-daubed petri dishes, Chu ‘plants’ these microspores and carefully monitors their development.

So how does anther culture help to simplify the process of hybridization? In order to get the pure-breeding lines necessary to do hybridization, it is normally necessary to breed a plant through six or more generations. But because there is no sex involved in anther culture—each seedling is genetically identical to its pollen-donor parent—a pure-breeding plant can be obtained in a single generation. It may not sound like a big deal to the uninitiated, but to a rice-breeder, five generations represents more than a year of saved time.

variety is cultivated next to a row of normal (pollen-bearing) plants of a distinct variety, the normal ones inadvertently fertilize their female neighbors. The grains that mature on the female plant are hybrid seeds—ones that will grow into a higher yielding, stronger rice plants.

Hybrid rice proved to be China’s agricultural great leap forward. Thanks, in part, to Ping’s contributions, Chinese rice production shot up by a full fifty percent in the early 1970’s—an increase that staved off hunger for millions and allowed China to turn to industrial development. Over the past twenty years, the popularity of hybrid rice has spread, albeit slowly, across the Asia-Pacific. In 2001, more than 700,000 hectares (1.7 million acres) of hybrid rice crop was planted in

Vietnam, India, Bangladesh, the Philippines, and Myanmar. The United States, too, has jumped on the hybrid bandwagon; last year U.S. farmers planted some 10,000 hectares (25,000 acres) of hybrid varieties, primarily in Louisiana and Texas. Farmers



who come to the LSU Rice Research Station for training sessions in best farming practices can learn about hybrid

Anther cultured rice seedlings, such as these at the Louisiana Rice Research Station, have bypassed the need for a mother’s egg. They grow from male microspores in which the chromosomes have been artificially doubled with colchicine to produce the full complement of chromosomes. The process is analogous to creating a human baby entirely from a single sperm cell.

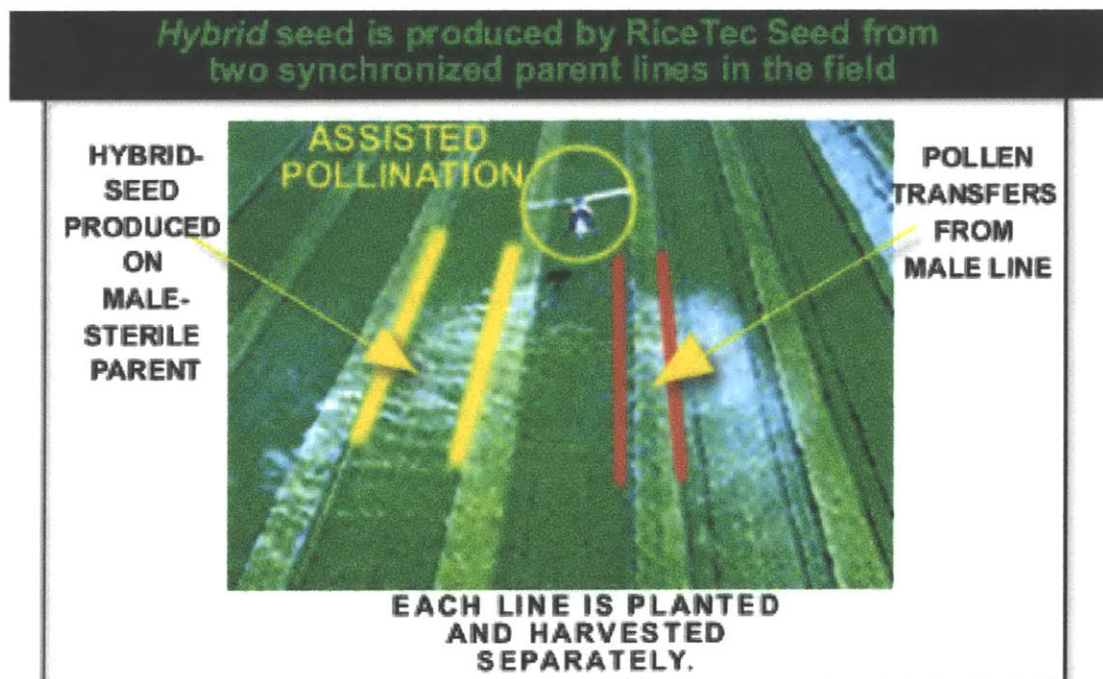
rice from Dr. Chu. “In the United States,” says Chu, “hybrid rice is still a relatively uncommon, but the demand for it here is also pretty low. With so much of our farming mechanized, yields

tend to be consistently high—even with regular rice—so there is just not the need for it that there is in Asia.”

For now, China remains by far the global leader in hybrid rice production—at 15 million hectares, hybrid varieties cover about 50 percent of China’s total rice acreage, while in most other countries, the hybrids account less than 10 percent. Nonetheless, hybrid technology appears destined to move into the mainstream in South-east Asia. The substantially higher yields of hybrid rice—often 15 to 20 percent more than the best inbred varieties—make for greater monetary yields. In a good year, a farmer planting hybrid rice can expect to earn \$120 to \$180 more per hectare.

One of the drawbacks of hybrid rice, however, is that it requires even more in the way of maintenance than the notoriously demanding regular rice. To obtain the great yields possible with hybrid rice, farmers must pay correspondingly greater attention to irrigation and the timing of fertilizer application. But a more fundamental problem lies in the very nature of hybrid rice: like the mule, it is vigorous, but it lives for only one generation. When a pure-breeding plant is mated with another pure-breeding plant to make hybrid rice, only the first generation—the “F1”—is guaranteed to be 100% hybrid. If a farmer tried to grow the seeds that develop (from self-pollination) on an F1 plant, the results would be an agronomic nightmare. Roughly half of the new F2 rice plants would be hybrid, but the other half would be pure-breeds resembling either of the two original parents. In the field, this might appear as clumps of tall rice plants interspersed with short ones, or bug-resistant plants jumbled with non-resistant ones. Such a medley is usually unworkable for the farmer, who depends upon consistency in order to spray against pests and to calibrate the harvesting machinery.

Traditionally, rice farmers save a proportion of grain from one year's harvest as seeds for the next season's crop. But in hybrid cultivation, fresh F1 seeds must be obtained each year—a need which has spawned a new industry devoted entirely to hybrid seed production. In China, in giant fields set aside solely for this purpose, rows of female rice of one variety are planted next to rows of male pollinator rice of a different variety. Workers armed with long bamboo poles walk through the rows, gently raking the male plants to encourage their pollen to shake free onto the adjacent female plants. It helps that the pollinator line is substantially taller than the female line; having been pumped with ample doses of gibberellic acid—a potent plant growth hormone—the pollinators virtually tower over their female neighbors. According to Chu, the same process is carried out in the Houston, Texas, albeit in a modified 21st century version. Rice-Tec, by far the largest hybrid seed producer in America, employs single engine biplanes rather than bamboo-toting workers. In a matter of minutes, these low-flying aircraft can cover hundreds of acres,



www.RiceTec.com

As welcome as the hybrid and miracle varieties were, the green revolution also brought with it some less savory consequences. Because these rices were designed to be grown with large amounts of chemical fertilizers and water, the poorest farmers could seldom afford the needed inputs. Consequently, wealthier farmers—and the agricultural biotech companies that sold them the hybrid seeds—reaped most of the benefits. Also, many critics of the green revolution voiced concern that widespread monoculture (the planting of only one or two varieties of rice) would eventually shove out traditional rice cultivars, thereby shrinking the total rice gene pool and weakening the species as a whole.

Concerns such as these are foremost on the minds of IRRI scientists as they gear up for a second phase in the green revolution. Why a second phase? Because throughout the 1970's and 80's—the peak years of the green revolution—rice harvests managed to rise almost every year, but by 1990, the spectacular growth had petered out. Meanwhile, Asia's population continues to burgeon. Even as population growth is actually on the decline in many first world nations, the developing world is adding new members faster than ever—predictions are that the global population will balloon by another 2.31 billion people in the next thirty years (compared to a growth of 2.12 billion in the previous thirty years). Even by conservative estimates, these numbers clearly demand a massive increase in the world food supply, as grain stocks have again plummeted dangerously low. Rice, according to producers, consumers, and researchers alike, is a prime candidate to fill the deficit: IRRI scientists say they are aiming to double the grain yield by the year 2020. “The population of Asia is expected to increase by 44 percent in the next 50 years,” says Dr. John Sheehy, a crop ecologist and statistician at IRRI. “At present, more than half the people in Southeast Asia have a calorie intake inadequate for an active life, and ten million

children die annually from diseases related to malnutrition. Yet simply to maintain our present per capita consumption, we will need 44 percent more rice within 50 years. The area for rice cultivation is continually being reduced by expansion of cities and industries, to say nothing of soil degradation. So we will need rice plants to deliver maybe 50 or 55 percent more.”

The Green-Green Revolution

In enlightened sequel to the first green revolution researchers will be considering a range of factors far broader than the ever-holy grail of grain yield. Environmental concerns such as global warming, soil erosion, chemical runoff, and water table depletion now vie for status with population growth as major challenges for the next generation of rices. Even if the first green revolution had not maxed out with respect to yield, its fertilizer- and water intensive practices would have proven unsustainable in the long run. IRRI’s 2002 annual report describes how heavy reliance on pesticides and other agrochemicals are deteriorating soil and water quality, even while pests are gaining resistance to the increasingly large doses of chemicals.

Large pools of stagnant water—characteristic of irrigated paddy farming—serve as breeding grounds for anaerobic bacteria, which emit significant amounts of methane, a potent greenhouse



Rice Blast, a fungal disease caused by *Pyricularia grisea*, does more damage to the global rice crop than any other single disease. If left untreated, these lesions will spread, eventually killing the plant.

gas. In answer to these ecological maladies, IRRI is advocating a somewhat counterintuitive policy: a return to age-old farming practices. Traditional cultivation methods—such as “integrated pest management” and “no-tillage seeding”—are again the cutting-edge of rice agriculture. The next era, say scientists at IRRI, will be that of the “green-green revolution”—with the second green being the original “affordable food for the poor” and the first green being the new goal: environmental sustainability.



Pin-striped rice fields are the result of interplanting blast-resistant hybrid rice with non-resistant glutinous rice. Interplanting rice dramatically inhibits the spread of rice blast disease and enables farmers to cut back on chemical fungicides. Farmers thus recover the financial damages normally incurred by rice blast and spend less money on pesticides. The savings can amount to US\$60 per acre. Photo: *Rice Today*, April 2003, IRRI publications.

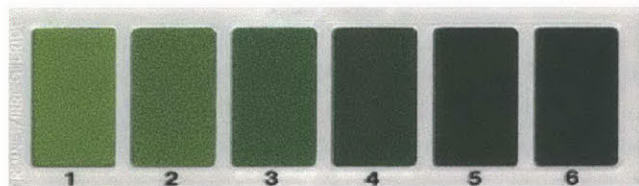
Not surprisingly, China is already out in front of the pack when it comes to green-green technologies. Dr. Zhitao Zhang, formerly the Deputy-General of the China National Rice Research Institute, and now at the Louisiana Rice Research Station to study rice-insect relationships, describes various ways Chinese farmers are learning to coax more rice from the land at less cost to the environment. “We put a plastic film covering—like your Saran wrap—over the rice fields to save water. It has been very successful.” Indeed, many of the solutions are surprisingly low-tech. Using a new technique known as “seedling throwing”, farmers circumvent the time-consuming and laborious process of transplanting. “The rice seeds are started in small plastic cups with a little soil, a little nutrients, and water,” describes Zhang, “Then when the

seedlings are about twenty centimeters tall, the little plants—with the soil still fixed in the roots—are thrown into the flooded fields, where they stick!” The weight of the soily roots, apparently, keeps the seedlings upright as they descend through the water and also helps anchor them into the mud. Other methods the Chinese have piloted are more sophisticated, like wheat-rice double-cropping and planting of “aerobic rice”—varieties that grow without needing to be flooded. One of the most successful experiments thus far, called “interplanting”, is again striking in its simplicity. Instead of planting large stands of a single type of rice, as they traditionally do, some farmers in China’s Yunnan Province are now planting a combination: one row of blast-vulnerable sticky rice followed by four rows of a disease-resistant hybrid rice. They have found that by making this one change, they are able to radically restrict the incidence of the fungal blast, by far the most damaging and widespread of rice pathogens. In less than two years, in fact, farmers have been able to abandon almost all of the chemical fungicides used previously against the blast. The scientists at Yunnan Agricultural University who conducted the interplanting study, speculate that the reason it works so well is that the blast-resistant patches of rice act as physical barriers against the spread of fungal spores. That is, when susceptible plants are separated from one another, the disease has less opportunity to spread. Also, because sticky rice is taller and pokes above ordinary rice, it receives more sunlight and heat in these mixed fields—two factors that appear to inhibit fungal growth. Of course, maintaining a field with diverse plants requires extra care to keep track of, to tend, and to harvest. In Yunnan province, farmers still harvest rice grain by hand, so this presents less of a problem. But researchers who took part in the mixed-cropping study—including a number of American ecologists and plant pathologists—see no reason why methods cannot be devised to extend mixed cropping to the mechanized farm industry. “People have said that these

kinds of ecological approaches wouldn't work on a commercial scale.” says Dr. Alison Power, an agricultural ecologist at Cornell University. But sticky-regular rice medleys now cover more than 100,000 acres in Yunnan province alone. “This is a huge scale,” Power says, and is ample evidence that with some innovative thinking, intercropping can be brought to the commercial level.

Less concerned with marketable development than with subsistence farming, IRRI researchers—according to Dr. Tom Mew, head of IRRI’s Entomology and Plant Pathology Division—are introducing interplanting technology to northeastern Thailand, Vietnam, and the Philippines. Writing in the IRRI quarterly journal *Rice Today*, Mew says that intercropping far surpasses traditional plant-breeding strategies to make rice disease resistant. Besides being time-consuming, in-bred blast resistance lasts only three to five years because the pathogen quickly evolves to outwit the plants’ resistance. Blunting a blast attack with a checkerboard of resistant and non-resistant rice enables the “battle” to last much longer. This may prove to be particularly important in northeastern Thailand, where the farmers grow jasmine rice. Of the 38 total varieties of jasmine, only 12 of them have blast resistant genes. If each of these resistance genes are sequentially bred into jasmine rice—and each of them lasts only three to five years—then fifty years from now, jasmine rice will be left with no defenses against the blast fungus. Interplanting, Mew believes, could effectively save the popular and precious Thai jasmine from extinction.

Eco-management practices often involve community service—both



The Leaf Color Chart ensures that nitrogen is applied at the right time and in the right amount needed by the rice crop.

Photo:<http://www.irri.org/irrc/nutrients/index.asp>

educating local farmers about the need for change and providing them with the tools to do so. One project, in particular, that requires close farmer involvement is called site-specific nutrient management. In a nutshell, this is an approach to fertilizing rice only at the time and in the precise amounts needed. According to IRRI scientists, as currently practiced, nitrogen fertilization is only about 30 percent efficient—that is, only one out of every three bags of nitrogen fertilizer applied to fields is actually taken up by the rice plants. The rest leaches into surface or ground water, from which it later escapes as methane gas or nitrous oxide (another potent greenhouse gas).

Conventional fertilizing recommendations give farmers fixed rates and timings for large rice-growing areas. But these guidelines assume that nutritional needs are constant over all terrains and unchanging through the years. The site-specific method, on the other hand, tailors fertilizer and water application to the location and allows for adjustment as conditions vary in time. The new approach encourages the use of indigenous nutrient resources such as manures and crop residues (rice stubble, for example) over chemical fertilizers, and it promotes efficient fertilizer application through the use of a leaf color chart. Looking like a strip of green paint chips in various shades, the leaf color chart is an at-a-glance indicator of nutritional status. Because the rice plants' leaves get paler as they run low on nitrogen, the farmer can simply monitor leaf color and compare it to the six panels on the color chart. So far, the new method has been pilot-tested in Bangladesh, China, India, Indonesia, Nepal, Pakistan, the Philippines, Thailand, and Vietnam, and has given promising results. Researchers from Zhejiang University in China say that farmers—initially reluctant to veer from the standard regimen of two-large nitrogen doses per year—became “quick believers” in the site-specific approach when demonstration plots in their village showed increased grain yield of 0.5-1.0 tons per hectare even though fertilizer had been reduced

by 10 to 30 percent.

What happens when you lump two good things together? More of a good thing, apparently. Zhang—who was trained in agronomy before going to the China National Rice Research Institute—says the greatest current advances in rice production are in combining site-specific management practices with hybrid rice technology. “We call this combination ‘super rice’,” says Zhang, “but actually there are many super rices, because each is unique to a particular region. The super rice of northern China is *Shengnong 666*, but the super rice of middle China is *Xieyou 9308*.”

A few numbers put into perspective exactly what is so “super” about super rice. Rice yields vary enormously across the world—in Bangladesh, for instance, where dryland cultivation is the norm, yields hover just beneath 3.0 tons per hectare. The United States, with its largely mechanized irrigation farming, averages yields of 6.6 tons per hectare, while countries like Vietnam and Indonesia that use a variety of methods (both irrigated and dryland) fall somewhere in-between: 4.1 tons per hectare for Vietnam and 4.3 for Indonesia. One hectare of super rice, in contrast, yields an extraordinary 11-12 tons of grain. When Zhang presents these statistics to a room full of LSU graduate students and post-docs, mouths literally fall open. “Can you do that?” asks one incredulous professor. “Yes, we can,” Zhang responds with insuppressible pride. “China can feed the Chinese people. Only China can feed the Chinese people.”

From Rags to Riches: Rice in the USA

Rice is feeding the Chinese, but it is also feeding an increasing number of Americans. Per capita consumption of rice has gone from a modest 9 pounds per year in the mid-1960's to somewhere between 25 and 30 pounds today (estimates vary depending on whether the rice used in beer-making is counted). Seven states—Arkansas, California, Louisiana, Mississippi, Missouri, Texas, and Florida—planted a total of 3,251,000 acres of rice in 2002-03 for a total of 9.7 million tons of unmilled grain. Compared with China's 175 million ton output in that year, U.S. production may not amount to much by world standards, and yet America still manages to rank consistently high on the list of global rice exporters. This is because most rice in the world never travels more than 10 miles from farm to table; in China, for instance, approximately 90 percent of the rice harvest remains in-country, and Japan actually must import rice to fill its bowls. But Americans—who are neither on the brink of starvation nor traditionally a rice-eating people—leave more than enough of the yearly harvest to be shipped abroad.

A number of groups, rice farmers included, would love to see Americans become more of a rice-eating people. Nutritionists tout it as a superb staple: naturally low in fat and sodium, high in complex carbohydrates, and easy to digest, eating more rice is among the easiest steps a person

Louisiana Rice

The Cajun people are the descendants of the Acadians—a group of French who settled in Nova Scotia in the 17th century, but were expelled from the land by the British in the mid 1800's. They were, for the most part, subsistence rice farmers, fishermen, and wild game trappers. Living off the land and forest, the Louisiana Acadians—or "Cajuns"—combined those influences in their colorful and spicy cooking. An indigenous favorite is "dirty rice", so named because the chopped-up meats (traditionally chicken gizzards, ground beef, or pork) give it the appearance of dirt mixed up in rice. Other Cajun classics include Hoppin' John (red beans and rice), jambalaya, gumbo, and *etouffé* over rice.

As anyone who has ventured down to New Orleans for *Mardi Gras* knows, the Cajuns' love for rice lives on in the bayou country. Today the average Louisianan eat five times more rice per year than the average American.

Parboiled Please!

For the millions who grew up on a parboiled product such as Uncle Ben's, rice is something altogether different than what most Asians call rice. Parboiling entails taking rice that is still in the husk



and blanching it briefly in boiling water. This drives the vitamins and oils in the bran layer into the endosperm, making parboiled rice slightly more nutritious than regular rice. The heat of blanching also gelatinizes the starchy endosperm so that parboiled grains are extra hard and glassy-looking when dry.

It was not Uncle Ben who first devised this technique, however. Asian Indians have long parboiled their rice as a way to keep the grains from crumbling during the harsh milling process. And it was West African women—the great-great grandmothers of the black Texas rice farmers symbolized by Uncle Ben—who brought parboiling to North America. As Judith Carney writes in *Black Rice*, “The method of parboiling represents the diffusion a female knowledge system from Africa, which survived slavery in the cooking practices of their free male and female descendants.”

can take towards a more healthful diet. Jim Hoppe, former president of the USA Rice Council and current president of the Louisiana Rice Council, says the best-placed efforts to popularize rice are those in restaurants and in public school systems. “After all,” he says, “folks like to eat what they know—what they grew up on as kids.”

Part of making way for rice in the 21st century American's diet will be putting to rest its old image as a “poor man's food.” For in America it was, initially, just that. Brought to the North American continent in the holds of a slave-ship, rice was first cultivated by African slaves on colonial plantations. The grain easily became the mainstay in the diets of Carolina blacks, much as it was for their ancestors in West Africa. Still one hundred years after the civil war put an end to the era of plantation farming, rice remained the dietary cornerstone for many black families in the rural South. It became the staple of the rich African-American cookery known as “soul food.”

Writer and culinary anthropologist Vertamae Grosvenor has written extensively about growing up in

the Carolina low-country, where the people and the culture were interchangeably referred to as “Gullah” or “Geechee.” As she described in a recent radio interview on National Public Radio:

“...growing up there in the low country, we were known as ‘rice eaters.’ But it was derogatory when we moved to the North... We was bad-talking Geechee—rice-eatin’ Geechee from South Carolina. I saw no history in that, I just thought that was really something bad that you did. Other people had mashed potatoes...I’d lie at school...I’d say ‘we had mashed potatoes last night’ and of course we had rice, rice, rice, rice, rice. Even if you had mashed potatoes, you were gonna have rice; even if you had macaroni and cheese you were gonna have rice... I thought as a kid, after we moved north that I would never eat rice in public. I would never eat rice in my own house: I would never have rice on my shelf, in my pantry...I didn’t know there were so many kinds of rice, and I didn’t know that I had such a shared history with billions of people in the world...eating rice, you know?”

But rice was not confined to African-American kitchens. In Louisiana, for instance—which began growing rice soon after the collapse of the Carolina rice industry—the grain was enormously popular among the Cajun and Creole peoples. Still, it was not until World War II, when the first boxes of Uncle Ben’s Converted Rice hit grocery store shelves, that rice began to move into mainstream American culture. In the post-WWII years, in the era of federal welfare programs and a move towards social equity, rice became “everyman’s food” —a source of nourishment for hard working, middle-class America. Even as it became a fixture in many kitchens nation-wide, rice continued to bear the country bumpkin connotations captured in this 1950’s radio jingle: “*I come from Carolina, so pardon my drawl, I’m here to sell Carolina Rice to y’all.*” In other words, rice was something one might cook for a meal at home, but it was not a dish to prepare for guests, and certainly not something one would order in a fancy restaurant.

In recent years, rice has finally managed to shed its blue-collar image and has broken into upper-crust society. This is in part due to an abundance of ethnic restaurants—Indian, Chinese, Japanese, Thai, and Mexican—where rice is inevitably part of the main course. In a curious reversal of rice’s slow migration across the globe, an international assortment of rice dishes can be found converging on a single block in downtown Manhattan (or in a lowlier version, in a food court at the local mall). Many Americans are, for the first time, being introduced to a world of rice outside boil-in-a-bag Minute Rice—to the diverse flavors, textures, and aromas of Indian *basmati*, Italian *arborio* and, Thai *jasmine*. The popularity of these imported varieties has been so great, in fact, that it has spawned a new market specifically for so-called “designer rices”—essentially spin-offs from the foreign types. A Texas-based company called RiceTec is one of the leading manufacturers of designer rice, with brand-names such as Tex-Mati, Kas-Mati, Jas-mati, “Japanese-style” Sushi Rice, and “Italian-Style” Risotto. But rice is not like a perfume that can be sniffed, analyzed, and chemically reconstituted



“Designer Rices” such as these created by Houston-based biotech company Rice Tec and marketed by Rice Select, are an attempt to mimic the characteristics of some of the world’s most famous rices. Most are simply American varieties that have been bred to approximate the flavor, aroma, texture, and cooking qualities of the native types. Then, using a special milling process, the rice grains are honed to the proper shape and size.

in the lab. In order to obtain an American version of basmati or jasmine, the native strains had to be adapted to North American climactic conditions.

One of the earliest rices to be thus developed was Jasmine-85, so named because it was derived from Thai jasmine rice and was first introduced to the U.S. market in 1985. Jasmine-85 never garnered much attention, however, because it was noticeably grayer in color than imported jasmine and had a slight off-taste—rice connoisseurs wouldn't have it. Now Chris Deren of the University of Florida's Institute for Food and Agricultural Sciences has decided to make another go at readapting jasmine rice. Since obtaining germ plasm of jasmine rice from IRRI in 1995, Deren has been bombarding the seeds with gamma rays. His goal is to induce a mutation that will cause the rice plant to flower early—a change that will allow the rice to grow and be harvested prior to the onset of the cool North American fall season. Like many living organisms (including humans), rice displays a phenomenon known as photoperiod sensitivity. This means that rice's growth is influenced by the length of the day, or more specifically, how many hours of sunlight it receives. In Thailand—where temperatures rarely drop below the 50 degree Fahrenheit lower limit for tropical rice growth—jasmine rice would be planted in March or April and would begin flowering when the days grew shorter than twelve hours,

Biopiracy

The fear that American-grown jasmine will undercut the sales of the genuine Thai product has sparked a rancorous debate pitting non-governmental organizations and Thai farmers against the American agricultural biotech industry. In November of 2001, thousands of farmers from Thailand's Isaan province rallied in front of the US embassy in Bangkok, protesting against the possibility that Deren would obtain a patent on jasmine rice, threatening their ability to export Thai jasmine to any country abroad. Deren has since promised not to patent any variety that he develops, but another concern still looms. Five million families in Thailand grow jasmine rice and depend heavily on the revenue of exports to the United States; in 2001, for example, sales to the U.S. pumped 1.2 million dollars into the Thai economy. Loss of this income will hit small-scale farmers the hardest—a fact that has human right's groups up in arms and brings to the fore a whole slew of issues about globalization and its effects on the underdeveloped world. (*continued*)

generally around October. But by October in the United States, it is already too cold at night for rice to produce grain; so, Deren wants to create a day-length *insensitive* variety that can be planted at any point in the Spring and that will flower 90 days later. After subjecting a batch of rice seeds to gamma rays, Deren monitors the seedlings' growth, rigorously ensuring that they receive more than 12 hours of sunlight per day. The crucial moment comes some three months after planting: if the rice begins to flower at 90 days despite the long bouts of sunshine—which tell a normal plant that it is too soon to blossom—Deren

knows he has found a “photoperiod mutant,” one that has lost its sensitivity to day length.

At this point, Deren's jasmine derivatives are still in the experimental stages: the 1.5-acre

A similar debate involving Indian basmati rice recently came to a truce when RiceTec—the biotech corporation that markets Tex-Mati, Jas-Mati, and Kas-Mati—agreed to cede all but four of twenty patent claims it had made on Basmati rice. Included in its concessions were the rights to advertise using the name “Basmati” and to appropriate the unique qualities of traditional Basmati.

Such disputes are likely to pop up with increasing frequency as biotechnology digs further into the realm of agriculture. But the NGO's and the Thai farmers may have less than they think to worry about. According to Jim Hoppe—who plants about 100 acres of aromatic varieties per year and runs a small mail-order business for them—the American jasmine derivatives just don't match up to the genuine article. “It's really the darndest thing,” he says, “In taste tests, where we give a bowl of jasmine rice and a bowl of Jas-Mati rice to an Asian person, they will get it right every time. They will point to the import and say, “That my rice,” and then will point to the other and say ‘That *not* my rice.’”



plot in Belle Glade, Florida, where the varieties are being tested is miniscule compared with the 20,000 acres of all kinds rice harvested annually in Florida alone. And with U.S. imports of Thai jasmine rice exceeding 350,000 tons per year there is plenty of incentive to develop a



commercially viable product. An eager bunch of American companies watch Deren’s progress, for the “specialty rice” market is a lucrative one: jasmine and its international kin fetch prices far higher than those of standard varieties. Compared with about \$11 to \$15 per 100 pounds of regular American rice, a Thai jasmine may go for \$26 per 100 pounds and the finest Indian basmati can garner up to \$43 per 100 pounds. Consider that a company may sell several thousand *tons* of rice per year and it becomes easy to understand why specialty rice looks so nice.

If there is one thing that perennially plagues the rice farmer more than anything else—and that dips most deeply into his profits—it is an infestation of weeds. In the U.S., one weed in particular is loathed above the others: red rice—also referred to in parts of Louisiana



Red Rice, still in its husk (far right) looks almost identical to cultivated rice. But the grain within (center) is more brittle and crumbles like chalk in the milling process. Even a few grains of red rice per hundred pounds of harvested grain dramatically lowers the market value of the entire batch.

as “public enemy number one.” In its husk, red rice looks for all intents and purposes like the cultivated type; but when stripped of its husk and bran, the endosperm reveals a more chalky, opaque white. “Try to put red rice through a milling machine,” says Tim Croughan, a geneticist at the LSU Rice Research Station, “and the grains will shatter and jam your machinery.” And whatever doesn’t get pulverized often escapes getting milled, leaving behind bits of bran-coated rice grains. According to Croughan this is more of a problem than it might at first seem. Rice-eaters are a finicky bunch, he says. A bag of rice mottled with specks of reddish-brown bran would simply never come off the grocery store shelves “Shoppers would take one look at the rice and wonder what was wrong with it.”

Red rice is extremely difficult to control because it easily interbreeds with regular rice; in fact, red rice is also a member of *Oryza sativa*, only a different variety. As Croughan points out, holding two seeds side by side in his palm “you can hardly tell them apart just by looking at them. Red rice has this little barbed hook at one end, but other than that, the weed and the good stuff are practically twins.” And because it *is* so similar to cultivated rice, any measures taken against red rice invariably harm the cultivated crop—for decades rice-breeders and farmers have been struggling to fend off the weed with little success. In Jim Hoppe’s experience, after a few years of consecutive planting in the same field, the plot will be so overrun with red rice that he is forced to abandon it for several years. And red rice is not a problem only in Louisiana—all across North and South America it is the single most damaging factor in the rice agricultural industry. So it was with considerable excitement that scientists at the Crowley Rice Research Station unveiled in 2001 a new weapon against red rice: Clearfield 141.

If red rice is “public enemy number one”, then Tim Croughan is the chief undercover

investigator and SWAT team rolled into one. Since 1981 his lab has been on the hunt for a mutant rice that would be resist a herbicide potent enough to destroy red rice. Their approach involved soaking rice seeds in a chemical carcinogen known as ethyl methyl sulfonate to induce random genetic mutations, allowing the plants to grow, and then subjecting them to massive doses of herbicide. Using this technique, Croughan and his students screened more than *one billion* seeds over twelve years before finally hitting upon a winner. Later dubbed Clearfield 141, this rice plant survived the normally fatal experience of a dousing with an herbicide called imidazolinone. This chemical—marketed for rice under the name *Newpath*—is known as a “single-site-of-action herbicide”, meaning that it works by blocking a particular enzyme critical to the plant’s survival. In the case of *Newpath*, this enzyme is acetyl lactate synthase (ALS), a protein involved in the production of the essential amino acids leucine, isoleucine, and valine. Just the right mutation in the ALS gene, however, and the protein changes shape so that the herbicide is no longer able to recognize it. Clearfield 141 is relatively unfazed by the herbicide, but red rice is wiped out. Genetic sequencing of Clearfield 141 revealed that a single amino acid—out of a total of 650 that make up the ALS enzyme—had been affected. This change, however, was in the molecule’s “sweet spot”—the site where the herbicide molecule would normally bind and inactivate it.

Clearfield 141 survived the herbicidal onslaught, but still suffered enough damage to keep researchers looking for better anti-red rice artillery. So Croughan’s team began searching through another billion seeds looking for, as he puts it, “the second needle in the haystack.” In 1999, they obtained a rice plant that was ten times more resistant to imidazolinone herbicide than even Clearfield 141. Says Croughan, “The way we determine levels of resistance is to treat the plants with different levels of herbicide, then observe how much injury or death results. Through a

combination of laboratory, greenhouse, and field tests, we determined that it takes about 10 times as much herbicide to cause the same level of injury or death with Clearfield 161 as it does with CL141.” The new mutant—christened Clearfield 161—was sent off to a laboratory to be genetically sequenced. Croughan still shakes his head in disbelief when describing what they found. Out of all 650 amino acids that could have been mutated in the ALS enzyme, Clearfield 161 revealed a change in the DNA just *three* bases away from site of the Clearfield 141 mutation. Since each amino acid is encoded by a sequence of three DNA bases, this meant that CL161 was altered in the amino acid immediately adjacent to that mutated in CL141. “I guess it makes sense if you think about it,” says Croughan, “both changes are in the enzyme’s active site.” Still, after irradiating more than two billion seeds, it fascinates him that the two best performers contain mutations that are literally next-door-neighbors. Both Clearfield 141 and 161 have now been extensively field tested and are being distributed to farmers all across Louisiana and other rice-growing states. According to Croughan, plans are in the works to bring Clearfield rice to South America by 2003, where Colombia, among others, suffers from a particularly nasty infestation of red rice.

Croughan’s Clearfield rice has been met with acceptance—even relief and excitement—almost across the board. But this has not been the case with Liberty Link rice, another variety developed in 1993 at the Crowley Rice Research Station. The “liberty” gene, explains plant pathologist James Oard, comes from the soil-borne bacterium called *Streptomyces hygrosopicusfungus*. Inserted into a popular Louisiana rice known as *Cocodrie* (“alligator” in Cajun), the transferred gene, or “transgene,” provides resistance against a broad-spectrum herbicide. A field sown with these transgenic plants can easily be sprayed for weeds without

harming the rice. Even though Liberty Link rice has been proven to work phenomenally well—in Oard’s pictures, the Liberty Link rows look healthy while the controls have died and wilted back into the water—public acceptance of transgenic rice has proven to be a problem. Many farmers are wary of releasing genetically modified (GM) rice into their fields, fearing it could contaminate their non-GM crop. While there is no hard scientific evidence to date indicating that GM foods have any negative health effects in people or animals, there is still the danger that American consumers will—like their European counterparts—turn strongly against them, and farmers of GM rice would suffer the consequences. But Oard is still optimistic that the superior performance of Liberty Link and other transgenic rices will eventually win out. Speaking about the public’s current ambivalence over genetically modified foods, Oard says, “It may be true today, but we don’t know what’s going to happen in the future. If the public says ‘OK’, we’ll be ready; we won’t have to play catch up.”

If transgenic rice stands a fighting chance to win public acceptance, its best odds lie with one very special transgenic variety called “golden rice.” So named because of its yellow color,

The Golden Rice Debate

Almost immediately after the creation of golden rice was announced to the public in 2000, it came under heavy fire from critics of the agricultural biotech industry and anti-GM advocates. Among the more vocal members of the opposition was Greenpeace, which has called golden rice “fool’s gold,” challenging that 1) it does not provide sufficient amounts of beta-carotene to make any significant nutritional difference, 2) the underlying causes of vitamin-A deficiency (poverty and lack of dietary diversity) were not addressed by golden rice, and 3) measures such as supplementation (pills) and food fortification should be considered before biofortification. In an online interview with author Michael Fumento, Potrykus responded to these allegations. *“Greenpeace has a strategy to convince people that golden rice provides so little beta-carotene that it is useless. This group and its allies base their argument on 100 percent of the daily recommended allowance, thus hiding the fact that far lower values are effective against mortality, morbidity, and blindness.”* On the issue of golden rice versus supplements, Potrykus pointed out the twin problems of expense and distribution. The purified beta carotene pills advocated by Greenpeace cost about US\$185 per 25 milligrams, or roughly \$4.50 per day to get the adult recommended allowance of 600 retinol activity equivalents (1RE= 1 microgram retinol). (Continued)

golden rice has been genetically modified to produce beta-carotene, the chemical precursor to vitamin A. Lack of sufficient vitamin A, according to the World Health Organization, is a condition that affects some 230 million children worldwide—causing nearly one million childhood deaths per year and half a million cases of irreversible blindness. Furthermore, the vitamin A deficiency, or VAD, is largely preventable: according to UNICEF, vitamin A supplements can prevent blindness and can lower a child's risk of dying by about 23 percent.

Even with funding from governments and non-governmental organizations, the costs of covering all those in need would be astronomical. Moreover, vitamin supplements often fail to reach the far-flung rural townships where they are needed most.

Still, Potrykus emphasized that golden rice was never envisioned as a panacea. He sees it instead as a tool to *"complement traditional interventions...in the cheapest and most sustainable way possible."* Obviously a varied diet rich in vitamins and minerals is the ideal—but if the poor had access to and could afford red meat and plenty of green leafy vegetables, then malnutrition would not be the huge problem that it is.

Says Dr. C Kamesara Rao, Executive Secretary of the foundation for Biotechnology Awareness and Education in Bangalore, India, *"We are aiming the benefits of golden rice at the poorest of the poor who cannot get anything other than rice, green chilies and salt, if at all."*

Most cases of VAD occur in places of the world where rice is the major staple food, since the part eaten by humans—the grain—supplies none of the beta carotene necessary for the body to make vitamin A. Back in 1985, a German geneticist by the name of Ingo Potrykus began floating the idea that rice—instead being a Third World liability—could serve as way to combat VAD. With fifteen years of experience with genetic engineering—twelve of those with cereal crops—Potrykus agreed with Per Pinstrup-Anderson, Director General of the International Food Policy Research Institute, that "a sustainable solution [to vitamin deficiency] will come only when it will be possible to improve the content of the missing micronutrients in the major staple crops."

Potrykus knew that the natural rice gene pool does not have the genes necessary to produce vitamin A; the only way to get vitamin-enriched rice would be borrow those genes from another plant. Moreover, because rice endosperm lacks beta-carotene, the nearest chemical to

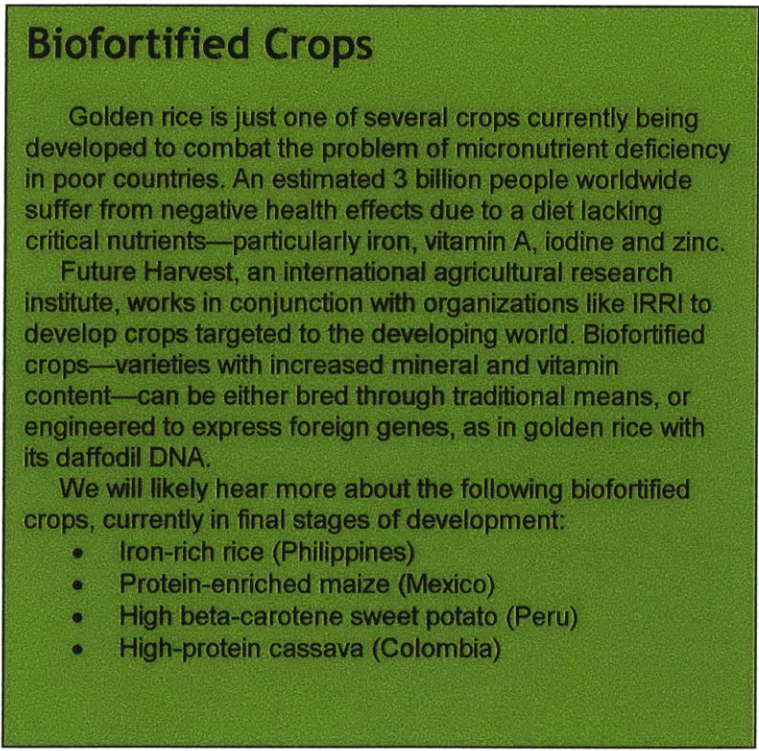
precursor to vitamin A, Potrykus knew that he needed to engineer not just one gene, but *an entire biochemical pathway*—something that had never before been done.

In 1991 Potrykus teamed up with Peter Beyer, a German biochemist who was working at the time on gene regulation in flowering plants. Beyer was trying to isolate from daffodils, in fact, the very genes that would be

needed to establish the vitamin A pathway in rice. This so-called “terpenoid” pathway is essentially an assembly line of daffodil enzymes working to take in a specific protein precursor at one end, perform a series of chemical modifications, and spit it out at the other end as vitamin A. In the rice endosperm, the nearest relative to vitamin A is a protein

called geranylgeranyl-pyrrophosphate (GGPP), so theoretically, at least, it should be possible to turn it into beta-carotene by introducing the four daffodil enzymes downstream from GGPP in the pathway: phytoene synthase, phytoene desaturase, z-carotene desaturase, and lycopene cyclase.

Theoretically, that is. In practice, re-rigging rice to express the components of the terpenoid pathway proved to be a thorny endeavor. It took another ten years and three post-doctoral students before Potrykus and Beyer finally had in their hands a beta-carotene enriched rice.



Biofortified Crops

Golden rice is just one of several crops currently being developed to combat the problem of micronutrient deficiency in poor countries. An estimated 3 billion people worldwide suffer from negative health effects due to a diet lacking critical nutrients—particularly iron, vitamin A, iodine and zinc.

Future Harvest, an international agricultural research institute, works in conjunction with organizations like IRRI to develop crops targeted to the developing world. Biofortified crops—varieties with increased mineral and vitamin content—can be either bred through traditional means, or engineered to express foreign genes, as in golden rice with its daffodil DNA.

We will likely hear more about the following biofortified crops, currently in final stages of development:

- Iron-rich rice (Philippines)
- Protein-enriched maize (Mexico)
- High beta-carotene sweet potato (Peru)
- High-protein cassava (Colombia)

How had they finally done it? As it turned out, the most effective way of getting daffodil genes into rice was to exploit the unique properties of a soil bacterium known as *Agrobacterium tumefaciens*. In nature, *Agrobacterium* survives by attaching to a wounded plant cell, snipping out a chunk of its own DNA, and transferring it to the plant cell through a pore in the bacterial membrane. Once inside the plant cell nucleus, the transfer-DNA, or T-DNA, gets incorporated into the plants regular DNA and the host cell begins making bacterial proteins. Scientists have



Drs. Karabi Datta, Swapan Data, Ingo Potrykus, and Peter Beyer examine a panicle of golden rice at the International Rice Research Institute. (Photo reproduced, permission pending, from IRRI 2002-2001 Annual Report.)

figured out, however, that if they replace *Agrobacterium*'s T-DNA sequence with another gene of interest, then the bacterium will deliver *that* gene into the plant cell nucleus. So what Potrykus

and Beyer did, essentially, was engineer two different lines of *Agrobacterium* to deliver genes constituting the terpenoid pathway—two from daffodil and one from a bacterium called *Erwinia uredovora*. Together the genes constituted the complete set of instructions necessary to produce beta-carotene. These transgenic *Agrobacteria* were then added to a Petri dish full of rice embryos, where they could infect the rice cells, and in the process, transfer the beta-carotene genes.

On March 31, 1999—the date of his retirement as Professor of Plant Sciences from the Swiss Federal Institute of Technology—Potrykus revealed golden rice for the first time in a public symposium. Polished to a golden shine, the rice grains of different lines varied in yellowness, revealing differing quantities of beta carotene within; in the best line, 85% of the carotenoids were of the beta variety.

Having created golden rice, Potrykus and Beyer wanted to ensure that it went into the right hands—and into the mouths of those it was intended to benefit. From the outset they had decided that golden rice should be given to subsistence rice farmers free of charge and that the technology should be made freely available. But giving golden rice away turned out to be much harder than they imagined. The Rockefeller

300 Sisters of Iron Faith

Human nutrition studies can be notoriously difficult to conduct—complicated as they are by the extreme variability in people's lifestyles. So when IRRI scientists wanted to do a trial of a promising iron-fortified rice, they looked for a group of people with very similar and very easily-monitored daily behavioral patterns. They found their subjects in an unlikely place.

Twenty seven nuns from a convent in Manila volunteered to eat IR68144, the iron-enriched rice, almost exclusively for six months. After the trial period was over, tests revealed that the serum ferritin levels in their blood had leaped—sometimes two to three times higher than normal. But while the results were clearly significant, the small scale of the trial left many researchers unconvinced.

Thus, 300 nuns between the ages of 20 and 35 were recruited to take part in a second IR68144 trial. Half of the sisters were put on a diet of iron-enriched rice while the other half were given regular rice. According to IRRI's quarterly journal *Rice Today*, the sisters are the perfect test group, since their disciplined lifestyle and modest diet normally leaves most of them slightly anemic. In addition to close supervision by a panel of nutritionists, the sisters tirelessly submitted to frequent weight checks, blood tests, and all kept detailed food, sleep, activity—even mood—journals. (continued)

Foundation, which had supplied funding to Beyer's lab, commissioned an audit to determine the number of Intellectual Property Rights (IPRs) and Technical Property Rights (TPRs) that had gone into the golden rice experiment. As Potrykus himself would later recount, "the outcome was shocking": Seventy IPRs and TPRs belonging to 32 different companies and universities would need licenses before they could establish so-called "freedom-to-operate."

Realizing that they were in over their heads, Potrykus and Beyer established a "Golden Rice Humanitarian Board" to oversee the matter of

patent rights and technology transfer. Fortunately, the agricultural biotech company Astra-Zeneca (now called Photo Syngenta), which had exclusive rights over one of the genes used in making golden rice, also agreed to very generous definitions of "subsistence farmer" and "humanitarian use"—conditions which would be important in making it as widely distributable as possible. In exchange for commercial marketing rights in the U.S. and other First World markets, Astra-Zeneca agreed to cede the rights on "humanitarian" use and to publicly support the effort to put golden rice into the hands of poor farmers. Potrykus credits a cover story in July 2000 *TIME* with spurring another biotech giant, Monsanto, to offer royalty-free licenses for any of their patent technologies that might help further the development of golden rice.

By the end of nine months, the researchers hope to have gathered enough data to determine whether the iron in IR68144 is efficiently absorbed by the human body, and to gauge how the high levels of zinc—a mineral known to enhance iron absorption—in IR6844 contributes to the effect. Beyond the physiological impacts of eating an iron-fortified diet, the study will also provide new information about the psychological effects of iron-deficiency anemia.

It has been estimated that some 30 percent of the world's population suffers from this malady—including 60 percent of all women in Asia and 40 percent of all schoolchildren. Anemia impairs immunity, reduces physical and mental vitality, and is responsible for up to 20 percent of maternal deaths. If IR68144—which was bred quite by accident in an unrelated effort to find rice with tolerance to low-temperature—proves to be an effective iron supplement, it will be a major victory. And the sisters of Manila, by religiously adhering to their iron-fortified rice routines, will have done a supreme service not only for science but for the world's poor and malnourished population.

In January of 2001, Potrykus flew to the Philippines to deliver golden rice seeds in person to the International Rice Research Institute. Dr. Swapan K. Datta, IRRI's chief plant biotechnologist, says their first task will be to investigate the safety and efficacy of golden rice. This will entail, among other things, re-doing Potrykus' *Agrobacterium* experiments using varieties of rice that people actually eat. Because while Potrykus had used a *japonica* strain common in the lab, it is not one widely eaten in the poor countries of Southeast Asia—here the most popular rices are high-yielding tropical *indicas*. One variety that has already been chosen is BR29 from Bangladesh. BR29 is ideal, says Datta, because “the farmers are happy with it, the market is happy with it, consumers are happy with it. We, and our counterparts in Bangladesh know this plant through and through. All we have to do is engineer BR29 with the beta-carotene pathway, and since we are totally familiar with the original plant, we will be able to quickly but thoroughly analyze the outcome of the genetic modification, and make sure nothing else has changed. We won't have to worry about pest and disease resistance, grain flavor, acceptability, or anything like that.”

The search for other candidate golden rice plants has centered on Vietnam, India, the Philippines, and Mozambique. Six to ten varieties will be chosen for the first batch and for each variety, tens or hundreds of different lines will be engineered. This is necessary, says Datta, because some will be unhealthy, others will not produce enough seed, and still others may not produce enough beta-carotene. In its current incarnation, golden rice can provide between 20 and 40 percent of the daily 1000 microgram requirement for Vitamin A. With most experts acknowledging that this is not good enough, efforts are underway to increase the beta-carotene content to a level where the daily allowance could be reached in the 300 grams of rice per day

eaten by most Asians. Once a good golden rice line is established, its seeds will be sent off to individual countries, where they will be further analyzed and then distributed to local farmers. While acknowledging the many challenges—both scientific and social—that lie ahead of golden rice, Dr. C Kameswara Rao of the Foundation for Biotechnology Awareness and Education in Bangalore, India, is optimistic about its future. “Golden rice signifies a shift in the target of GM crops from the farmer to the consumer,” writes Rao, “Millions of poor in the developing world need it. Golden rice deserves to be given a chance or prove itself to the contrary. Let us hope that the dust settles soon and the sun shines on golden rice.”



<http://www.fao.org>

“This was ‘Woman’s Wuck’” — Judith Carney, *Black Rice*.

Throughout West Africa women are the sowers, gatherers, and processors of rice. In Southeast Asia, women transplant the rice seedlings and weed the fields. In colonial America and until recently, in Europe, women were the planters, weeders, and millers of the harvest. And almost without exception, the cooking of rice also falls within the female domain.

Women have been essential to rice cultivation for several centuries: In the mid-1800’s, Father Huc, a Lazarist French Missionary traveling across South-East Asia described the following rice field scene: “More than once it happened to us to see a plough drawn by a woman, while her husband walked behind, and guided it. Pitiably it is to see the poor things sticking their little feet into the ground as they go, and drawing them painfully out again, and so hopping from one end of the furrow to the other.” And Jacqueline Piper, in *Rice in South-East Asia* writes, “The water buffalo is clearly the main agricultural beast of burden in the flooded paddies—next in importance to women, who contribute up to 80 percent of the human labour expended in South-East Asian rice farming.”

Itinerant women laborers known as *le mondine* were until recently, the water buffalo of the Italian piedmont. Every year, these women would descend from their hillside villages to the Po River valley, where they would spend weeks weeding and harvesting the rice crop. “They arrived from all parts of Italy,” recounts one Italian historian, “to perform the delicate task of rooting out the weeds while leaving the young rice in place.”

Immortalized in the 1954 film classic *Riso Amaro* (“Bitter Rice”), the lives of *le mondine* were tedious and harsh. Away from their families and friends, the women slept in over-crowded dormitories and spent their days in the rice fields hunched over, up to their knees in water, under a blazing sun. To take their minds off the heat and the ferocious clouds of mosquitoes, the women often sang as they worked. One of their favorites, *Ciao Bella*, was later adopted by the Italian Communist Party to express its anger at the social injustice of the government system.

In much of Asia and Africa women continue to be the primary labor force on the rice farm, performing tasks, like transplanting rice seedlings, which require little in the way of brute strength but hours of back-bending diligence. While boys are increasingly being given the option of going to school, girls often remain tied to the farm—a situation that many feel exacerbates the gender inequity in education and healthcare already rampant in much of the developing world.

As city jobs lure a generation of young men away from the farm, women in many Third World countries are having to shoulder more of the agricultural workload. In recognition of this problem, improving the plight of women laborers has become an explicit goal of the International Rice Research Institute. Its recently published *Sustaining Food Security Beyond the Year 2000* sounds an optimistic note: “Rice science can contribute to greater participation of rural women in decision making by enriching their body of knowledge and their repertoire of skills and widening their range of contacts with the outside world.”

5 THE FUTURE HARVEST

By all accounts, the years since 2000 have been exciting ones in the long history of rice. In January of 2001, the agribusiness corporation Syngenta completed a draft sequencing of the *japonica* rice genome. Soon after, the Beijing Genomics Institute (BGI)



announced a draft of the *indica* genome. With a cover in the April 2002 issue of *Nature* and another in *Science*, rice celebrated a rare honor—that of being the first cereal crop with a fully sequenced genome. The work had begun some five years earlier, when Japan spearheaded the formation of the International Rice Genome Sequencing Project (IRGSP), an effort involving research institutions in Japan, the United States, China, Taiwan, South Korea, India, Thailand, France,

the United Kingdom, and Brazil —making it a global venture on par with the Human Genome Project (HGP). As rice basked in the limelight of science celebrity status, it proved, yet again, to be beneficial to its human manipulators. The unraveling of the rice genome marked a significant milestone in collaboration among scientists from different countries, as well as between the private and public research sectors. Drawing on the resources of universities and biotech laboratories all around the world, the IRGSP built an organizational network of rice workers to rival that of the ancient Cambodian Khmer Kingdom or the traditional Balinese *subak*. If the need to maintain irrigation canals and to designate water rights once spawned civilized governments

United Nations declares 2004 International Year of Rice

Acting on a proposal from the Philippine government, the United Nations General Assembly voted in December of 2002 to declare 2004 the International Year of Rice (IYR). The Assembly noted that rice feeds more than half of the world's population and thus stands to play a crucial role in alleviating poverty and malnutrition, as well as in ensuring national food security. Events for the IYR will be collaborative efforts of the UN Food and Agriculture Organization (FAO), governments of rice-producing nations, several non-governmental organizations, and other branches of the UN. While definitive plans for IYR are still in the works, one event is almost a certainty: the 25th International Rice Research Conference will be held in the latter half of the year in Vietnam.

and cooperative communities; rice in the modern era is creating webs of cooperation that span the globe. To stretch the imagination, the IRGSP was a glorified *subak*, whose job it was to divvy up the rice genome and to maintain international canals of communication. It a project that was unprecedented for its scope and meticulousness of design: *Oryza sativa*'s 12 chromosomes were divided into several chunks, each of which was assigned to a team of researchers (the United States' five participating groups got 3, 10, and the head and tail of chromosome 11). Meanwhile, the private corporations Syngenta and BGI also cranked out a draft of the rice genome, and—in a move that was critical to the speed with which the final draft was finished—agreed to make their data openly available to the public.

Of all things that scientists could have added to the growing list of sequenced species, though, why did they pick rice? For starters, they knew that rice is the most important cereal crop for half of the world's population. If they could obtain the genetic blueprints for rice, it would enable them to begin mapping traits for yield, disease resistance, and tolerance to environmental stresses like drought and high-salt soils. Pinpointing crucial genes would also make it much easier to transfer beneficial traits into locally adapted lines without having to do the lengthy work of plant-breeding. With traditional crossing, every trait in a parent plant—including those the

researcher may *not* want to transfer—gets thrown into the gene pool. Getting rid of those undesirable traits requires several rounds of “back-crossing”—mating a plant with a pure-breeding recessive plant—before a line is genetically consistent enough to use in a cross. Being able to extract one or two genes from a rice plant, while leaving the rest behind, was something that could only be done with a good sequence map of the genome in hand.

The reason that scientists were keen to sequence rice above the other cereal grasses is that the rice genome is by far the smallest of the bunch. Weighing in at 430 million base pairs—rice is a nice compact bundle compared to corn at 2 *billion* bases (5 times as large), or wheat with a mammoth 16 billion bases (40 times as large). Despite their huge discrepancies in genome size, all the cereal crops—including rice, wheat, barley, rye, sorghum, oat, and millet—display “synteny”, or similar arrangement of genes on their chromosomes. This similarity reflects their shared evolutionary history, and makes it possible to apply information about the rice genome to other cereals with much more DNA.

In many ways, however, genome sequencing is the easy part. As those who have followed the Human Genome Project know, the post-sequencing years are the less dramatic, plug-and-chug years in which scientists attempt to learn what all those genes actually do. This is the science of functional genomics. One common method geneticists use to determine the function of a particular gene is to simply delete it. By using radiation or chemicals, researchers can target an area of the chromosome for destruction, and then look to see how the rice plant is affected as it grows. Another functional genomics tool—one being used by researchers at IRRI—is something called an “introgression line.” This, essentially, is a rice plant that carries a wide range of unique chromosome segments implanted from various commercial rices varieties and wild (non-

cultivated) rices. These chromosomal chimeras enable researchers to see how certain genes affect the overall genetic, biochemical, and physiological systems in the rice plant. Recently, for example, IRRI scientists discovered an introgression line that, despite being starved of water, grew perfectly well and produced ample amounts of grain. From these hardy little plants the researchers were able to isolate a number of proteins that the rice produced in response to drought stress, and working backwards, were able to identify the genes involved. Similar studies have focused on rice's response to salt stress and on the genes that protect rice against insect and disease pathogens.

A third functional genomics method is one that involves "microarrays" or "gene chips." Already commonly in the study of another plant, *Arabidopsis thaliana*, microarrays are small silicon wafers whose surfaces are studded by upwards of 20,000 genes. This chip can be used as a sensor to detect genetic messages that are turned on or off when the plants are exposed to stress. A particular pattern of colored dots on the microarray reveals the expression of genes at any given time, enabling the researchers to identify hundreds or even thousands of genes that combine and interact to achieve a particular function, such as tolerating drought, resisting disease, or producing more nutritious grains. And Dr. Leung, the geneticist who heads the functional genomics team at IRRI, is optimistic about the chips' time-saving potential. "This technology allows us to discover in weeks what would, in the past, have taken maybe two years of work, looking at the genes one at a time."

Ultimately, Leung believes, it will take about ten years for scientists to complete the writing of rice's functional genomics "dictionary." If that seems like an inordinately long time, it helps to consider the magnitude of the task. Unlike the case with humans, the long history of

Oryza sativa has produced an enormous divergence in DNA sequences. There are 50,000 genes in rice, but according to Leung, “the function of each may vary in every rice variety because the genetic background of one is different from that of another.”

Deletion mutants, introgression lines, and gene chips represent the forefront of rice research at the molecular level. But rice science is never far removed from seeds, soil, and fertilizer of the farm. In many ways, the Louisiana Rice Research Station in Crowley sits at the intersection of biotechnology and good old-fashioned farming. “Any new technology, after all, is only useful if the farmer is willing and able to use it,” says Chu. After studying at the Shanghai Academy of Agricultural Sciences and then training for one year at IRRI, Chu opted to settle in Crowley precisely because of its hands-on, application-oriented approach to rice research.

Sipping from a tall glass of Chinese green tea that looks very much like rice straw floating in lake water, Chu sums up his feelings about his work with a story. “I have a twenty-year old son who goes to M.I.T... He was first into computer science, but then switched to biology, so I thought he might like to work here for the summer. *Boy*, was I wrong. ‘Dad,’ he tells me, ‘I don’t know how you do it—the whole day pulling grass, getting weeds up.’ I guess he thought it was boring.”

Chu takes another sip of tea and shrugs. “There are different kinds of life. You either like it or you don’t. Our slogan is ‘we love rice.’”

We love rice. A sentiment probably first voiced by Chu’s ancestors in China several thousand years ago. A sentiment that echoes around the world in languages, cuisines, religions, and social structures. Versatile enough on the ground to inhabit every region of the earth and flexible enough in the kitchen to accommodate a global range of tastes, rice has come be

inseparable from human life. For its part, rice has benefited greatly from this partnership with humans—today *Oryza sativa* boasts a colossal family tree whose branches stretch ‘round the world and whose members are the most prolific of any grain on Earth. As a biological organism whose sole purpose is, evolutionarily speaking, to ensure the persistence of its genes, rice is perhaps the winningest crop species of all time. We love rice, it is true. But we cannot help but wonder if the feeling isn’t mutual.

—NOTES—

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