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QUALITY-PROTEIN MAIZE

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Advisory Committee on Technology Innovation
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This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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Preface

In Latin America, Africa, and Asia, several hundred million people depend on maize for their daily food. For many, it is the main source of dietary protein. Poverty makes it almost impossible for them to afford meat, eggs, or milk, except perhaps on a few special occasions. Some cannot afford even beans or other protein-rich plant foods to supplement the maize. And many raise very young children on foods that are almost entirely derived from maize.

This dependence on a single crop creates a vulnerability in these societies because traditional maize varieties are poor in protein quality. By itself, traditional maize in such high proportions cannot sustain acceptable growth and adequate health, especially in children, pregnant and lactating women, and the sick.

To help rectify this deficiency, researchers have attempted, for about 25 years, to create nutritionally improved types of maize. This effort was stimulated by the 1963 discovery that a little-known mutant maize contained proteins that are nearly twice as nutritious as those found in normal maize. Called "opaque-2 maize," its protein had a nutritive value about 90 percent of that of proteins found in skim milk—the standard against which cereal protein is normally measured.

The implications of this discovery were considered remarkable. It was estimated that adding the opaque-2 gene to the world's maize crop would add 10 million tons of quality protein to the world food supply. That, in turn, was expected to alleviate malnutrition among hundreds of millions of poor people in Latin America, Africa, and Asia.

But in the 1970s many practical problems arose. Compared with ordinary maize, opaque-2 yielded less grain, and its grain weighed less, had higher moisture at harvest, and succumbed more to fungal infections and storage insect infestations. Many users disliked the grain's dull and chalky appearance, having been accustomed to hard and glossy kernels. Most industrial processors objected to the floury texture of the soft kernels, which were more difficult to store and to mill.

Opaque-2's development was then dealt a near-fatal blow when, beginning in 1974, a series of letters and articles appeared in medical and nutrition journals claiming that the world in fact had little or no protein shortage. The human requirement for protein is not high, said the writers, and if people would just eat more of their existing staples, the "protein gap" would disappear. Many nutritionists supported that view, and the fundamental reason for the creation of opaque-2 maize was undermined. By the mid-1970s, interest had declined almost to the vanishing point.

Nonetheless, a few scientists persisted in trying to overcome the technical limitations of opaque-2. A notable effort was that of a small team of maize breeders at the Centro Internacional de Mejoramiento de Maíz y Trigo (CIMMYT). For 10 years, in their laboratories and fields in Mexico, they continued improving the agronomic qualities of the new maize. By the early 1980s, they claimed to have developed experimental varieties with high nutritive quality, high yields, normal moisture content, traditional appearance, and conventional hardness. By 1986, they had, it seemed, fundamentally transformed opaque-2 maize into a maize that was "normal" in all respects except for its superior nutritional value. They called the new variety "quality-protein maize" (QPM).

The purpose of this study is to review QPM's status, to determine whether its previous limitations have indeed been overcome, to consider the potential of this transformation of one of the world's major crops, and to bring an appreciation of QPM—so far little known beyond a limited circle of plant breeders—to a wider audience.

The panel that produced this report met in April 1986 at the CIMMYT headquarters in Mexico. Over a period of three days, panel members interviewed CIMMYT researchers, analyzed details of the QPM data, and traveled to a field research station to examine test plots. The NRC staff then followed up the panel's meeting by contacting other researchers (see contributors' list) and integrating their comments with those of the panel into the current text.

This report is intended mainly for agencies engaged in development assistance and food relief, officials and institutions concerned with agriculture in developing countries, scientists with relevant interests, and corporations involved in cereal science. It is a joint project of two divisions of the National Research Council: the Board on Agriculture and the Board on Science and Technology for International Development (BOSTID). The report continues a BOSTID series that explores promising plant resources that heretofore have been unknown, neglected, or overlooked. This series is issued under the auspices of BOSTID's Advisory Committee on Technology Innovation (ACTI).

Established in 1971, ACTI's mandate is to assess unconventional scientific and technological advances of particular relevance to problems of developing countries.

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- *Triticale: A Promising Addition to the World's Cereal Grains (1988)*
- *Lost Crops of the Incas (In preparation).*

The panel members are grateful to the CIMMYT staff for their assistance and hospitality, as well as for the yield information and other basic data on which this report's conclusions are based.

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1
Malnutrition and Protein Quality

There are between 300 million and 2.5 billion chronically undernourished people in the world today. These are not necessarily the famine-starved, with skeletal limbs and swollen bellies, nor are they necessarily in imminent danger of death. This is a much larger group that is dying slowly—dying because of ignorance rather than famine, malnutrition rather than starvation, dying sometimes amid plenty, and dying at the astonishing rate of 40,000 a day.

Behind this grim statistic are beggars in India, barrio dwellers in Mexico, refugees in Somalia, peasants in Peru, subsistence farmers in Indonesia, nomads in Kenya, and others destitute in almost 100 nations. Many live in sprawling urban slums, ghettos, and shantytowns, but more live in rural areas. Of these, the greatest numbers are laborers or tenant farmers who do not own land, or, if they do, it is a small plot for which they cannot get the seeds, credit, and technical support needed to grow crops profitably.

About 40 percent of all the malnourished are children, and chronic malnutrition is particularly devastating to the young. According to statistics of the United Nations Children's Fund (UNICEF), 28 children die each minute—14 million each year—because of malnutrition and attendant diseases. Yet, because it is continuous and undramatic in a daily sense, malnutrition is often uncomprehended and even unobserved.

Most of the rest of the malnourished are women. And the mother's malnutrition commonly leads to malnutrition in the child. Millions of emaciated mothers are giving birth to emaciated babies, many of whom soon die. The developing world produces more than 90 percent of all the underweight babies born each year. A 1982 World Health Organization (WHO) review of infants in 90 countries concluded that 16 percent—some 20 million babies—were born weighing less than 2,500 grams.[1] In the worst areas, almost one in every three babies was born below this weight.

[1] By region, the proportion of infants with low birth weight was 31.1 percent in South Asia (Bangladesh, India, Iran, Pakistan, and Sri Lanka) and 19.7 percent in Asia as a whole, 14.0 percent in Africa, 10.1 percent in Latin America, 6.8 percent in North America, and 6.5 percent in Europe. WHO, 1984.

Low-birth-weight statistics amply reflect the devastating consequences of malnourishment during and after pregnancy. Babies born weighing less than 2,500 g are three times more likely to die in infancy than are those born weighing more than 2,500 g. Even when they survive, their chances of healthy growth and development are greatly reduced.

THE CAUSE OF MALNUTRITION

Before the early 1970s, most nutritionists viewed malnutrition in developing countries primarily as a problem of protein deficiency. Kwashiorkor, the disease that results in swollen bellies, listlessness, changing hair color, and other manifestations, was attributed to a lack of protein. To publicize the problem, books and papers were written and speeches given. The world, it seemed, had a massive protein deficiency, and an international relief effort was mobilized. Development agencies eagerly supported programs for increasing protein supplies.

But then in 1973 a report from the United Nations[2] lowered the previous protein-requirement figures. People, it now seemed, did not need as much protein in their daily diet as had been supposed. Soon, strongly worded papers appeared condemning the former focus on protein.[3] Malnutrition, it was said, was overwhelmingly due to lack of energy (food calories), not protein.

Many leading nutritionists supported the new view that marasmus (an extreme manifestation of inadequate food energy), rather than kwashiorkor, was really the main problem in global malnutrition. Consequently, there occurred a huge shift in the portrayal of the world's food needs. Learned journals carried statements such as "the protein gap is a myth,"[4] and national and international development agencies were advised to abandon their support of programs aimed at boosting protein production and protein quality. They switched from the creation of better food to the creation of more food. In a sense, the whole subject of nutrition was downgraded and the emphasis instead was placed on agriculture and increasing food-crop production.

However, some nutritionists were not convinced that this was justified, and the deemphasis of protein and food quality touched off controversy. Views became polarized; debates became rancorous. Whether protein or energy is the prime cause of malnutrition in

[2] FAO/WHO, 1973.
[3] See, for instance, McLaren, 1974.
[4] See, for example, Waterlow and Payne, 1975.

developing countries and whether quality is more important than quantity were hotly disputed.[5]

These divisions of opinion arise because malnutrition is a complicated scientific, geopolitical, and economic problem, undergirded by uncertainty and overlain with sociological complexity. Moreover, nutrition itself is a relatively recent science with many areas of disagreement.

In the 1980s, as debate continues over the basic nature of malnutrition, the polarization and rancor seem to be decreasing. Recent publications indicate that the lines dividing kwashiorkor and marasmus are not distinct: both protein and energy are deficient in the diets of the more vulnerable groups in developing countries, and protein and energy are so interrelated that benefiting one benefits the other.[6]

SPECIAL GROUPS

For the world populace as a whole, there probably is no great need to improve the quality of protein. Normal adults have a relatively low demand for protein, and their intake of everyday staple foods probably already overcomes any serious deficiencies. However, superimposed stresses raise a person's protein needs and can push these needs above the levels of normal intake. At that point, protein becomes a root cause of malnutrition. Thus, protein quality can be the limiting factor for pregnant women, nursing mothers, newborn and weaning infants, the elderly, and the sick of all ages.

Actually, these special groups collectively comprise a large part of the populations of Africa, Asia, and Latin America. At any one time, they number hundreds of millions. Despite their heightened protein needs, however, few ever get to eat quality-protein foods such as meat, milk, eggs, or fish. For most, plant products have to be the main protein suppliers: for a great number, it is a cereal; for others, it is a root crop. This is of concern because most cereals are notably low in both protein content and protein quality, and conventional root crops have very low levels of protein.

MALNUTRITION AND QUALITY PROTEIN

Whether the problem is one of food quality or simply hunger, the children are affected most dramatically. Of all the special groups, children—before birth, at birth, during weaning, and in sickness—are the most vulnerable.

[5] The uncertainties revolve around which type of nutrient is more limiting. The point is not that protein or protein quality is undesirable but that in the extreme, when facing a crisis with limited resources, they may not be the most critical factors on which to concentrate.

[6] See, for instance, Hegsted, 1978.

Growing bodies need protein to build muscle and brain tissue and to ward off infections and parasites. Thus, even if an average adult's energy and protein requirements are fully met by eating a cereal, a child's heightened protein requirements may remain unmet. The potbellies and sickness commonly seen among the very poor and ill-fed are tragic indications that this is probably occurring.[7]

Theoretically, it should be possible to overcome this by getting children to eat more. But in practice this is not easy. Malnourished children are usually not ravenously hungry; they seem not to want to eat more. During nutritional trials in Thailand, for example, malnourished children who brought their lunches to a day-care center often would eat less than they brought.[8] In this, and many other cases, food availability does not seem to be the limiting factor.

Why malnourished children do not eat more is uncertain, but it could include several possible reasons:

- Bulk. Most diets in the poorer areas of the Third World are extremely bulky, and a small child's immature digestive system may not be able to process enough food to give an adequate protein and energy supply. (This is especially because the food is often inadequately cooked due to lack of fuel.)
- Monotony. Diets based on a single staple, eaten day after day, may be simply too monotonous to sustain adequate appetite.
- Lack of mother's time. To obtain adequate protein from potatoes, common maize, rice, and many other staples, a child would have to be fed continuously for most of the day. In most areas, mothers do not have sufficient time for this. Furthermore, if the children have poor appetites, mothers are not encouraged to cook constantly.
- Sickness. Although sick people have heightened protein needs, their appetite often fails, generally resulting in reduced intake. (For more on the effects of sickness, see below.)

Whichever reason is the actual cause in a given case, a child's reluctance to eat becomes less serious when the quality of the staple diet is improved. With food of better quality, any amount of intake goes further towards satisfying bodily needs. Moreover, there is good evidence that quality protein stimulates appetite.[9]

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[7] Science should be able to answer this, but the true protein requirements of healthy, preschool children are in doubt, and the protein requirements of acutely malnourished infants are in even greater doubt. At present, there is no scientific proof that children can reach their full potential while consuming any of the major staple foods as their only source of protein. In some regions, children receive inferior foods because of social customs that reserve the best foods for adults, especially working men.

[8] Hegsted, 1978.

[9] See for example, Viteri et al., 1981. Children fed ad libitum a 70:30 mixture of maize and beans consumed more than the same children fed ad libitum a 90:10 mixture.

SPECIAL SITUATIONS

Several situations put even further demands on food quality. In these cases, potential benefits can almost certainly be gained by increasing the protein quality in staple foods. Some examples are:

Where staples are low in protein. Tens of millions of poor people in tropical countries survive on cassava, yams, plantain, and other foods that are so lacking in protein that (even though they may satisfy energy needs) they almost certainly cannot fulfill a child's protein needs. To satisfy its requirements, the child would have to cram an impossible amount of bulky food into a stomach already swollen with digesting starch, and it would get an unhealthy excess of calories.

Where weaning foods are lacking. Of all stages in the human life span, the transition from breast milk to solid food, at ages between 6 and 24 months, is the stage of greatest nutritional hazard. An infant may live well on its mother's milk (possibly at the expense of her nutrition), but then suffer immediate malnutrition on weaning. This is because the foods available after weaning usually cannot match the nutritional qualities of breast milk. Indeed, in most areas there are no weaning foods whatever; babies are switched abruptly from mother's milk to adult foods. For young bodies, frequently fighting off diseases and parasites, these are usually inadequate in quality to sustain adequate growth and health, even when plentiful enough to satisfy hunger.

In some areas, weaning foods are made by combining the local staple with a supplementary protein source, most commonly a legume. In principle, this boosts the protein intake, but in practice, the amounts given are usually small, and the protein has low digestibility. Thus, such supplements fall far short of equaling milk and are usually poorly digested by immature digestive tracts.[10] Although millions of children survive on these weaning foods, their growth can hardly be considered optimal and many become malnourished.

Sickness. In low-income countries, children are often sick as much as 30 percent of their young lives. Millions said to have died from diseases are actually victims of underlying malnutrition. Whereas well-nourished bodies throw off respiratory infections, diarrhea, diphtheria, and measles, malnourished bodies often succumb. In addition, severe diarrhea further burdens intestines already wasted by malnutrition, making them less able to absorb nutrients.

It is a vicious circle: a malnourished child gets a gastrointestinal or bronchial infection or an intestinal parasite; it stops eating; it deteriorates into extreme protein deficiency within a few days (wasting

[10] Throughout Latin America, for example, mothers seldom or never use cooked beans as weaning foods, but sometimes they give the cooking broth to babies 3-4 months of age. Unfortunately, this broth is high in tannins and is poorly digested. When fed along with maize, it even worsens the situation by decreasing the digestibility of the maize. Even milk can have adverse effects because of lactose intolerance in some children. (Information from R. Bressani.)

THE NEED FOR QUALITY PROTEIN

Late in 1987, a research team from three U. S. universities reported their finding that the human requirement for several essential amino acids is higher than previously thought. The team's summary of their conclusions is presented here.

We have undertaken a reassessment of the requirements for the individual indispensable (essential) amino acids in healthy adults. Based on (1) estimates of the obligatory rates of loss of indispensable amino acids; (2) published data on whole body protein turnover and amino acid recycling; and (3) interpretation of results of studies involving measurement of amino acid oxidation rates from ^{13}C-tracer experiments, we have concluded that the requirements for lysine, leucine, valine, and threonine are likely to be about 2–3 times higher than current requirement figures as proposed in 1985 by the Food and Agriculture Organization of the United Nations/World Health Organization/United Nations University (FAO/WHO/UNU). If these revised estimates and approaches for determination of needs are accepted, a new amino acid scoring pattern for the adult can be developed. It is essentially similar to that for the child (age 2–5 years) as proposed by FAO/WHO/UNU, except for a lower threonine and slightly lower lysine content.

Using this new scoring pattern to assess the capacity of diets in developing regions to satisfy human amino acid requirements, we have concluded that lysine is limiting in diets characteristic of a number of countries, such as Nigeria, Guatemala, and Ghana, for example. Furthermore, this new analysis indicates that if common hybrid cereals provide more than about half of the total dietary protein, there is a risk of a dietary lysine limitation. We conclude, therefore, providing our hypothesis concerning the inadequacy of current requirement estimates is correct (and there is now good support for this), that considerations of dietary protein quality and quantity should continue to be an important feature of the design and implementation of food nutrition and agricultural programs and policies.

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protein through catabolic loss), and thus becomes even more malnourished. In turn, the malnutrition heightens the effects of the disease or parasite. To make matters worse, mothers frequently feed sick children a liquid food, often a thin gruel or sugar water, each of which is low in protein and exacerbates the problem.

Catch-up growth. Improving food quality is important for returning malnourished and/or sick people to a normal state. For such catch-up growth, protein needs and essential amino acid requirements are much higher than normal, and thus food quality becomes much more important.[11]

Where animal feeds are inadequate. In many locations animals, too, suffer malnutrition and fall far short of their potential. In some cases—especially with pigs and to a lesser extent with chickens—the use of a quality-protein source could dramatically boost the production and lower the price of meat, milk, and eggs. Thus, indirectly, it would also improve human nutrition.

REACHING THE SPECIAL GROUPS

To improve the nutritional status of the malnourished and to prevent malnutrition from affecting the rest of the vulnerable populace is a daunting challenge. To reach sick children, weanlings, lactating mothers, pregnant women, and others scattered across scores of countries on at least three continents requires various approaches. Broadening the diet to incorporate a wider range of foods is one. Increasing the availability of conventional staples is another. Boosting the nutritional quality of basic staples is yet a third—one that relates directly to the topic of the present report.

Converting a staple food into a form more nutritious than normal would seem, in theory, to have considerable merit. At one fell swoop the nutritious new form can reach all of the special groups in many different and remote areas, and, as a bonus, it may benefit the health of the rest of the population. Thus, as long as there is no agronomic or economic penalty, upgrading the nutritional quality of basic staples seems well worth consideration.

For this reason, therefore, any nutritious form of maize deserves special attention. Of the 300 million to 2.5 billion people who suffer the afflictions of malnutrition, at least half live in countries where maize is a major part of the staple diet.

[11] To allow children that are between one and two years old to grow at twice the normal growth rate, the energy requirement must be raised 4 percent, but the protein requirement must be increased about 30 percent. (See table 53, FAO/WHO/UNU, 1985.)

2
Maize

Maize was the principal food of the ancient civilizations of the Western Hemisphere: the Incas of Peru, the Mayas of Central America, the Aztecs of Mexico, and the many tribes of eastern North America. In the pre-Columbian New World it was the most important cultivated crop, depended on by peoples over a vast area from southern Chile to southern Canada and at altitudes from sea level to 3,300 m.

Before November 5, 1492, the plant was known only to the inhabitants of the Americas. But on that day two of Christopher Columbus's crew, returning from a trip to the interior of Cuba, presented their leader with "a sort of grain" they said the Caribs called maize. The Admiral transported the intriguing seed back to Spain as one of the wonders of the New World.

In this way, maize left its ancestral home and, within a comparatively short time, became an important source of food in scores of tropical, subtropical, and warm-temperate countries.

Today, maize is one of the handful of plants that can be said to support the world's food supply. In area planted, it ranks as the second or third major crop. In 1985, according to the Food and Agriculture Organization of the United Nations (FAO), it was grown on 133 million hectares. It is grown from latitude 40°S in Argentina to latitude 58°N in Canada and the Soviet Union. And it is grown at all longitudes: somewhere in the world a maize crop matures every month of the year (see map, pp. 10–11).

Maize now supports a worldwide business worth $40 billion annually. Moreover, it is rapidly becoming more popular: annual world production almost tripled between 1930 and 1980, and it increased a remarkable 14 percent—from 395 million to 449 million tons[1]—between 1980 and 1985. Most of the crop is used in the country in which it is grown; only about 10 percent enters international trade, yet even this small fraction provides more than two-thirds of the total international trade in feed grains.

[1] Throughout this report, all amounts in tons refer to metric tons.

The maize crop is now so large that its annual production represents about 90 kg of grain for every person on earth. Averaging 9.5 percent protein, it contributes some 42 million tons of protein a year, which represents 15 percent of the world's annual production of food-crop protein (figure 2.1). It also represents 19 percent of the world's food calories.

MAIZE AND THE THIRD WORLD

In many areas of the developing world, maize is a vital staple, particularly for the rural poor. It spread quickly and widely among poor countries because it was robust and highly adaptable to a wide range of environments and because of its many valuable properties. For example, maize:

- Gives one of the highest yields per hour of labor spent;
- Provides nutrients in a compact form;
- Is easily transportable;
- Is protected against birds and rain by its husks;

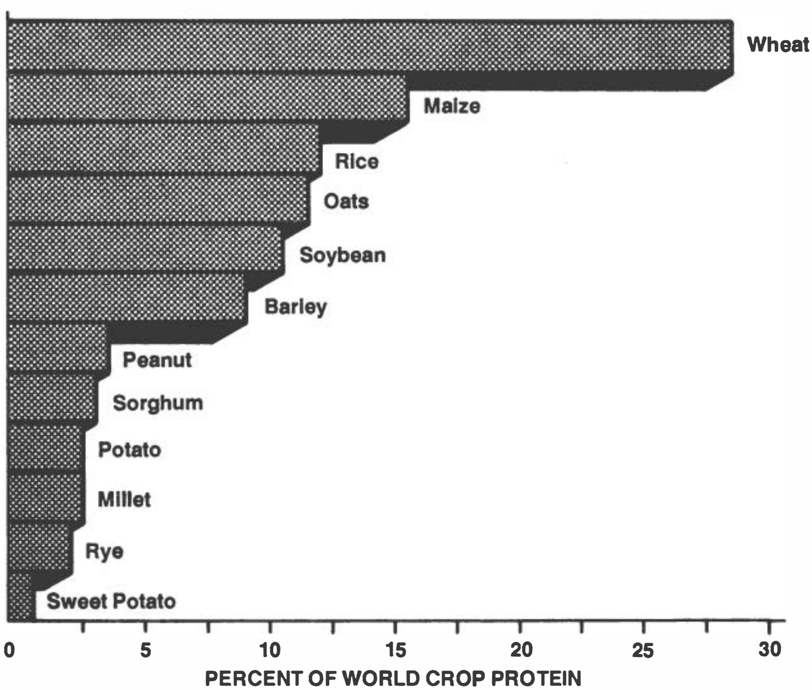
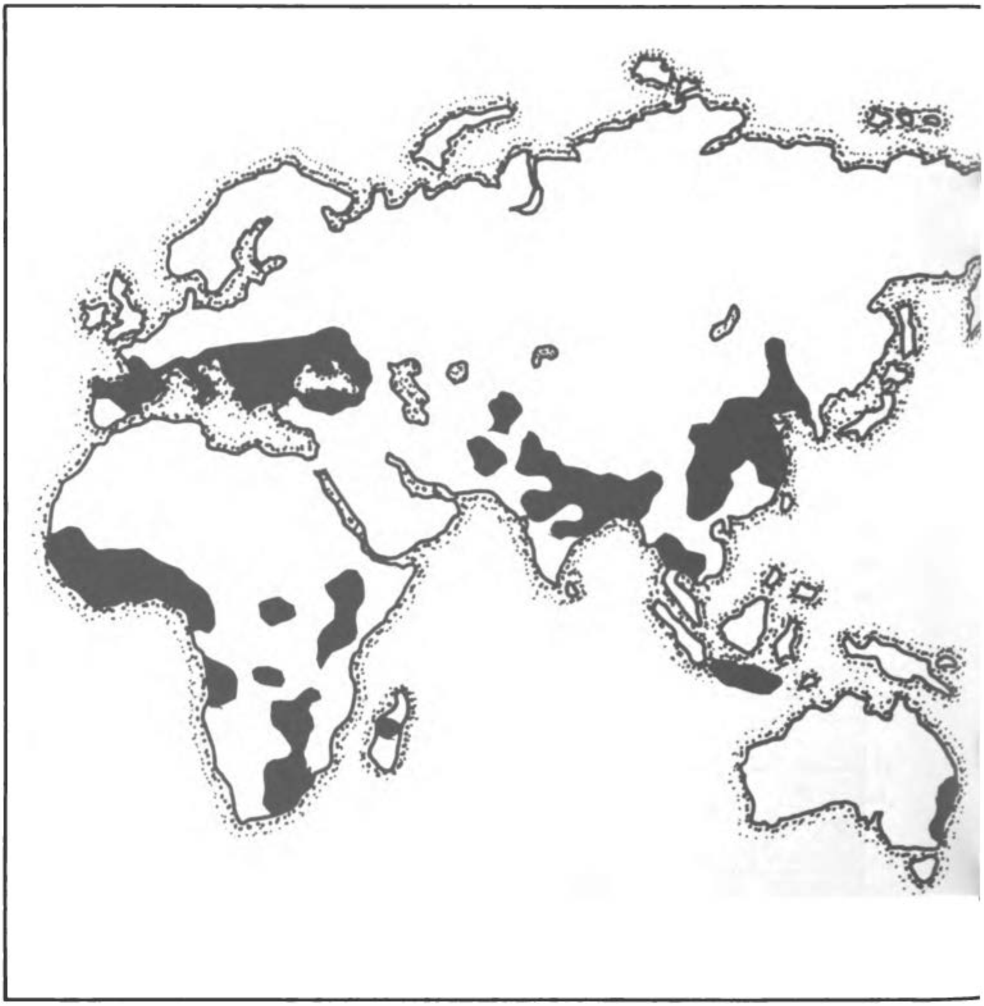


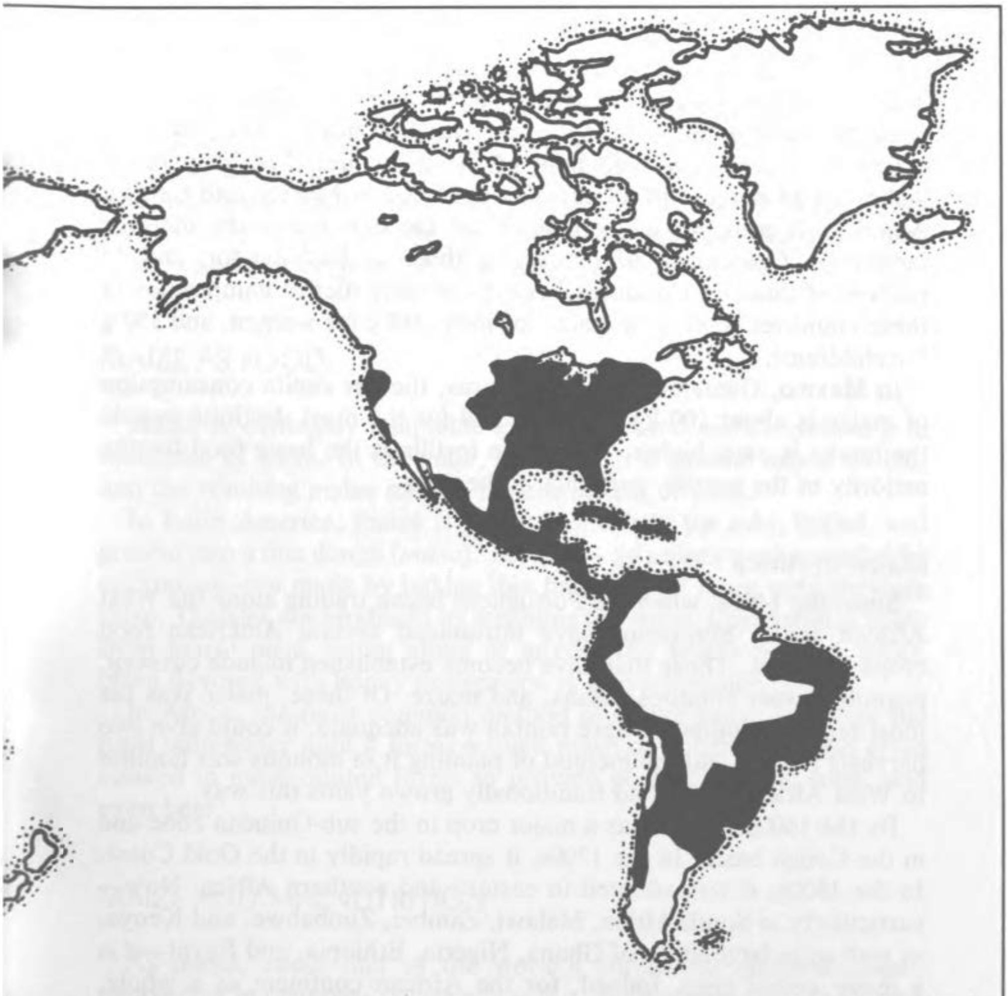
FIGURE 2.1 Maize contributes 15.4 percent of the protein produced by the world's crops—more than any other plant except wheat.



Maize is the most widely distributed crop and the most important cereal in the world after wheat and rice.

- Is easy to harvest and can be shelled by hand;
- Stores well if properly dried;
- Is relatively free of major disease epidemics;
- Competes with weeds better than other cereals;
- Does not shatter and thus can be left standing in the field at maturity; and
- Has cultivars with different maturing periods.

Moreover, maize is one of the most versatile of all agricultural



products, being employed as human food, livestock feed, and raw ingredient for hundreds of industrial materials.

Because of all these benefits, maize became a favorite crop with farmers in scores of developing countries. It is the staple of at least 200 million people in Brazil, El Salvador, Ecuador, Guatemala, Haiti, Honduras, Mexico, Nicaragua, Paraguay, Venezuela, Benin, Ghana, Kenya, Malawi, Nigeria, South Africa, Tanzania, Zaire, Zambia, and Zimbabwe. Maize is also an important food crop in the Mediterranean region, the Middle East, and parts of Asia.

Maize in Latin America

As in ancient times, maize is still the major grain of most of the Americas. Today, farmers in Latin America and the Caribbean plant some 10.2 million hectares of it each year. For much of the populace, maize constitutes the main bulk of the daily diet. For instance, it makes up 85 percent of all cereals consumed in Mexico and Central America. It provides 65 percent of all the calories in the diets of families in Guatemala, 62 percent of those in El Salvador, and 49 percent of those in Honduras.[2] A typical daily diet of campesinos in these countries is 500 g of maize for men, 350 g for women, and 150 g for children.[3]

In Mexico, Guatemala, and Honduras, the per capita consumption of maize is about 100 kg per year, and for the most destitute people the intake is even higher. The maize tortilla is the basic food for the majority of the people, particularly the poor.

Maize in Africa

Since the 1400s, when the Portuguese began trading along the West African coast, Europeans have introduced several American food crops to Africa. Those that have become established include cassava, peanuts, sweet potatoes, beans, and maize. Of these, maize was the most rapidly adopted. Where rainfall was adequate, it could give two harvests a year, and the method of planting it in mounds was familiar to West Africans who had traditionally grown yams this way.

By the 1600s, maize was a major crop in the sub-Guinean zone and in the Congo basin. In the 1700s, it spread rapidly in the Gold Coast. In the 1800s, it was adopted in eastern and southern Africa. Now—particularly in South Africa, Malawi, Zambia, Zimbabwe, and Kenya, as well as in large areas of Ghana, Nigeria, Ethiopia, and Egypt—it is a major cereal crop. Indeed, for the African continent as a whole, maize is probably the leading cereal.

In many African countries, maize is the basic food for subsistence farmers, miners, and city dwellers. In most areas, its importance is as great as that of wheat in the Mideast and rice in Southeast Asia. In fact, Africans consume nearly one-fourth of the world's total food maize.[4] In Kenya, Malawi, Zambia, and Zimbabwe, per capita consumption is about 100 kg per year. In Tanzania, Mozambique, Benin, Togo, Cameroon, and Egypt, per capita consumption is about 40 kg per year.

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[2] INCAP, 1969.
[3] Information from R. Bressani.
[4] Byerlee and Winkelmann, 1981.

Maize in Asia

In most of Southeast Asia, where conditions are suited to paddy rice, maize has never been more than a secondary cereal. But where climates are too dry for paddy rice, it has become important—for instance, in parts of Pakistan, India, China, Indochina, the Philippines, and Indonesia. Today, maize is second only to rice in most Asian countries. In Nepal and the Philippines, for example, the per capita maize consumption is about 40 kg per year.

MAIZE AS FOOD

Maize is extremely adaptable and is prepared and consumed in a multitude of ways. In the main, however, it is ground and pounded, and the resulting maize meal is boiled, baked, or fried.

In Latin America, maize is steeped with lime (or ash), boiled, and ground into a fine dough (*masa*). Tortillas—an unleavened pancakelike cornbread—are made by baking thin flat cakes of *masa* until they are crisp. Tamales are produced by steaming the *masa*. Cornbread is made from maize meal, either alone or mixed with wheat flour. A gruel, often flavored with honey or peppers, is also consumed.

In Africa, the most common method of eating maize is to boil the meal with water until it forms a thick mush or dough. It is also often cooked in more diluted forms to provide porridge, gruel, soup, and even beer.

MAIZE AND MALNUTRITION

As noted, about half of the world's chronically undernourished people live in countries where maize is a staple (figure 2.2). In Central America, for instance, poverty-stricken adults commonly consume only maize. A typical diet consists of 20 or more tortillas a day, supplemented with hot peppers, some native greens, and little or nothing more (table 2.1). Many children of the poor also eat few nutritious solid foods, and when they do, the amounts are small.[5]

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[5] For example, a 3-year-long analysis in the poorest town in Guatemala showed that during their first year of life only a few children got any of the most nutritious foods. Moreover, when they did get nutritious foods, the amounts being ingested were very small. Out of 45 8-month-old children, only 2 consumed cow's milk (averaging 32 g each per day), only 2 consumed eggs (less than 1 g each), and none got meat or beans. By the time they were 11 months old, only 1 was drinking cow's milk, 16 were getting eggs (merely 5 g), 24 were getting meat (averaging less than 1 g), and 2 were consuming beans (also less than 1 g). (Garcia and Urrutia, 1978.)

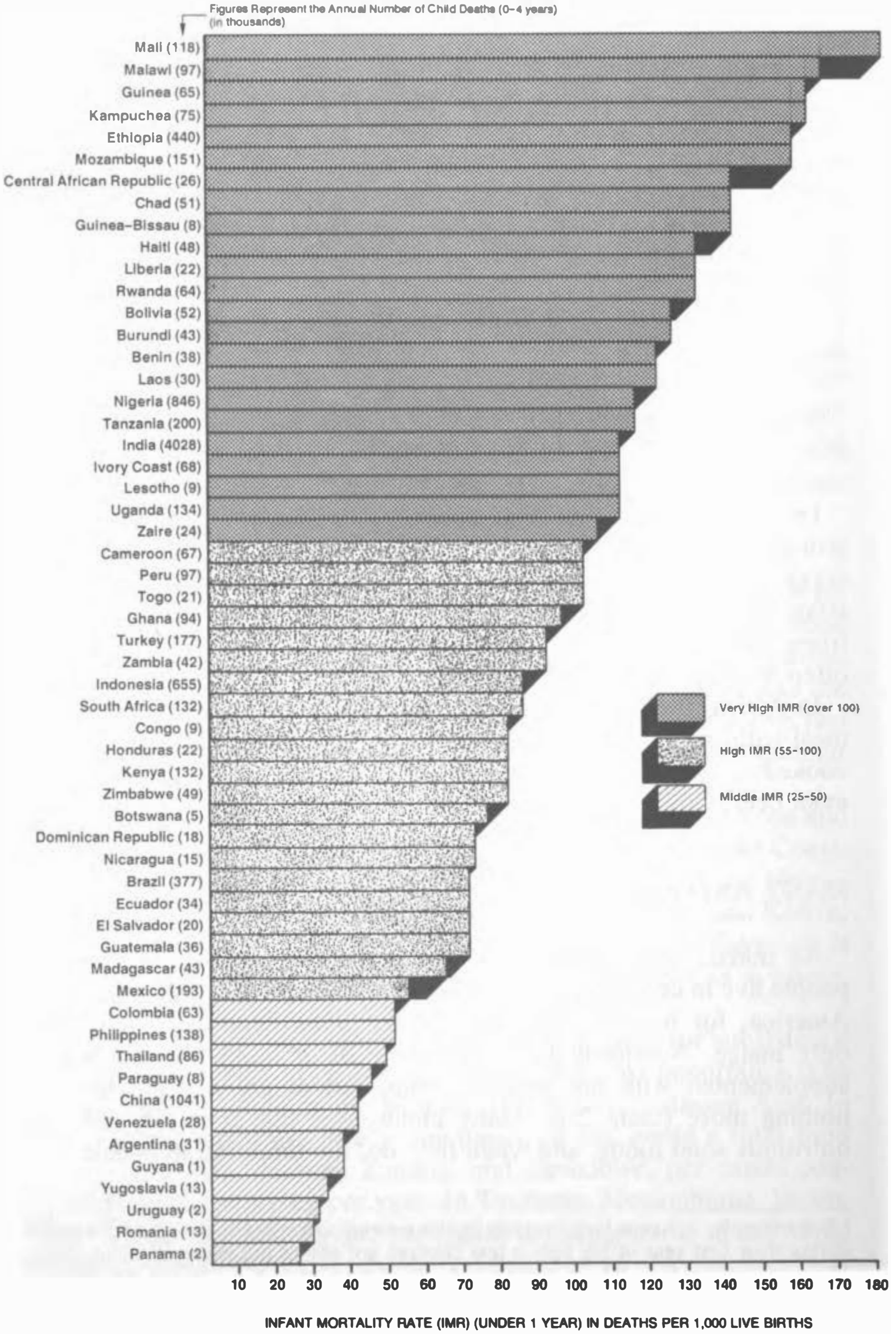

FIGURE 2.2 The infant mortality in some maize-growing countries is extremely high. Collectively, these countries account for more than 10 million deaths a year due to malnutrition. (UNICEF, 1985. [Figures are for 1983.])

This is of concern because maize is low in protein quantity and protein quality, both of which are insufficient to satisfy the protein needs of the special groups that are most vulnerable to malnutrition. The prevalence of protein-calorie malnutrition among village and slum children in dozens of African and Latin American countries demonstrates the underlying inadequacy of maize-dependent diets.

As noted, maize kernels contain, on average, only about 9.5 percent protein—a low figure compared with legume seeds such as beans (23 percent), peanuts (26 percent), or soybeans (38 percent). But an even more serious limitation is maize protein's low levels of two nutritionally vital amino acids, lysine and tryptophan. Both are essential amino acids that people (and other simple-stomach animals such as pigs and poultry) must obtain from food because they cannot synthesize them for themselves. Roughly half of the protein in a kernel of common maize is composed of protein types that contain almost no lysine or tryptophan.

Maize is deficient in an important vitamin as well. It is low in available niacin, and bodies deficient in this B-vitamin develop pellagra. First described after maize was introduced to Europe, pellagra (characterized by dermatitis, diarrhea, and dementia) spread widely throughout most of the maize-dependent regions of the world. (It is also found in sorghum-dependent populations in southern Africa, East Africa, Sudan, India, and elsewhere because sorghum, too, lacks biologically available niacin.)

TABLE 2.1 Average Daily Food Consumption (in grams) for Three Population Groups in Santa María Cauqué, Guatemala 1964–1972.[a]

Type of food	Weaned children at 3 years of age	Women in third trimester of pregnancy	Mothers in third trimester of lactation
Tortillas (maize)	226	595	666
Vegetables	41	53	35
Sugars	29	83	58
Beans	27	56	43
Bananas	17	7	2
Fruits	14	15	24
Breads	14	30	21
Rice & pasta	7	9	8
Eggs	8	7	8
Meat	6	21	15
Cow's milk	2	0	0
Fresh cheese	0	2	2
Coffee	2	5	5
Fats/oil	0	1	3

[a] This analysis of the food intake of three population groups during a period of six years shows the huge dependence on maize as a basic food as well as the low intake of food products from animal origin. Maize is the cheapest cereal in the area, is produced locally, and contributes 47 percent of the calories of the diets of preschool children and around 60 percent of those of pregnant and lactating mothers.

SOURCE: Garcia and Urrutia, 1978.

MAIZE AND PELLAGRA

Since maize is deficient in lysine, tryptophan, and niacin, how did the American Indians escape pellagra when maize was their principal food for thousands of years?

The answer is that throughout much of the Americas the Indians prepared their maize using lime. For example, tortillas are prepared by cooking the dried kernels in a weak solution of lime water (made from wood ash, shells, or other sources) for at least half an hour before they are ground to yield the dough. Modern research has shown that this frees up the small amount of niacin that is otherwise unavailable to humans. Liming also supplies calcium, an essential mineral.

Indians were undoubtedly unaware that their method for preparing maize increased its nutritional value; the procedure was probably adopted because they found that the hard kernels were softened by the lime water and could be ground more easily. However it happened, it was a happy discovery.

Although still occurring where diets are unduly dependent upon maize, the acute form of pellagra has vanished from most of its former range. Since World War II it has been found only occasionally. Nonetheless, chronic pellagra, even at a low level, is a threat; any disruption in food supply can cause it once again to become a scourge. Forced migrations, crop failures, import restrictions, civil disturbances, wars (of which there were 40 in 1986), and natural calamities all can reduce the availability of dietary ingredients that now (barely) keep the disease suppressed. Such disruptions force people back on a subsistence diet, and where maize or sorghum are staples, pellagra will emerge once more.[6]

MAIZE AS FEED

During its worldwide dispersal, maize became the world's chief animal feed. Today it provides more feed than any other grain. For this purpose, it is outstanding: high in energy, low in fiber, and easily digested by most livestock species. Industrialized countries, such as the United States, use their maize crop mainly as feed and depend on it to produce their meat, milk, and eggs. (If one includes these animal products along with direct consumption by people, maize actually provides the United States with more food than any other crop.)

[6] For a review, see Stratigos and Katsambas, 1977. One major cause of present-day pellagra is alcoholism.

The grain is fed mostly to pigs, cattle, and poultry, but also to sheep. The plant's stems and leaves are also an important forage, and are fed green, dried, or ensiled.

In developing nations—where, by the year 2000, some 60 percent of the world population is projected to live (or hope to get enough food to live)—no more than 3 percent of available cereal grains goes into animal feed. But this is beginning to change, and the amount of grains that developing countries divert to animals is expected to increase to much higher levels in coming decades.

3
Nutritionally Improved Maize

OPAQUE-2 MAIZE

Not until 1963 was there much hope of boosting maize's levels of lysine, tryptophan, and available niacin. That year, three Purdue University scientists—Edwin T. Mertz, Oliver E. Nelson, Jr., and Lynn S. Bates—were searching for maize kernels (actually endosperms) high in lysine. Using the recently developed automatic amino acid analyzer, they found one mutant maize that had about twice the normal levels of lysine and tryptophan. This "new" maize produced soft, opaque kernels instead of the hard, transparent ones typical of most maize grown in the world (figure 3.1), but its composition would make it extraordinarily nutritious by comparison with normal maize. The new maize, called opaque-2,[1] had the same amount of protein as conventional maize,[2] but its protein contained not only twice the normal levels of lysine but elevated levels of tryptophan as well.

News of this discovery came at a time when protein malnutrition and "the protein gap" were among the most discussed world problems. It energized nutritionists, plant breeders, and decision makers. In opaque-2 maize they saw, for the first time, a way to raise the nutritional quality of a vital cereal food.

All around the world, maize breeders began transferring opaque-2 genes into local maize varieties, and they enthusiastically rushed the

[1] It was named opaque because, when placed over a light box, its kernels appear dark; normal, vitreous maize kernels are transparent enough to allow light to pass through. It was designated "2" because it was the second mutant that researchers had discovered in the opaque group. It was sometimes known as "high-lysine" maize, a partial misnomer because it is also high in tryptophan and its nutritional benefits far exceed those provided by lysine alone.

[2] Throughout this report, the protein referred to is that of the endosperm rather than that of the germ or whole kernel. The nutritional quality of the germ is roughly the same in both common maize and nutritionally improved maize. The opaque-2 gene influences only the protein of the endosperm, the major source of protein in the kernel. Early forms of opaque-2 maize had an unusually high proportion of germ because their endosperm was shriveled; current versions have plump endosperm and a proportion of germ like that in normal maize.

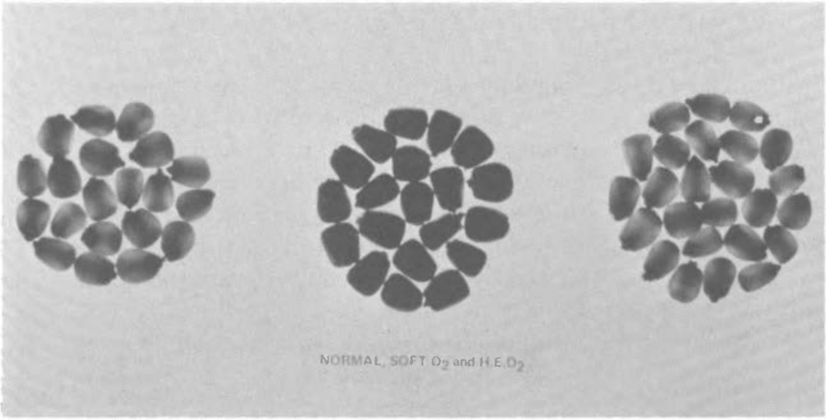

FIGURE 3.1 Opaque-2 maize (center) differed from normal maize (left) in having soft, chalky kernels rather than hard kernels. QPM (right), on the other hand, has the "normal" hardness. (J. Kinney)

new crop into production. Soon, opaque-2 varieties were being marketed in Brazil and Colombia; vigorous research programs were under way in Eastern Europe and the Soviet Union; and opaque-2 production in the United States rose from essentially nothing in 1970 to an estimated 240,000 tons in 1975.

From the beginning, feeding trials indicated that the new maize could significantly improve protein-deficiency malnutrition as well as prevent pellagra. For instance, a Colombian pediatrician, Alberto G. Pradilla, fed the new maize (under controlled metabolic observation) to seven children who were in advanced stages of malnutrition and near death. One six-year-old weighed no more than a normal two-year-old, and had skin lesions, a swollen body, no appetite, and severe diarrhea. One five-year-old was in the same state; his hair, reddened and brittle, could be plucked out by handfuls. After merely two weeks of eating opaque-2 maize, both children were improving; body swelling had subsided, diarrhea had ceased, and weight had started to increase. Within 100 days they had recovered and looked normal.[3]

However, as is common in plant breeding, the desirable characteristics of the new crop turned out to be closely associated with undesirable ones. The opaque-2 grain was chalky, not shiny, as is preferred in most regions. Moreover, its ears were small; its yields were 8–15 percent lower than those of traditional maize varieties; it was more susceptible to fungi and insects, both in the field and in storage; and it dried more slowly. In addition, the opaque-2 kernel

[3] Pradilla et al., 1975; Harpstead, 1971.

weighed less than normal because air spaces surrounded its loosely packed starch granules.

Soon came disillusionment; opaque-2 maize began losing its appeal. Hardly anybody seemed to like it. Farmers refused to grow it because of its poor field performance—even where governments provided subsidies to encourage its cultivation. Millers resisted handling it because of its poor storage characteristics—regardless of the premium price they could charge. And consumers would not buy it because of its soft, floury texture and unconventional appearance—despite its nutritional benefits.

By the late 1970s, opaque-2 maize had been discredited.

QUALITY-PROTEIN MAIZE

Despite almost universal abandonment, research to improve opaque-2 maize continued at the Centro Internacional de Mejoramiento de Maíz y Trigo (CIMMYT), near Mexico City.[4] For more than a decade, maize breeders and chemists at this international research center, which was established to improve the performance of the world's maize and wheat, tried one approach after another.

Eventually, they settled on the process of combining the opaque-2 gene with genetic modifiers—genes that themselves do not express a trait, but that influence the way a major gene expresses itself. The main thrust was to use genetic modifiers to harden kernels, to make the endosperm transparent, to raise yields, and to make the grain dry faster.

Over the last decade, this approach has brought about a slow but continuous improvement in the qualities that should raise its consumer acceptance, as well as in the traits that should raise its farmer acceptance. All of this had to be done without losing the nutritional value.[5] The key was the development, by Evangelina Villegas, of analytical methods so sensitive that tissue could be sampled from a single kernel without damaging its ability to germinate. With this, individual kernels that showed desirable nutritional and agronomic traits could be both identified and propagated.

The research has produced a new class of maize that combines the nutritional excellence of opaque-2 maize with the kernel structure of

[4] A few researchers at other institutions also maintained their faith and continued opaque-2 studies (see sidebar).

[5] This demanded close coordination between the plant breeders making the selections and the biochemists making the nutritional analyses and is one of the best examples of cross-disciplinary research cooperation that can be found.

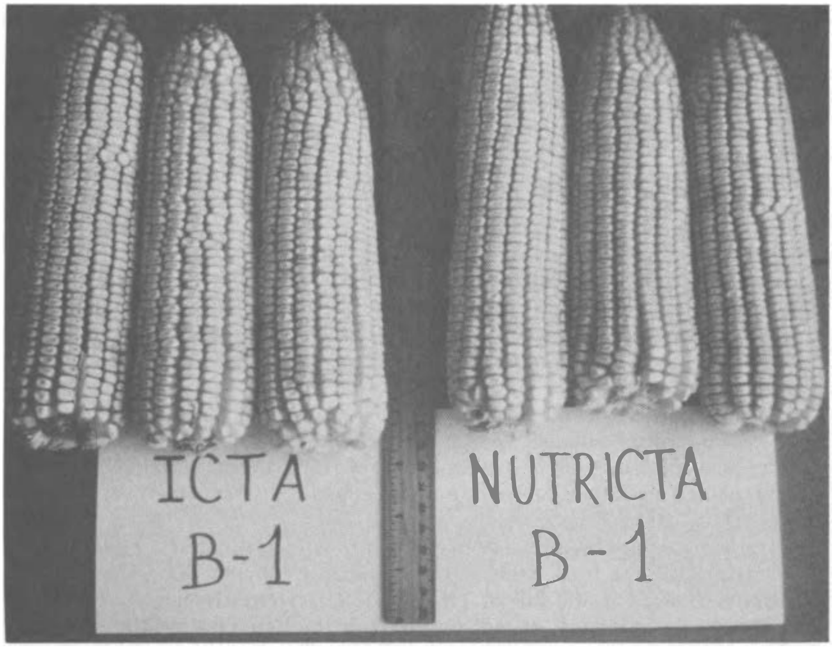

FIGURE 3.2 Ears of QPM (right) are now indistinguishable from those of normal maize (left). (ICTA)

conventional maize varieties (figure 3.2). CIMMYT labeled the new type "quality-protein maize" (QPM).[6]

The basic QPM germplasm now at CIMMYT comprises about 30 experimental populations with widely different adaptabilities, maturities, and grain types. It includes both white and yellow grain types.

This germplasm resource is now beginning to generate interest among researchers and industry. In 1987, for example, agronomists in 40 countries requested seed for 127 experimental trials. As a result, QPMs are in formal international trials in most parts of the world. In addition, four QPM varieties have been commercially released in the developing world: Nutricta in Guatemala, Nutri-Guarani-V241 in Paraguay, Tuxpeño 102 in China, and Population 63 in Vietnam. Other varieties have been released in Eastern Europe.

This rising enthusiasm for QPM is reminiscent of that for its predecessor, opaque-2 maize, some 20 years ago. Thus, it is important to assess carefully how QPM measures up in the qualities that led to the previous failure.

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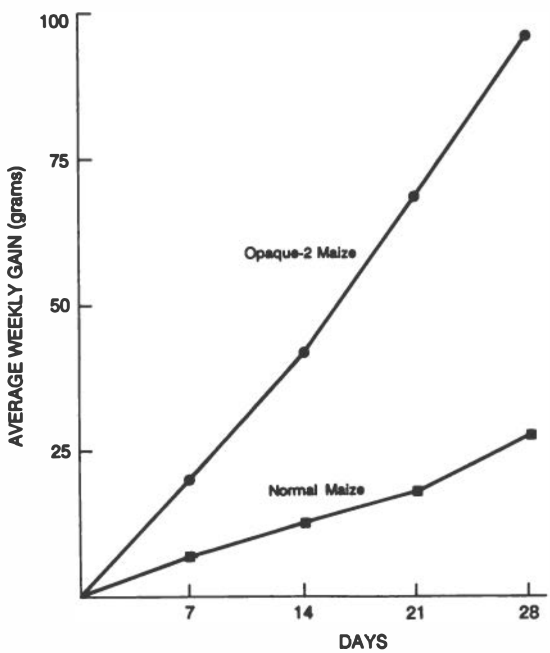
[6] Despite the emphasis on hardening the endosperm, some work still continues with opaque-2 (now called soft-endosperm QPM or QPM-SE). This is because in a few regions, notably the high Andes, soft, floury maize is preferred over the hard type that is popular elsewhere.

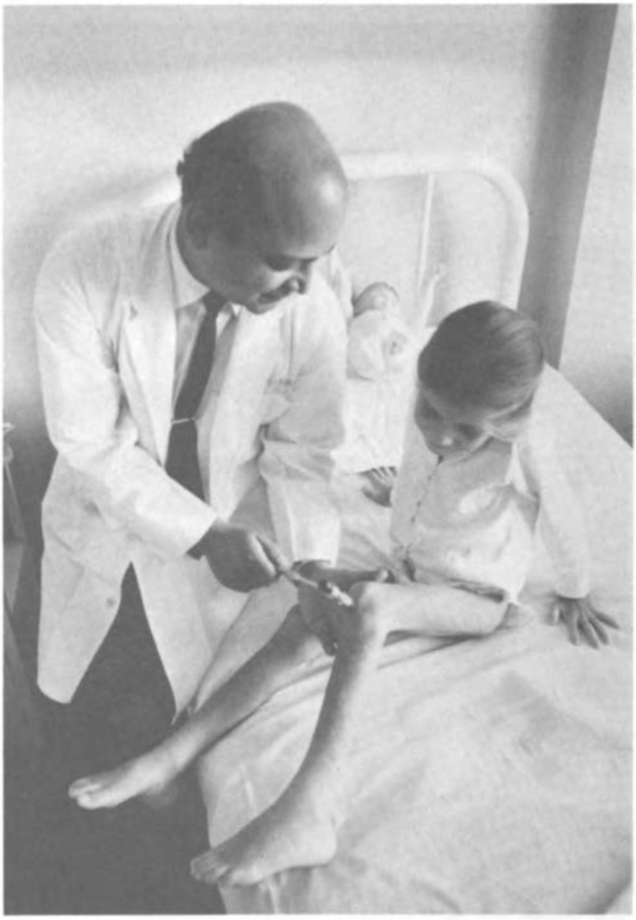
The first demonstration of the nutritional quality of opaque-2 maize came from rat-feeding studies conducted by Edwin Mertz, Oliver Nelson, and graduate student Olivia Veron in 1964. The following is Mertz's description.

The first feeding test was made with about 3 kg of opaque-2 popcorn. The popcorn was ground and incorporated into a diet containing 90 percent popcorn, 5 percent corn oil, 4 percent mineral mixture, and 1 percent vitamin fortification mixture. This ration was compared with one containing the same amount of one of our best hybrids, Indiana 257. Six weanling albino rats were placed on each diet. At the end of 28 days, the average individual gain of the rats on the opaque-2 popcorn was 86 g, that of the animals on Indiana 257, 23 g, a 3.7-fold difference.

In the photograph, the animals on opaque-2 popcorn are shown on the right, the control animals on the left. They are arranged in descending order according to weight. The smallest rat fed opaque-2 popcorn (bottom right) gained more than twice the amount gained by the largest rat receiving Indiana 257 (top left).

The results with opaque-2 popcorn were very exciting, and we immediately repeated the tests using our small supply (about 3 kg) of opaque-2 maize harvested in the fall of 1964. The diets were identical with those used with the popcorn, except that another high-quality hybrid, Indiana 453, replaced Indiana 257. The graph shows the growth curves obtained in this feeding test. In 28 days, the individual average gains on opaque-2 maize were 97 g, and on Indiana 453, 27 g, a 3.6-fold difference.





Ted Spiegel

An early demonstration of the nutritional quality of opaque-2 maize for humans came from trials in which it was fed to malnourished children in Colombia. The photographs show one child before and after the trial. The following description was reported by Francis C. Byrnes of the Rockefeller Foundation, the project's sponsor.

Nine-year-old Ana Ruth did not know why her aunt had left her in the hospital. But her younger brother had died at home just two weeks before, and her aunt, already overburdened with caring for her own five children, decided to let the University of Valle's hospital worry about the little orphan girl's final care and burial. Her condition was critical. She was suffering not only from serious protein deficiency, but also from pneumonia, which frequently occurs in victims of malnutrition. In the Metabolic

Ted Spiegel

Unit, Dr. Alberto G. Pradilla and his staff took over. As they treated Ana Ruth for pneumonia, they also placed her on a minimum-level protein diet, watching carefully the sodium-potassium balance in her system so as to avoid the risk of sudden death from additional strain on the heart.

Ana Ruth responded rapidly. She lost almost one kilogram of water a day for three consecutive days, and the bloating and swelling abated. Once she was on a recovery diet, her abnormal hair fell out, and her head began to sprout a fuzz promising a luxuriant growth of silky black hair.

Ana Ruth is one of seven critically malnourished children restored to health at the university's hospital. She and the other six children quickly achieved a normal nutritional balance on a diet using maize as the protein source—not ordinary maize, but the newly developed quality-protein maize called "opaque-2."

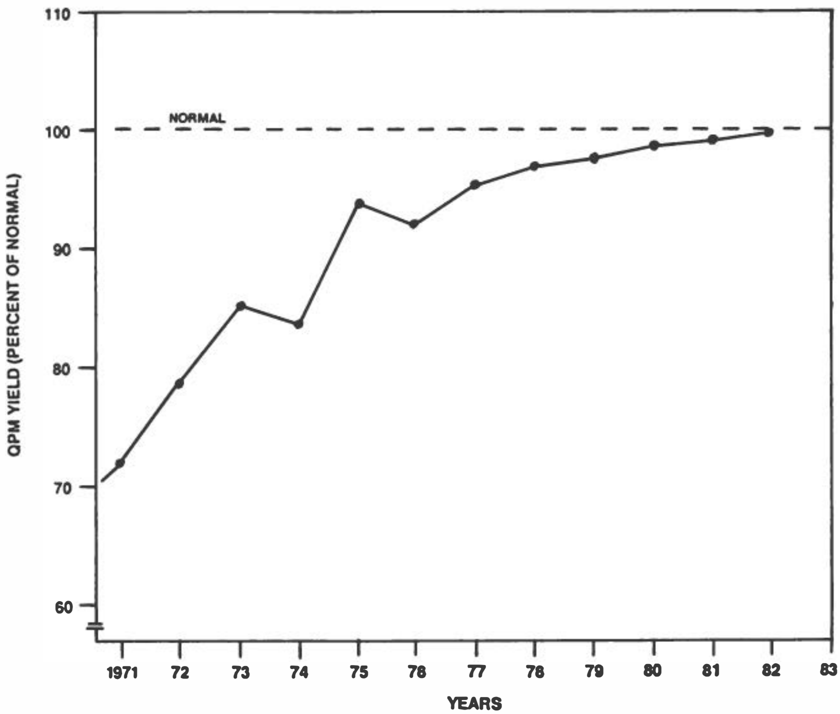


FIGURE 3.3 Grain yields of nutritionally improved maize have been rising steadily for more than a decade and are now essentially equal those of normal maize. The figure is based on international trials expressed as a percentage of normal-maize check in different years across more than 10 test locations in various parts of the world. Both types of maize were treated identically, and the normal check was usually the top-yielding commercial variety of the test location. (CIMMYT)

Yield

Of all the features that held back opaque-2 maize, low grain yield was the most crippling. CIMMYT's most significant advance in its 16 years of work on QPM has been to overcome this. Today, within the range of experimental error, certain QPM genotypes can equal the yields of the conventional maize varieties now under cultivation in developing countries (figure 3.3). Indeed, during the growing seasons of 1983, 1984, and 1985, several experimental QPM varieties performed better than the normal-maize checks in several regions of the world. In some cases they equal the yields of the latest experimental releases of normal maize.

Some examples follow:

Mexico. In Mexican experiment stations, QPM yields have been as high as 6,900 kg per hectare. Indeed, three open-pollinated QPM

OTHER PIONEERS

In this report we have concentrated on CIMMYT's conversion of the soft opaque-2 maize to hard endosperm QPM. This has led to the form of nutritionally improved maize that is most likely to be released into Third World production for food use. However, a few other researchers continued studying the original opaque-2 maize.

In the United States, these were notably at U.S. Agricultural Experiment Stations (at Purdue University as well as at the universities of Illinois, Kansas, and Missouri). In addition, Crow's Hybrid Corn Company of Milford, Illinois, has been working on opaque-2 maize for more than 15 years and now sells a number of hybrid varieties. Trials with them at the University of Nebraska have yielded promising results in pig rations (appendix A).

Elsewhere, opaque-2 programs continued in Germany (University of Hohenheim, Stüttgart), Italy (Istituto Sperimentale Cerealicoltura, Bergamo), and Yugoslavia (Maize Research Institute, Belgrade). South Africa has conducted a particularly noteworthy effort at the Department of Agriculture in Pietermaritzburg and in 1987 released a hybrid for commercial use (chapter 8).

varieties (La Posta QPM, Obregon 7740 QPM, and Tuxpeño-1 QPM) gave yields close to those of two hybrids and one open-pollinated variety, all of which are widely used commercially. In trials at more than 20 locations around the world, Mexican QPM varieties have shown yields fully comparable to those of common maize—the actual performance of seven samples were 98, 110, 107, 105, 100, 97, and 95 percent of the control (see figure 7.2).

Guatemala. In Guatemala, where tests have been extensive, QPM yields have equaled or exceeded those of open-pollinated varieties of common maize in virtually every recent trial. In one, the newly released QPM (Nutricta) and the most popular normal-maize variety in Guatemala (ICTA B-1) were compared. Nutricta yielded 4,211 kg per hectare; the normal maize yielded 4,217 kg per hectare. In another, Nutricta equaled the yield of Guatemala's best experimental varieties of (open-pollinated) common maize as well as of some leading commercial hybrids (see figure 8.2).

China. In China, the yields of one QPM variety (Tuxpeño-H.E.o_2) have been as high as those of its normal-maize counterpart (Tuxpeño-1).

These encouraging observations suggest that the yield limitations of opaque-2 maize have been overcome in at least some genetic backgrounds. Indeed, even if QPM may not ever be fully equal to normal maize on all sites, the overall differences already seem too small to preclude it from being commercially competitive in many locations.

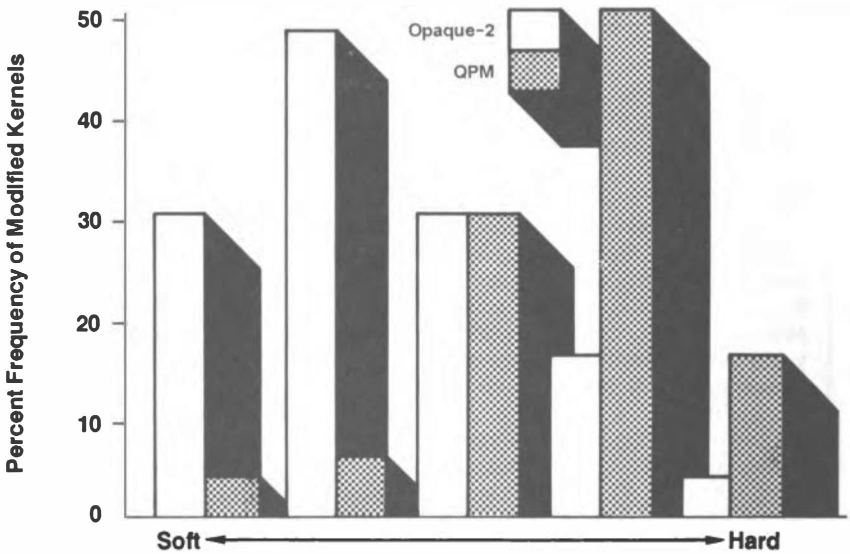


FIGURE 3.4 As maize breeders at CIMMYT took opaque-2 maize through nine generations they changed the preponderance of soft endosperm (clear bars) to a preponderance of hard endosperm (stippled bars). The figure shows the percent frequency of modified kernels. The ratings are based on a scale of 1 (completely soft) to 5 (completely hard). (Based on data in Vasal et al., 1984a)

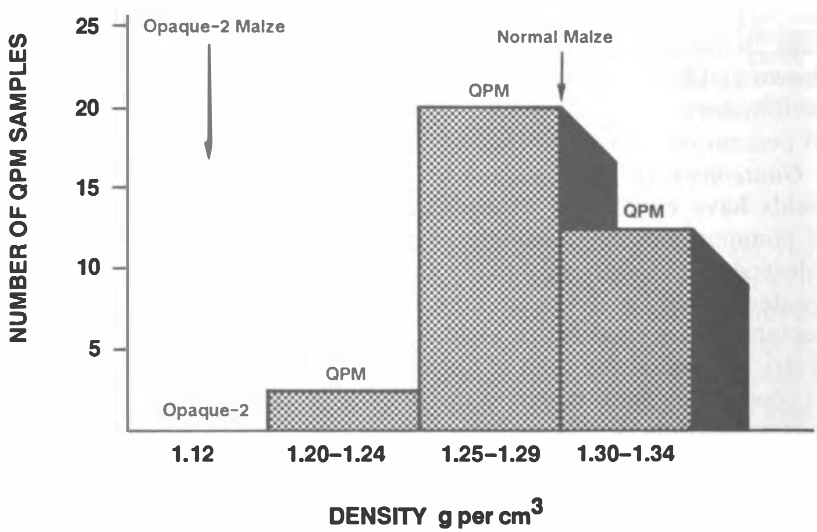


FIGURE 3.5 QPM kernels now mostly have the density of normal maize (1.29), and differ greatly from the density of opaque-2 maize (1.12). The denser packing of the starch granules now makes the endosperm hard. The graph shows the frequency distribution of grain density in 31 QPM populations. (Protein Quality Laboratory, CIMMYT)

Kernel Type

The conversion of opaque-2 maize into QPM has drastically changed the kernel structure. Overall, it can be said that the trait for soft, opaque, floury endosperm has, for all practical purposes, disappeared. In contrast to opaque-2 maize's chalky and dull appearance, QPM kernels are shiny and transparent like those of traditional (flint or dent) maize varieties (figures 3.1, 3.2).

The density has increased as well. QPM kernels are just as hard as those of maize traditionally grown throughout most of the world. Their endosperm cells are tightly packed, there are few air spaces around the starch granules, and in any given batch there are virtually no soft kernels (figures 3.4, 3.5).

As a result, kernel texture and density no longer seem to be factors restricting acceptance by farmers, millers, or consumers. Moreover, with the improved hardness, QPM can be harvested and handled by conventional machinery without the kernels being crushed or cracked.

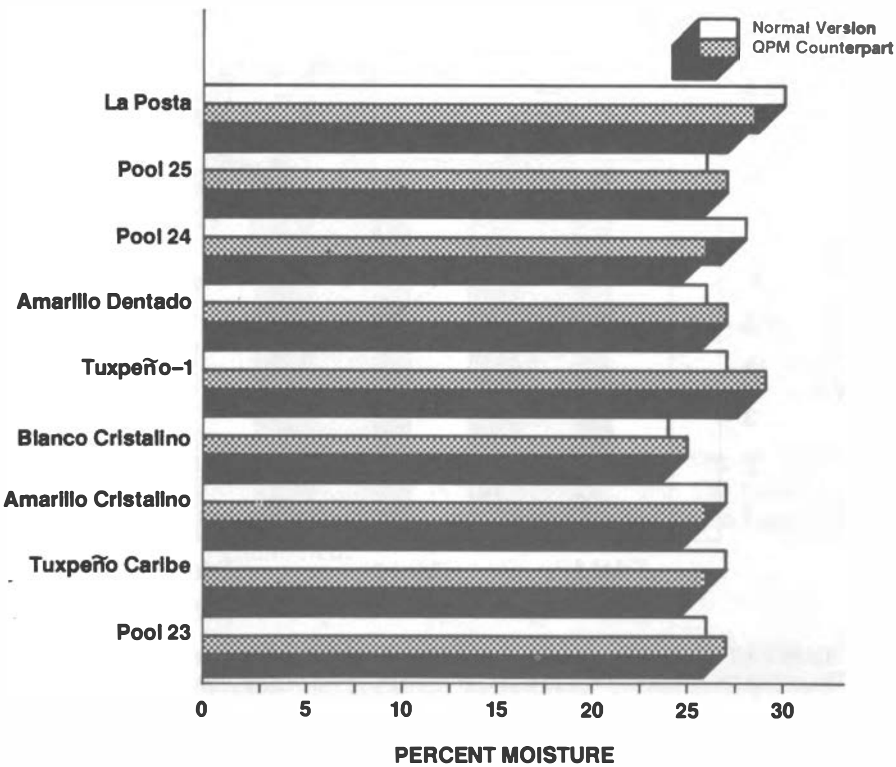


FIGURE 3.6 The moisture content of normal and QPM versions in the same genetic backgrounds is now essentially identical. These moisture levels were recorded at Poza Rica in 1977. (CIMMYT)

Moisture Content

Excessive moisture at the time of harvest plagued opaque-2 maize. Its kernels were generally 2–4 percent higher in moisture than were those of traditional maize. This meant that it required additional drying after harvest, and that it was more likely to become moldy.

Early on, CIMMYT researchers noticed that different opaque-2 strains dried at different rates. By tagging plants that flowered (silked) at the same time and by measuring the relative rates at which these dried down at harvest time, they could select ears that dried faster than average.

As a result, QPM varieties now have little of the slow-drying characteristic that limited opaque-2. Today's QPM dries at a rate comparable to that of normal maize (figure 3.6). The dry-down time no longer seems to be a barrier.

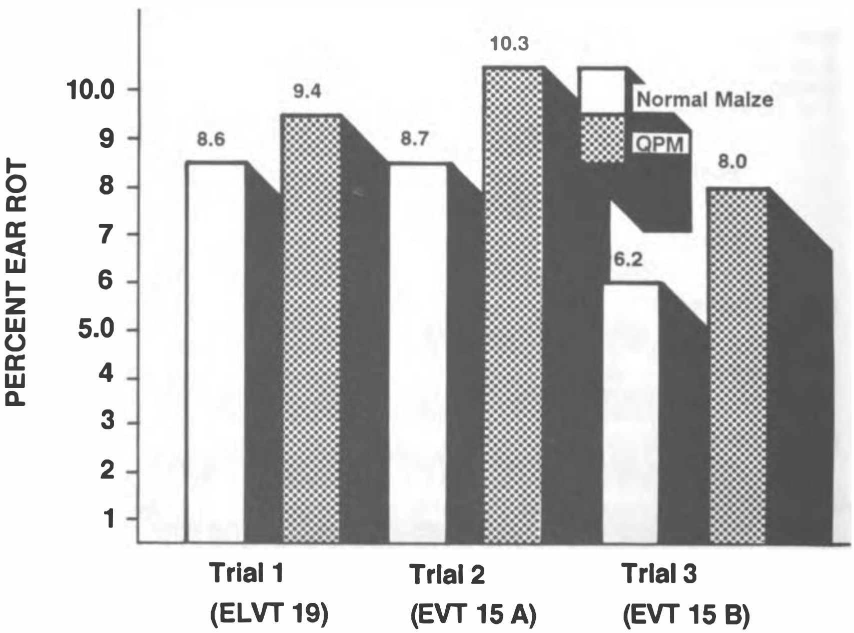


FIGURE 3.7 The ear-rot resistance of QPM materials has been improving gradually. This results from improvement in kernel phenotype, better drying following physiological maturity, and reduced frequency of genes responsible for pericarp splitting. It also derives from population improvement involving selection for resistance under natural and artificially induced disease conditions. The figure shows ear-rot incidence of QPM compared with the best normal-check maize entries in three different trials under severe forcing conditions. On average, the QPM materials still show higher incidence of ear rots but not disastrously so, even under these worst-case conditions. (Vasal et al., 1984b)

Disease Resistance

As noted, the soft, nutritious, higher moisture kernels of opaque-2 maize fostered fungal growth. In particular, the crop was more susceptible to "ear rots" than normal maize. To speed up the incorporation of mold-resistance, CIMMYT scientists created artificial infections. They cultured ear-rot fungi in the laboratory, and then injected the spores into developing maize ears. Also, they grew QPM at humid tropical locations where ear rots are naturally prevalent, even on normal maize.

Under these forcing conditions particularly good progress has been made. Although ear rots still affect QPM materials more than their normal counterparts, susceptibility is decreasing generation by generation (figure 3.7).

In most locations, fungal infections are now usually no worse than in common maize varieties. Only in humid regions where ear rots are exceptionally severe are the differences still noticeable.

Resistance to fungal disease has increased partly because QPM kernels are harder and dry more quickly than those of opaque-2. It has increased also because the influences that cause the endosperm to shrink and the seed coats to split—which opens the kernels to infections—have been reduced or eliminated.

Apart from ear-rotting organisms, other maize diseases seem to attack both QPM and normal maize with comparable severity.

Storage Stability

The difficulty of storing opaque-2 was due mainly to insects penetrating the soft kernels. However, the cracking and splitting of the seed coat also fostered decay, and it was particularly bad in mechanically harvested samples because machinery tended to damage the soft kernels.

With QPM, storage damage is no worse than in common maize because the endosperm hardness is virtually the same; the excessive incidence of broken kernels and the resulting storage damage has essentially been eliminated.

Nutritional Value

Over the years of development, the genetic modifications have been accompanied by constant chemical monitoring. Thus, the advances have been made without losing nutritional benefits. The QPM of today retains in essence all of the the high-quality nutritional components that were in the opaque-2 maize of the 1970s (figure 3.8).

As a demonstration of its nutritional quality, more than 20 malnourished children have been "treated" with QPM in a Guatemalan

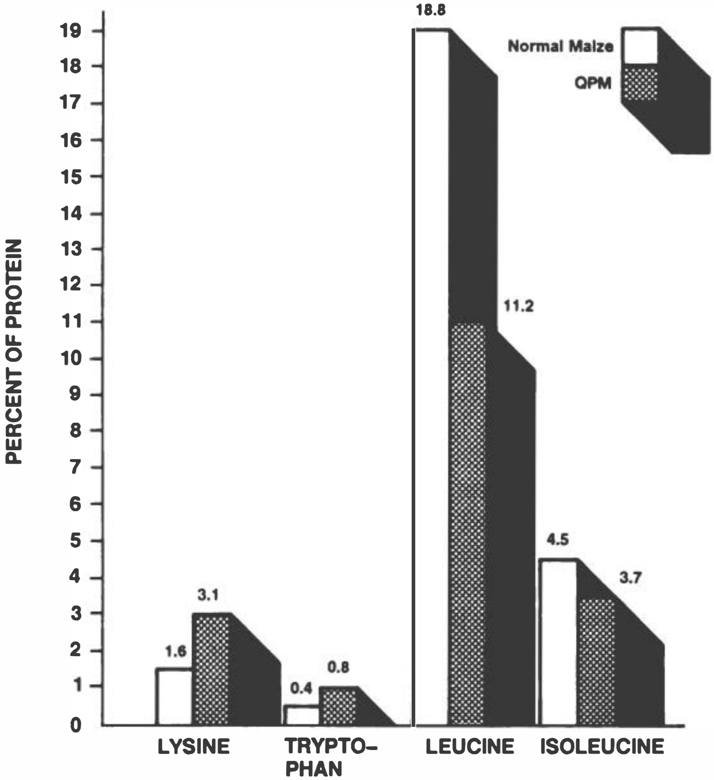


FIGURE 3.8 QPM has about twice the lysine and tryptophan of normal maize. It also has less of an imbalance between leucine and isoleucine. This is possibly beneficial because leucine is thought to interfere with the biosynthesis of niacin. The graph shows the average amino acid content in normal maize and QPM endosperms measured in g per 100 g of protein. (E.I. Ortega and E. Villegas, Protein Quality Laboratory, CIMMYT)

hospital. In the series of tests, the physicians found it to be a flexible "cure," thanks to its acceptability and its superior biological value.[7]

Research in Lima, Peru, has shown that babies in their second year of life grow normally when QPM is fed as the only source of protein in the diet (see box).[8]

QPM's benefits result mainly from its lysine and tryptophan, but they go far beyond that. Although QPM has about the same amount of protein as common maize, it has twice the *usable* protein because the quality and biological value of its protein is so much higher. For example, the biological value of common-maize protein is equal to about 40 percent of the biological value of milk protein, whereas the

[7] Information from A. Fuentes.
[8] Information from G. Graham.

At the Instituto de Investigación Nutricional in Lima, Peru, QPM has been fed to malnourished children with striking results. In a controlled in-patient situation, infants recovering from malnutrition were provided diets in which cow-milk "baby formula," QPM, or common maize supplied all of the protein.

In one program, the diets of six infants were diluted to critical levels of intake so that protein-quality differences between QPM, common maize, and casein (the protein in milk) could be distinguished. At the low level of 6.4 percent calories as protein, apparent nitrogen absorption (the difference between the intake of nitrogen and the amount excreted in the feces) from QPM (70 ± 5 percent) and common maize (69 ± 7 percent) was much lower than from casein (82 ± 4 percent). This indicates that the amount of protein passing from the digestive tract into the bloodstream was much higher in casein than in either form of maize—a reflection of the better digestibility of the animal protein over these vegetable proteins.

At the same time, however, the apparent retention of nitrogen (the difference between the amount absorbed and the amount excreted in the urine) from QPM (34 ± 4 percent) was much higher than from common maize (22 ± 10 percent). Nitrogen retention is a measure of the amount of protein retained by the body to build tissues such as muscle, liver, spleen, and brain. Therefore, these results suggest that QPM was almost 50 percent more effective than common maize at fostering growth in these malnourished children.

Breath hydrogen excretions were much lower in children consuming QPM than in those consuming common maize. Because breath hydrogen comes from carbohydrate fermentation in the large intestine, the differences reflect the amounts of carbohydrate passing undigested through the small intestine. The lower level of breath hydrogen from QPM diets indicates that its carbohydrate is far more digestible than is that of common maize.

In a second program, the diets of eight similar infants were formulated at a level where 90 percent of the calories were provided by maize and were fed for three months. It was found that QPM could be the only source of protein and fat with just enough added sugar to make up the necessary remaining calories.[1] This diet supported growth rates statistically indistinguishable from those provided by milk formula.

In combination, these results confirm in real-life conditions that the level of utilization of both protein and carbohydrate is considerably greater in QPM than in common maize.

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[1] In these diets, protein provided 9 percent of calories; fat, 10 percent of calories; and carbohydrate (fiber, starch, and simple sugars), 81 percent of calories. Commercial infant formulas are similar to this, containing 9 percent calories as protein; human breast milk contains 6–7 percent calories as protein.

biological value of QPM protein is about 90 percent of that of milk protein.[9] Thus, QPM's nutritional benefits approach those of milk protein, a common standard of nutritional excellence.

Whether QPM will benefit victims of pellagra is not certain, but it does seem likely because of its elevated levels of tryptophan, the biological precursor of niacin.

Also, there are indications that the yellow-kernel types of QPM may prove unusually valuable in helping to overcome xerophthalmia, a vitamin A deficiency that is the primary cause of childhood blindness in many developing countries.

Processed Foods

CIMMYT and others have recently studied food products made with QPM. Tortillas, breads, biscuits, and cakes have been prepared with good results both in acceptance and nutritional value. Visiting scientists and trainees have prepared typical *nshima* and *munkoyo* products of Africa, with equally good results. And a large food company in Mexico City has tested quality snack foods using QPM maize. In all cases, the QPM had normal functional properties and yielded products with normal characteristics.

In the United States, similar tests have been made. In trials at Texas A & M University, corn chips and tortillas made with QPM were found to be normal in physical and commercial characteristics. Their superior protein quality was clearly established by chemical analyses and bioassays (see chapter 6 and appendix A).[10]

[9] Bressani et al., 1969a.
[10] Sproule et al., 1988.

4
The Promise of QPM

GENERAL CONCLUSIONS

Quality-protein maize (QPM) appears to be an outstanding product. From current evidence, there seem to be no fundamental technical uncertainties still to resolve. In their remarkable research, scientists at the Centro Internacional de Mejoramiento de Maíz y Trigo (CIMMYT) have overcome or minimized the problems that formerly discredited opaque-2 maize: low yield, low acceptability, high disease susceptibility, slow drying capabilities, and poor storage qualities. Thus, in principle, QPM should be as acceptable and as inexpensive as common maize, and its nutritional advantage should come at little or no penalty to the farmer or consumer.

Whether the world needs quality protein is not as evident as it seemed when opaque-2 maize was developed in the early 1970s. However, despite uncertainties expressed by some nutritionists, the panel expects major health benefits to be derived from QPM. QPM carries the promise of creating both better food and more food, and of producing quality protein without sacrificing carbohydrates and calories. Over the long term, QPM should benefit tens of thousands of maize-reliant communities and millions of poorly nourished people.

In a sense QPM is nutritionally risk-free. If its present performance remains stable or is further improved, its use requires that nothing be given up. Switching from common maize to QPM demands no sacrifice of yield, money, calories, or nutrients. The only difference between QPM and common maize is a reorganization of proteins that in QPM emphasizes more nutritious subtypes (see chapter 6).

INTRODUCING QPM

The promise of QPM is probably greatest in areas of the world where people depend on maize, sorghum, or root crops to feed young children. In other areas where meat, milk, or highly digestible legumes are readily available at a low price and are routinely fed to the young, there is less concern about the protein quality of maize. However, where these quality-protein sources are scarce, expensive, or traditionally withheld from small children, there are powerful reasons for testing QPM.

Happily, it is not really a new crop. Millions of people are accustomed to growing and eating maize. QPM demands no unexpected inputs of fertilizer, pesticides, irrigation, or agronomic practices. And QPM should require little or no change in eating habits and almost no modification of the food-supply system. In this, it differs from previous approaches to relieving protein shortages, which usually involved the introduction of exotic legumes, algae, or food supplements that demanded substantial changes in personal eating habits or national food supply.

QPM is expected to perform well under a wide range of conditions. It was created in a process that shuttled seeds back and forth between a "good" growing site and a "poor" one (see chapter 7). Only seeds from progenies that could survive both conditions were advanced. This, together with maize's broad adaptability, means that QPM should demonstrate tolerance to harsh conditions and poor management.

QPM and Children

Some nutritionists doubt whether the introduction of any type of maize in infant feeding should be advocated. However, if maize is already being used in this way, then QPM should not make the situation worse, and in fact seems likely to improve it. For millions of children in Latin America and Africa, there are particularly auspicious prospects for QPM. There, maize and low-protein root crops tend to make up much of an infant's diet.

Metabolic-balance studies have already shown that children who consume maize as the only source of protein increase their nitrogen retention by 50–100 percent when they switch from normal maize to nutritionally improved maize.[1] Such increases should translate into equivalent rates of weight gain, lean-body-mass growth, growth in stature, and protection from the manifestations of protein deficiency.

QPM is likely to have special importance for use in weaning foods, catch-up growth, and improving birth weights:

Weaning foods. Nutritionists agree that wherever people depend on cereals alone or cereals and beans for weaning children, QPM is likely to produce benefits. For the fully weaned infant, the new grain should satisfy protein needs while satisfying a reasonable amount of calorie

[1] Viteri et al., 1972.

needs. For partially weaned babies it should also be beneficial.[2] Thus, in the age groups from about four months to three years, it should reduce mortality from malnutrition and improve growth rates among societies whose dietary staple is maize.

Catch-up growth. For children trying to recover growth after being malnourished or sick, QPM should also be valuable. Their protein requirements are proportionately higher than normal. For many, they are so high that protein becomes limiting—particularly in the youngest, and notably after episodes of diarrhea.

Improving birth weights. As mentioned, a prime cause of infant death is low birth weight. A principal contributory factor is the mother's own low level of nutrition, and the use of QPM during pregnancy could raise levels of child survival. Low birth weight is associated with 30–40 percent of the millions of infant deaths in the developing world. In many countries, food supplements for "at-risk" pregnant women have been shown to be effective as a preventive measure. QPM should be at least as good.

QPM and Beans

As noted, maize is often consumed with beans. The beans contribute lysine, tryptophan, and niacin, and the combination would seem to give QPM little nutritional significance. However, beans are more expensive to buy than maize; they cost more to grow and they yield less. Also, they require long cooking time, which is a problem as firewood becomes increasingly difficult to find. Moreover, since high-yielding cereals were introduced in Latin countries, bean production has decreased, whereas maize production has increased. In addition, beans are not consumed every day. Also, beans are difficult to digest by very young children. Throughout much of Latin America, for example, parents withhold beans until a child is at least two years old. Thus, during the most vulnerable growth period, children often need lysine and tryptophan, even if the rest of the family is eating a steady diet of beans. The same is probably true in India and Pakistan, where people eat chickpeas, lentils, and pigeon peas (dahl), which are also not fed to the youngest children. The same may also be the case in parts of Africa, where cowpeas are the chief legume supplement.

In summary, therefore, even those who eat beans and other legumes should get a more balanced diet with QPM as their cereal rather than common maize.

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[2] Despite the overwhelming value of breast feeding, there is growing recognition that it is important to use weaning foods to supplement mother's milk after about the age of four months. At this time the breast-milk supply can fall short of the growing infant's demands for protein and energy. Information from S.N. Smith. Also see Waterlow and Thomson, 1979.

A Nutritional Safety Net

In a broad sense, QPM could provide a nutritional safety net for a country, valley, village, or family, even if it is not vital for everyone. In a child's diet, it provides more latitude for error where beans or other foods are used to supplement local carbohydrate staples. Indeed, for all of the population, the switch to QPM from normal maize makes any dietary irregularity less important, and any reliance on legumes or other supplements less crucial to health. In remote areas, especially those not accessible by mass transportation, it could provide children a nutritional security that could be sustained by local effort without reliance on the outside world.

Even where there is no visible malnutrition, the presence of QPM could be important. Fiscal, political, fuel-supply, or agricultural crises often bring cutbacks in services. Indeed, even countries with praiseworthy commitments to the poor have been forced to stop funding social services, dismiss schoolteachers, reduce food subsidies for pregnant mothers and children, close clinics, and halt immunization programs for lack of funds, foods, fuel, or spare parts.

It should be understood that QPM's benefits do not merely double the level of effective maize protein. People actually show better use of all proteins—no matter what the source. This is because malnourished bodies use poorly even the small amount of nutrients they may get. Malnourished children, for instance, void much of their meager protein in their urine. If fed QPM, this wastage can be minimized or stopped. Indeed, improving a person's overall nutritional status means that bodies absorb all nutrients—vitamins, iron, and other minerals—more easily. Moreover, as noted earlier, a diet of quality protein stimulates appetite.

Economic Development

The normal way to measure a crop's yield is in kilograms per hectare, but with QPM there is an additional level of yield: the amount of nutrients produced per hectare. With this new crop, productivity can actually be expressed in terms of the efficiency of feeding people. In this sense, the nutritional benefits of QPM have broad implications for economic development. For instance, each gram of QPM gives the same amount of usable protein as at least two grams of normal maize. By extension, therefore, QPM makes maize farming at least twice as efficient in terms of protein production. Or, said another way, half the land area can fulfill an individual's protein requirements.

It has been calculated, for instance, that in Guatemala it takes 0.013 hectares to feed a child for a year with QPM, whereas it takes 0.035 hectares to feed that same child with ordinary maize. For adults, the relative advantage is less because adults have lower protein requirements than children, but the conclusion, nevertheless, remains that QPM makes maize production more efficient.[3,4]

Animal Feed

QPM has a clear and certain value in livestock production—particularly where soybeans or fishmeal are expensive or unavailable (as in the maize-producing regions of West Africa). Young animals require diets higher in protein than young people.[5]

In most locations, substituting QPM for soybeans or fishmeal will reduce the cost of feeding livestock. However, the protein in QPM is not as concentrated, so that some supplements will probably still be needed. Nonetheless, using QPM is likely to make the production of animals (particularly pigs and chickens) more efficient. Indirectly, this will improve human diets by providing more meat and eggs. For some countries it could also reduce the foreign exchange paid out for imported feeds.

Nutritional Supplements

Several countries—Bolivia, Peru, Panama, Colombia, and a number of African nations, for instance—now make nutritional supplements based on mixtures of food legumes, cereal grains, and oilseed cake. These countries might particularly benefit from QPM.

In Central America, a pioneering supplement, Incaparina, has been a notable success, and its sales are rising throughout the region. First produced following the 1966 earthquake in Guatemala, when food was limited, it incorporated 3 percent yeast as a quality-protein ingredient. Later, as yeast became too expensive, lysine was substituted. Now lysine has also become too expensive, and the formulation is currently being modified to incorporate QPM.

In addition, Incaparina's producers are experimenting with removing the starch from QPM to produce a protein concentrate. This has a nutritional makeup similar to that of an oilseed meal. Indeed, QPM protein concentrate is soon expected to replace cottonseed meal in the Incaparina formulation.

Snack Foods

QPM is especially promising for tortilla chips and other maize-based snack foods. The snack-food industry is perennially charged with

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[3] Bressani and Elias, 1979.

[4] Because conventional maize and QPM have roughly equal contents of protein, carbohydrate, and fat, their formation requires the same amount of sunlight. It costs the maize plant virtually no additional photosynthetic energy to produce lysine and tryptophan than to produce more common amino acids.

[5] People grow relatively much more slowly. A 4.5 kg piglet may gain 450 g per day (10 percent of its body weight), a 30 g baby rat gains 3-4 g per day (10 percent), but a 4 kg infant gains only about 30 g per day (1 percent).

peddling "junk food" of little nutritional value. The soft, floury kernels of opaque-2 maize did not lend themselves to the standard methods used in producing commercial snack foods. However, the kernels in QPM are likely to be suitable. Using QPM might provide both a nutritious product and an important public relations benefit. (For more information see appendix A.)

RECOMMENDATIONS

In any scientific development there is a time for caution and a time for boldness. The panel is convinced that with QPM the time for action has arrived.

QPM should be field tested quickly. It has been produced by the dedicated efforts of a small research team in the face of worldwide abandonment and at low budget. Now is the time for researchers to help assess QPM in the "real world" situation of farmers and malnourished people.

Although QPM has shown outstanding promise, to date it is only a promise. Any lingering doubts need to be rapidly resolved by an organized, international, cooperative effort. Testing QPM in national maize-breeding programs is vital, especially in countries with high incidences of malnutrition.

Areas of the world that should be targeted are those where people depend heavily on maize to feed small children; for example, the highlands of the Andes, Central America, most parts of Africa, and select countries of Asia, including Bangladesh, Indonesia, and the Philippines. QPM has promise, too, in areas where people could be persuaded to use it instead of their current cassava, plantain, sorghum, or other inferior-protein staples.

All over the world, low-income populations are increasing their dependence on cereals. With its good yields and high nutritional quality, QPM could become a powerful means for helping them become less vulnerable to malnutrition. As noted, maize is often the crop of the poor, and in the maize-growing areas of the world, millions of children living in poverty are not thriving. Here is an opportunity to explore this new approach to relieving an intolerable situation. There is every reason to expect health benefits, particularly in weanlings and malnourished infants. QPM has the advantage in that it allows a country to combat such dietary deficiencies by using its own farmers and resources. Indeed, in most areas, it should allow a family to combat its own malnutrition without outside help.

5
Limitations and Uncertainties

Quality-protein maize (QPM) has been produced, and its advancement is under way. However, despite its outstanding potential, uncertainties over its performance in general practice still exist. Although QPM has performed well in test plots and in some progressive farmers' fields, it hasn't yet been widely exposed to unsupervised farm use in subsistence settings. Research is still needed to support the steady and orderly development of what promises to become an important new food crop.

CUSTOMIZING

Overall, the next requirement is to intensify testing and selection in areas suitable for commercial production, and to test its acceptability for human consumption and industrial use, not just in laboratories but in the unforgiving world of commerce.

The QPM varieties developed by Centro Internacional de Mejoramiento de Maíz y Trigo (CIMMYT) have performed as well as common maize in trials and seem to have good adaptability. However, maize needs many varieties—each adapted to the soil type, growing season, altitude, latitude, pests, diseases, and human preferences of its own locality. It is QPM types for these localized situations that must now be perfected. Today's germplasm should be regarded as an intermediate product. In some locations it may perform well, but in others it will have to be locally refined and adapted before being released to farmers.

GENETIC STABILITY

Although the agronomic traits of QPM have been brought up to levels essentially equal to those of their common-maize counterparts, their stability has not been confirmed as yet. It is not certain, for example, that high yields and nutritional quality can be maintained with seed collected and resown in the same location year after year. The limited trials carried out so far show that the high yield is generally stable over two or three generations, but how many more years this will continue is not known.

Also uncertain is the stability of yield over different locations—that is, whether the same seed will give similar yields when planted in different places, even those with similar environments. Although there is no reason to expect that QPM varieties will be disastrously unstable, the crop has not been tested widely enough to quantify the consistency of its performance, and some types have proved unpredictable.

DELIVERY SYSTEMS

The introduction of any new crop variety brings a host of operational complications. No matter how good the material and how great the need in the countryside, if there is no "delivery system" to multiply and distribute seed and ensure a reasonable degree of purity, it will fail. QPM is no more demanding than any other new maize variety, but its organized introduction is nonetheless an important requirement.

CREDIBILITY

Trying to introduce a new version of a crop that once failed could encounter psychological hurdles. For those who remember the enthusiasm for opaque-2 maize in the 1970s, QPM suffers a "credibility gap." Researchers could be hesitant to undertake QPM studies because of the lingering memories of the earlier form that did not live up to its billing.

LACK OF DISTINGUISHING FEATURES

The fact that QPM is now indistinguishable in appearance from common commercial maize is also a potential limitation. (It is ironic that such a beneficial feature is also a weakness.) People could easily identify opaque-2 maize's soft, chalky kernels, but only in a laboratory can QPM be distinguished (by measurement of its lysine and tryptophan levels). This is a particular concern because genetic contamination is a potential problem, and even deliberate adulteration could occur. Unscrupulous farmers or dealers could adulterate QPM with common maize—a particular temptation if QPM is allowed to sell at a premium price.[1]

SOCIAL FACTORS

The nutritional advantages of QPM appear to be documented in laboratory experiments. However, they are not adequately authenticated in local diets of actual populations. QPM has outstanding promise where maize is a preferred item in the diet, but unforeseen factors may arise. People who have used maize all their lives may recognize subtle differences and may suspiciously reject QPM as "alien."

SPECIAL HANDLING

QPM seed plots must be isolated from the pollen of other maize types. This is true for any quality maize, but with QPM it is even more necessary because cross-pollination reduces both yield *and* nutritional value. Around the edges of the fields, cross-pollination with nearby common maize causes genetic contamination. (About 10 percent contamination has been measured in Guatemala.) To maintain the nutritional quality, farmers must save seed from the center of their fields and (for safety) replenish their seed from certified stocks every few growing seasons.

PESTS AND DISEASES

Because pests also benefit from good nutrition, commercially available QPM may prove somewhat more susceptible to storage problems than will normal maize. So far, there is no unequivocal evidence that this will occur, but QPM has shown some storage damage under experimental conditions.

A problem of particular concern is aflatoxin. Again, there is no unequivocal evidence that QPM is any more susceptible than normal maize to this toxin-producing fungus, but, like people, fungi respond to better nutrition. In two experiments comparing aflatoxin infections in QPM and normal maize, one showed no difference and the other was inconclusive because it showed both higher and lower levels of infection.

[1] One way to avoid this is to introduce QPM of a different color from the local common maize: yellow QPM where white maize is now standard and vice versa. Another method is to introduce hybrids, which must of necessity be sown using fresh seed.

SPECIAL ENVIRONMENTS

Because varieties are not yet selected for all sites, current QPM varieties have not performed well in a few select environments, especially those with specific disease or insect problems. In Thailand, for example, one test plot was wiped out by downy mildew fungus.[2] Thus, although current QPM varieties can approach normal yields, this is not yet necessarily true for every part of the world. The current materials seem best adapted to drier areas. A project under way to adapt QPM to wetter areas is now developing strains in which the husks cover and cling to the ears, thereby hindering the entry of pest and disease organisms. Work is also under way in promising QPM materials to develop resistance to maize streak virus, a serious disease in Africa.

HYBRIDS

The work so far has concentrated on open-pollinated varieties, but QPM is also promising for hybrid maize. Hybrids generally yield better and maintain their genetic qualities more consistently. For this, separate QPM lines must be generated and then joined to form hybrid combinations. A beginning has already been made; CIMMYT expects to test hybrids at farm level within a few years. Moreover, researchers at Texas A & M and other universities also have QPM hybrids in preparation.[3]

Although hybrids are a way of stabilizing the purity of the QPM traits, they have to be produced centrally, farmers must buy new seed each year, and hybrid seeds cost appreciably more than those of traditional, open-pollinated varieties.

MALNUTRITION

QPM is a quality food that is potentially within the financial reach of a vast population of malnourished people, but it is no panacea. Quality protein is not the only requirement for overcoming malnutrition. Building a person's body protein depends also on the supply of calories from carbohydrates and fats in the diet. (If these are not adequate,

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[2] However, downy mildew resistance can be developed in QPM materials rather quickly, and this is currently being done with some populations of normal maize in Thailand.

[3] Information from A.J. Bockholt. It should be noted that these are hard-endosperm hybrids, not the soft-endosperm opaque-2 types (see appendix A).

the body wastefully burns up food proteins for energy.) Indeed, QPM may be unable to solve the problem in its worst case scenario. Calories are possibly the limiting problem for people that most desperately need it, and some nutritionists claim that the calorie problem must first be solved. In addition, diets of the destitute are likely to be insufficient in critical minerals and vitamins (for example, calcium and riboflavin).

Also, malnutrition will persist because it is associated with medical problems—infections and diarrhea, for example. Its eradication will thus require the inputs of preventive medicine and medical care. In addition, any nutrition-improvement program should be a component of other interventions such as those that modify living conditions, improve water supplies and food storage, and increase income. It would be a mistake to infer from this report that nations need only feed QPM to their malnourished populations to overcome all malnutrition.

6
Food and Feed Uses

As noted, both common maize and quality-protein maize (QPM) have roughly the same amount of protein. They differ only in the types of protein each contains. In QPM, the balance is shifted to emphasize the most nutritious types.

MAIZE PROTEIN

The proteins in the endosperm of maize come in four types:

- Prolamines (soluble in alcohol solution);
- Glutelins (soluble in dilute alkali);
- Albumins (soluble in water); and
- Globulins (soluble in saline solutions).

In normal-maize kernels, prolamines predominate, accounting for 50–60 percent of the total protein (figure 6.1). This is unfortunate because prolamines (which are made up of two subfractions, called zein and zein-like), are low in lysine, tryptophan, and biological value.

In QPM kernels, on the other hand, prolamines are a smaller part of the total protein—only about 30 percent. In QPM kernels, it is the glutelins that predominate, making up about 40 percent of the total protein. This is the crucial nutritional advantage because glutelins are 18 times richer in both lysine and tryptophan than are prolamines (figure 6.2). They are also highly digestible and have a high biological value (table 6.1).

Opposite, top.
An ear of QPM (right) appears identical to an ear of normal commercial maize (left). Therefore, consumers will probably accept it readily. (CIMMYT)
Opposite, bottom.
In creating QPM, the crucial step was to give the kernels of opaque-2 maize (left) the texture of common maize (center). This transformation has been so successful that, even close up, common-maize kernels are indistinguishable from QPM kernels (right). Although QPM no longer has the dull look and soft texture of opaque-2 maize, it still has the nutritional superiority. (CIMMYT)

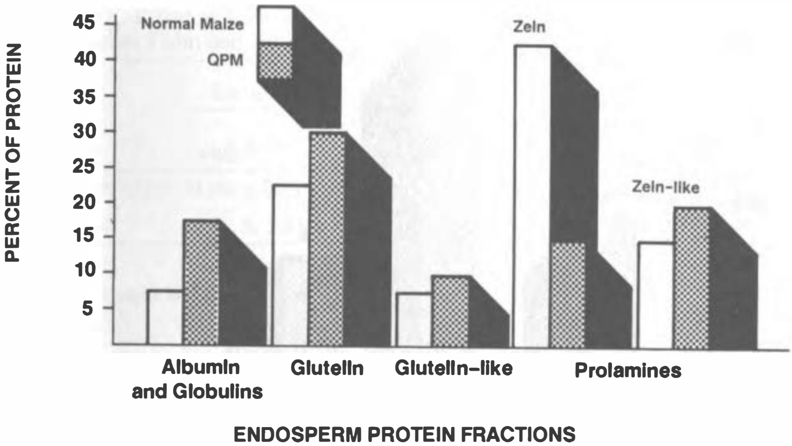

FIGURE 6.1 Maize protein is made up of several different types of subfractions. QPM has roughly the same overall amount of protein as common maize; however, the relative amounts of the four subfractions are very different. In QPM, the albumins, globulins, glutelins, and glutelin-like fractions are increased. On the other hand, the prolamines fraction is greatly reduced. This is the key to the increased nutritive quality because albumins, globulins, and glutelins are high in lysine, tryptophan, and digestibility, whereas prolamines are low in all three. (E.I. Ortega and E. Villegas, Protein Quality Laboratory, CIMMYT. The graph is based on endosperm protein fractions obtained by the Landry-Moureaux procedure; the samples were Tuxpeño-1 and Tuxpeño-1 QPM.)

TABLE 6.1 Nutritional Evaluation in Rats of Normal, Opaque-2, and QPM Maize.

Sample	Lysine[a]	Response Criteria		
		True Digestibility	Biological Value (percent)	Net Protein Utilization (percent)
Normal Maize[b]	2.6	98.1	62.7	61.5
Opaque-2 Maize[c]	4.2	96.0	77.6	74.5
QPM[d]	4.1	95.8	74.5	71.4
QPM[e]	4.0	96.6	76.2	73.6

[a] grams per 100 grams of protein
[b] Tuxpeño Crema-1
[c] Tuxpeño 0_2 (soft endosperm)
[d] Amarillo Dentado HEo_2
[e] Ant. X Ver. 181 HEo_2

SOURCE: Villegas et al., 1980.

With the proportion of glutelins increasing at the expense of prolamines, the overall lysine content in the endosperm protein rises from 2.6 percent in common maize to about 4 percent in QPM. Additionally, another amino acid, tryptophan, also increases substantially—an important factor because, as noted, tryptophan is both an essential amino acid and the biological precursor of the B-vitamin, niacin. The human body converts tryptophan into niacin, and any increase in tryptophan

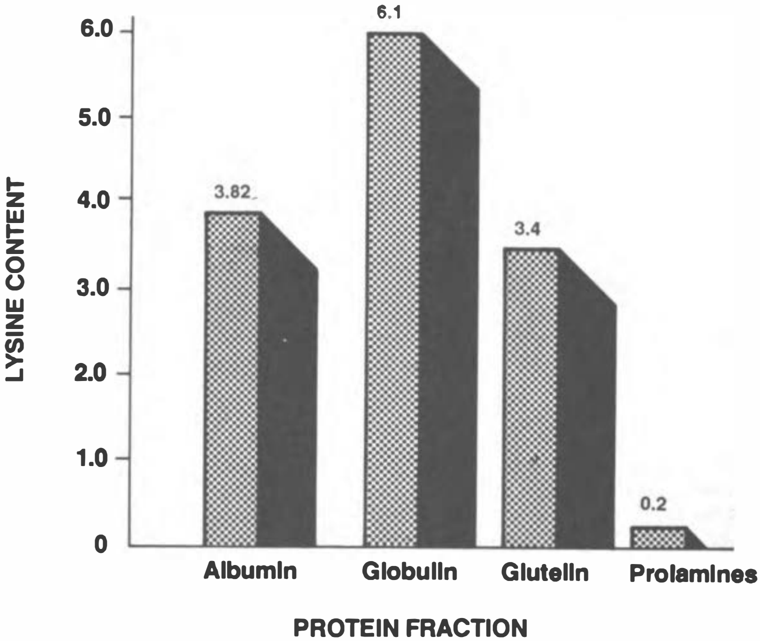

FIGURE 6.2 Whereas albumin, globulin, and glutelin are rich in lysine, prolamines are extremely low in lysine. Thus, in creating QPM by shifting the balance of the protein fractions away from prolamines and towards albumins and glutelins, the levels of lysine (and tryptophan) in the kernels increase. In addition, the effectiveness of this essential amino acid is enhanced because albumins and glutelins are much more digestible than prolamines. (Protein Quality Laboratory, CIMMYT. Measured in g per 100 g of protein.)

helps prevent pellagra almost as though the same amount of niacin were being added. (In this respect, QPM is like milk and eggs: both are low in niacin, but afford protection from pellagra because their proteins contain high levels of tryptophan.)

Moreover, as glutelins replace prolamines there are changes in amounts of yet other amino acids. For example, QPM has less leucine and more isoleucine than common maize, which reduces the preponderance of leucine. The more equal balance between these two amino acids is of possible nutritional benefit: some researchers believe that it boosts the production of niacin, thereby also helping to overcome pellagra.

Further, the change from prolamines to glutelins raises the amount of usable protein. Nutritionists often express usable protein as a percent of energy. QPM has a value of "usable protein as energy" of 8.3–9.6 percent—well above the currently accepted estimates of protein and energy needs for a 1-year-old child, for whom a value of 8 percent is considered adequate.[1] On the other hand, normal maize has a usable

[1] Bressani et al., 1969a.

TABLE 6.2 Effect of Protein Quality of Corn on Liver Retinol Reserves, Food Intake, Weight Gain, and Feed Efficiency in Rats.

	Liver Retinol Reserves				
	μg/g Liver	μg/Total Liver Weight	Food Intake g	Weight Gain g	Feed Efficiency g food/g weight gain
Yellow corn QPM	11.60 ± 2.88*	107.21 ± 37.16	162.0 ± 29.1	26.5 ± 9.2	7.0 ± 2.3
Yellow corn	9.3 ± 3.15	71.86 ± 16.26	130.5 ± 24.4	14.6 ± 3.1	9.4 ± 2.0

* X ± D. E.

SOURCE: Bosque and Bressani, 1987.

protein-as-energy value of 4.7 percent, which makes it unable to fulfill the requirements of a 1-year-old.

VITAMINS

QPM's niacin content is no higher than that of common maize, but, as just discussed, it has more tryptophan, a compound that the human body converts into niacin for itself. Also, its lower ratio of leucine to isoleucine (see figure 3.8) may further increase the bioavailability of niacin.[2]

Yellow maize has high levels of carotenoids—the colored plant pigments that give rise to vitamin A in the body. Recent experiments suggest that animals utilize these vitamin A precursors in QPM better than in normal maize (table 6.2). This is not unexpected because previous research on other foods has shown that improving protein quality increases the efficiency of carotenoid conversion and utilization.[3] Thus, with QPM vitamin A deficiency should not be aggravated, as happened previously with some skim-milk-based supplements. Indeed, yellow QPM may prove valuable in combating this insidious deficiency that causes blindness in children.

OTHER CONSTITUENTS

The minerals, carbohydrates, and lipids in QPM have essentially the same composition and are present in essentially the same quantities as those in common maize. QPM has the same energy content—about 360 calories per g—as its normal-maize counterparts.

[2] In recent years, the role of leucine and isoleucine has been a matter of hot debate among nutritionists. The thrust of current thought is that the ratio between the two is meaningful and that when leucine greatly outweighs isoleucine, pellagra is more likely to develop.
[3] Information from R. Bressani.

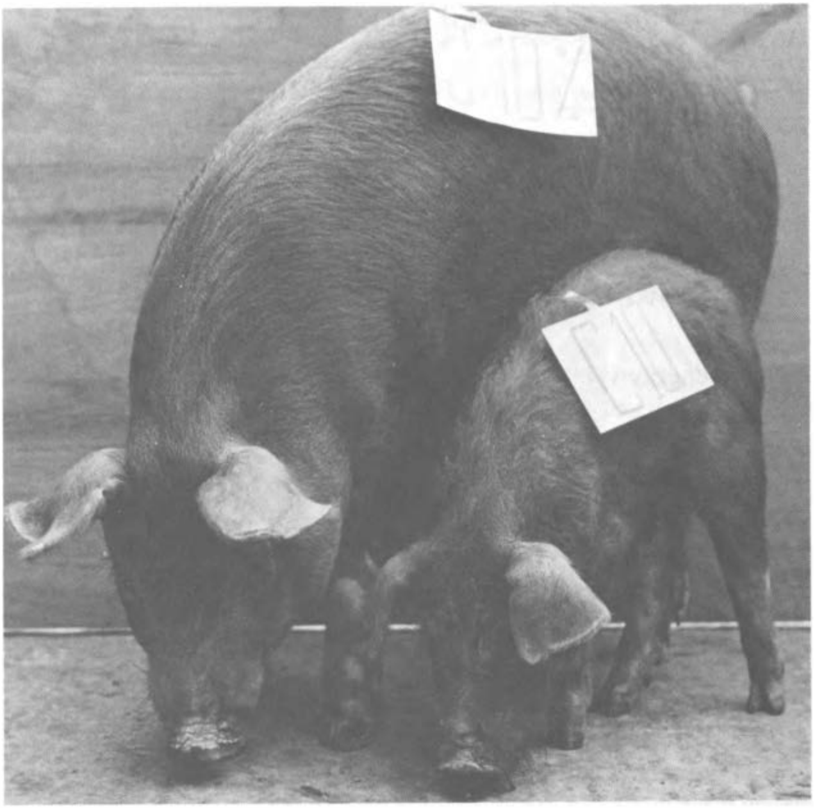

FIGURE 6.3 Comparison of pigs, 33-165 days old, fed either opaque-2 or normal maize. During the experiment, the pig fed the opaque-2 maize diet gained 256 g per day, while the animal fed common maize gained an average of only 21 g per day. The diets were provided free choice and were supplemented with vitamins and minerals. When used as the only source of protein, nutritionally improved maize was almost four times more productive than normal maize. (J. Maner)

ANIMAL TRIALS WITH OPAQUE-2 MAIZE

In the 1960s and 1970s, nutritional research with rats, pigs, and chicks showed that opaque-2 maize was a dramatically better feed than ordinary maize. The results are generally transferable to QPM because opaque-2 and QPM differ mainly in kernel texture and field performance; nutritional compositions are essentially identical.

In summary, the many early tests on animals showed the following:

- For young rats, opaque-2-maize proteins are well balanced. If used as the sole source of protein they show only a minor deficiency in lysine. Opaque-2 maize showed a protein efficiency ratio (PER) of

2.79 as compared with 2.88 for milk protein (casein) at comparable levels of protein in the diet. The results also indicated that processing the maize into foods (*masa* and tortillas) does not alter its high protein quality, although slightly lower PER values were found. Evidence that the niacin in opaque-2 maize is available to the niacin-depleted rat, as opposed to its low availability in common maize, was also found.[4]

- For pigs, opaque-2 maize can be used as the only source of protein during the finishing, pregestation, and gestation periods of the life cycle without reducing growth. Compared to the normal-maize diet, the opaque-2 maize diet produced equal performance with less supplemental proteins. Opaque-2 maize alone is not adequate for piglets, growing pigs, or lactating sows. For them, it must be supplemented with protein or amino acids to produce maximum performance.[5]

In Colombian trials, piglets fed solely on opaque-2 maize remained healthy and vigorous, while piglets fed solely on common maize developed a protein-deficiency disease and, after 110 days, began to die. Also, they grew three-and-a-half times faster on opaque-2 maize than on normal maize when it was the sole protein source (figure 6.3).

- For chicks, opaque-2 maize by itself did not produce normal growth. However, when supplemented with methionine, for which chicks have a high requirement, it produced better gains and feed conversion than did normal maize at below-optimal protein levels.[6]

In Guatemala, chick-feeding trials have shown a remarkable increase in feed efficiency when opaque-2 maize was substituted for common maize. In one trial, for example, chicks fed with opaque-2 maize from age 15 days to age 5 weeks had gained 446 g, whereas chicks fed with common maize or sorghum had gained only 223 g and 195 g, respectively. The corresponding ratios of feed to gain in body weight were 3.5:1 for opaque-2 maize, 8.2:1 for normal maize, and 11.3:1 for sorghum.[7] Thus, QPM seems promising for feeding chickens, perhaps the most common livestock throughout the Third World.

HUMAN TRIALS WITH OPAQUE-2 MAIZE

In previous decades, nutritional tests on humans showed that opaque-2 maize brought dramatic improvements in nutritional status (see, for instance, figure 6.4). In summary, the tests indicated the following:

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[4] Bressani et al., 1969b.
[5] Maner, 1975.
[6] Rogler, 1966.
[7] Jarquin et al., 1970.

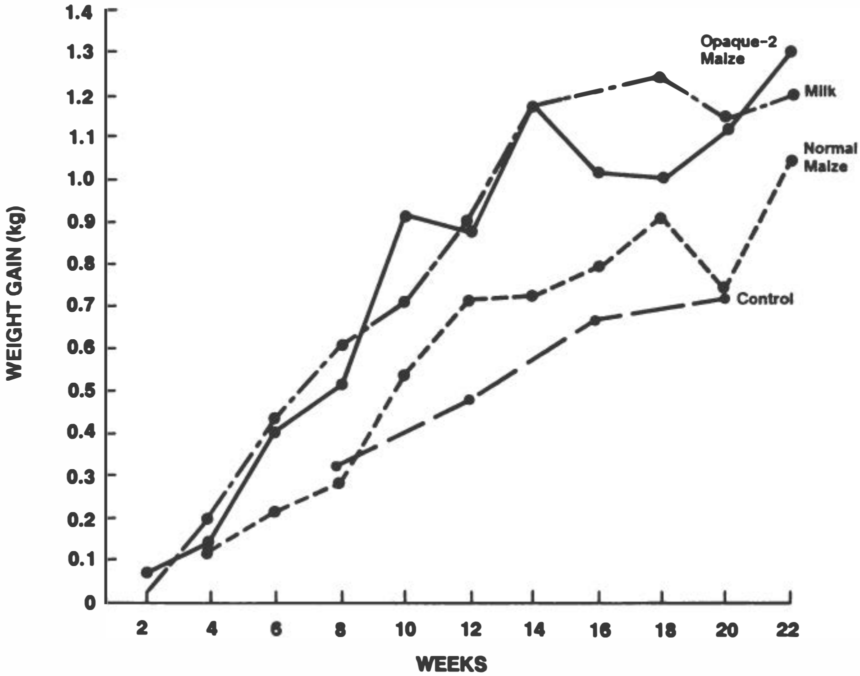

FIGURE 6.4 In India, the superiority of opaque-2 protein in comparison with normal maize protein has been shown in feeding tests carried out with children. The investigations were undertaken to determine the suitability of opaque-2 maize as a supplement to the home diet of 18- to 30-month-old children from low-income families. The figure shows the average cumulative weight gain.

The study involved feeding one midday supplementary meal to the three experimental groups. One received milk, one normal maize, and one opaque-2 maize. There was also a control group that received no supplementary food. Each child in the experimental groups was fed at iso-protein and iso-calorie levels for 182 days.

As shown, at the end of the feeding program, children fed on opaque-2 maize gained weight at a rate comparable to those of the milk group. In addition, their gains in height and chest measurement were comparable to those of the milk group. The children fed on normal maize gained better in head circumference than those fed on opaque-2 maize. Estimates of the chest to head circumference ratio and chest to arm circumference ratio also suggested better gains for the opaque-2 maize than normal maize. (Food and Nutrition Board, India, 1977)

- For adult males, 300 g of opaque-2 maize provides 93 percent of the daily protein requirement (and 40 percent of the daily calorie requirement). By contrast, 500–600 g of common maize could provide only 70 percent of the protein requirement (but it did provide 80 percent of the required calories).[8]
- For children, a daily consumption of 175 g of opaque-2 maize

[8] Clark, 1966.

guaranteed nitrogen equilibrium, whereas 250 g of normal maize was required to achieve this.[9]

Beyond laboratory experiments of that kind, there were several comprehensive feeding trials with malnourished children. For instance, in 1966, Guatemalan children in a metabolic ward were fed diets based either on opaque-2 maize or milk. The children fed opaque-2 maize retained as much nitrogen as did those fed milk. The digestibility of opaque-2 maize was 83.8 percent. The nitrogen-balance index (a good estimate of the biological value of proteins) was 0.72 for opaque-2 maize, and 0.80 for milk, suggesting that the protein in opaque-2 maize had a biological value equivalent to 90 percent of that in milk.[10]

Nitrogen-balance studies conducted in Colombian children 24–29 months of age who were recuperating from calorie-protein malnutrition concluded that: fed common maize, the children lost 54 mg of nitrogen per kg per day; fed opaque-2 maize, they lost only 8 mg of nitrogen per kg per day; and fed milk, they gained 2 mg of nitrogen per kg per day. Thus, the nutritionally improved maize was not quite as good as milk, but it was far better than the unimproved maize. In this experiment, a casein diet was used as the protein of reference. Nitrogen retention of opaque-2 maize was 27 percent, and of casein 30 percent; absorption of nitrogen of opaque-2 maize was 65 percent, and of casein 87 percent. Pradilla and coauthors concluded, "When the responses between the proteins from opaque-2 maize and of casein are compared, at the same level, net protein utilization and biological value of maize fall within the range of 80–90 percent of the value of casein."[11]

A 1983 dietary survey (24-hour recall) of 762 women and 292 children from rural Guatemala showed that lysine was the most limiting amino acid in 31 percent of the diets in women and in 36 percent of those in children. Tryptophan was the most limiting in 20 percent and 12 percent of the diets in women and children, respectively. (Methionine and cystine were the most limiting amino acids in about 45 percent of the diets.) If common maize (8.2 percent protein) was replaced by opaque-2 maize (8.2 percent protein), all diets would become satisfactory in tryptophan, and the percent of diets limited by lysine would decrease to 11 percent and 18 percent, respectively, in women and children. The percentage of diets with a chemical score of less than 75 percent would decrease from 35 percent to 15 percent in women and from 38 percent to 17 percent in children.[12]

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[9] Viteri et al., 1972.
[10] Bressani, 1966.
[11] Pradilla, et al., 1975.
[12] Valverde et al., 1983.

FIELD NUTRITIONAL TRIALS WITH QPM

Although the former nutritional trials with opaque-2 maize are applicable to QPM, most of the promising QPM materials have also been independently evaluated. They, too, show high performance (see table 6.1 and box page 33). Their true digestibility is slightly inferior to that of normal maize, but all surpass normal maize in biological value and net protein utilization.

Experiments now under way in Peru are showing that in malnourished children, QPM can be the sole source of protein. The subjects are children from the slums of Lima who are recovering from malnutrition. They are largely from Indian families familiar with maize and its preparation, and have been carefully screened so as to be free of disease or other complicating factor. The children are fed for three months and the gains in weight, height, and muscle mass are compared with those of children whose only protein source is milk formula.

The results show that on a gram-for-gram basis, children grow more slowly on QPM than on milk. This is explained by the fact that maize protein and maize carbohydrate (starch) are less digestible than milk protein (casein) and milk carbohydrate (sugars). Raising the QPM intake by 20 percent, to make up for this, provides equal growth rates. These trials indicate that only differences in protein and carbohydrate digestibilities separate QPM from milk as a food for catch-up growth in malnourished infants.[13]

FAMILY USE

For all its newness, QPM should require no change in the family's habits. People already using common maize should find QPM indistinguishable in appearance and feel. It has little or no differences in texture or flavor from normal maize. Moreover, QPM is as easy to prepare as common maize, and its cooking times are the same. Nor is there any difference in the flavor of breads, cookies, biscuits, tortillas, or other products made from it.

COMMERCIAL USE

QPM is as yet too new to have been used in commercial food products; however, baked goods have been made in the Centro Internacional de Mejoramiento de Maíz y Trigo (CIMMYT) laboratory using blends of whole QPM flour and wheat flour.

[13] This is not to suggest that milk can be replaced by QPM, but it does show that QPM can be a nutritional backup to milk. (Information from G. Graham.)

TABLE 6.3 Amino Acid Content of Processed Foods Made with QPM.

	Tortilla		Corn Chips	
	Normal Maize	QPM	Normal Maize	QPM
Arginine	4.4	7.2	4.5	5.7
Histidine	3.2	4.3	3.1	4.2
Isoleucine	3.5	3.5	3.8	3.5
Leucine	12.9	9.6	14.3	9.7
Lysine	2.5	4.2	2.6	3.9
Methionine*	2.1	2.1	2.7	1.6
Phenylalanine	5.3	4.5	5.1	4.4
Threonine	3.7	4.2	3.7	3.7
Tryptophan	0.50	0.86	—	—
Valine	4.7	5.5	5.2	5.6
Alanine	7.9	6.6	8.1	6.2
Aspartic Acid	6.2	7.4	14.2	14.9
Cystine*	1.5	1.8	—	—
Glutamic Acid	18.3	16.4	20.4	16.9
Glycine	3.7	5.3	3.8	4.7
Proline	7.3	8.1	13.9	—
Serine	5.2	5.5	4.8	4.5
Tyrosine	3.5	4.0	4.5	3.6

* Partially destroyed during acid hydrolysis. (Grams per 16 grams N)

SOURCE: Sproule, 1985.

As with any form of maize, QPM by itself has only a limited potential in leavened breads because it lacks gluten, the elastic protein needed to make dough rise. However, it shows promise for supplementing wheat flour. This is important because many maize-producing countries import wheat and find it necessary to dilute wheat flour with local flours to make it go further. As much as 20 percent QPM can be added to wheat flour without seriously affecting the loaf value and crumb quality of leavened breads. More than 25 percent, however, decreases the ease of rolling and reduces loaf volume.[14]

QPM has outstanding promise in unleavened foods such as tortillas and corn chips (table 6.3). The nutritional value of tortillas made with QPM was found to be superior to that of the normal-maize product.[15] Thus, QPM could have a major impact in Mexico and Central America where tortillas are basic to the daily diet.

In addition, the quantity of protein can be boosted even more by removing the starch from QPM kernels (without first eliminating the germ). This produces a food concentrate. A white and attractive product, it contains 36 percent protein and 14 percent oil and is nutritionally similar to soybean—a food that in Africa and Latin America is expensive and often unavailable because it is imported and

[14] Information from Protein Quality Laboratory, CIMMYT.
[15] Sproule, 1985.

requires foreign exchange. In the future, locally produced QPM concentrate might become a worthy soybean substitute.[16]

Wet-milling QPM into a whole-kernel meal should make several products available: a protein of much higher nutritional value than the endosperm meal; a carbohydrate of high digestibility; and a lipid component that contributes energy and meets essential fatty acid and vitamin E requirements. Fortunately, wet-milling is the custom in nearly all developing societies. (Dry-milling removes most of the germ; therefore, the high-quality protein and oil are largely lost.)

LIVESTOCK FEED

People indirectly consume vast amounts of maize in the form of animal products such as meat and eggs. This is especially so in the industrialized nations where maize is used to feed poultry and pigs. Because of maize's nutritional deficiencies, poultry and pigs, like humans, suffer malnutrition in many parts of the world. Their diet, too, can be grossly deficient in the amino acids essential for normal growth, health, and reproduction. For both poultry and pigs, QPM has a bright future.

[16] Development of QPM concentrate is being undertaken at INCAP in Guatemala (see chapter 4).

7
Genetics

When, in the 1970s, technical and economic obstacles dampened the widespread enthusiasm for opaque-2 maize, scientists at the Centro Internacional de Mejoramiento de Maíz y Trigo (CIMMYT) continued working toward transforming this plant into a crop that could compete with normal maize both in the field and in the marketplace.[1] Judging that the problems, although formidable, were not insurmountable, they set out to do the following:

- Create opaque-2 germplasm with a hard endosperm;
- Maintain the high-quality protein;
- Use breeding schemes that permit concurrent improvement of both kernel hardness and general agronomic traits;
- Screen the products at multiple sites to engender wide adaptability; and
- Develop simple chemical analyses for both preliminary analysis and for rapid assessment of large numbers of samples.

This was a daunting challenge. During its evolution over tens of thousands of years, maize has produced kernels that are high in prolamines. Transforming it into a low-prolamine form amounts to reversing the thrust of nature. The task is complicated even more because in this case the backcrossing procedure normally used to generate plant varieties is ineffective.

However, from the beginning researchers observed that, although most opaque-2 kernels are soft and chalky, a few ears have odd kernels that are partially transparent. They also noticed other rare kernels with islands or bands of hard endosperm. (In fact, even in nature a few opaque-2 kernels are difficult to distinguish from normal dent or flint maize.) Because these kernels still had high tryptophan and lysine

[1] Funds for this project were provided by the United Nations Development Programme (UNDP). Since 1970, a total of $7 million has gone to quality-protein maize (QPM) development. Today, UNDP is continuing, even increasing, its support for the breeding and international testing of QPM, as well as for training laboratory technicians from Third World nations in QPM analysis.

levels, the opaque-2 gene was obviously still present. Thus, these unusual kernels were not caused by mutations of the opaque-2 gene. Instead, they arose from the combined interaction of the opaque-2 gene with other genes.

GENE MODIFIERS

In simple, classical genetic terms, modifiers are genes that influence the expression of a nonallelic gene or genes. They are minor genes that exert their influence chiefly by intensifying or diminishing the expression of major genes. Their effects are weak.

The CIMMYT strategy to convert opaque-2 maize into quality-protein maize (QPM) has focused primarily on such genetic modifiers—those that can stimulate the opaque-2 gene to produce kernels with desirable marketplace characteristics.

Initially, CIMMYT researchers targeted kernel appearance and weight as priorities. They intercrossed opaque-2 types with partially transparent, dense kernels, thereby creating diverse "source stocks" of hard-endosperm opaque-2 maize. Several cycles of recurrent selection from each source stock then were employed to create genetic "families" whose kernels had both high nutritional value and desirable agronomic characteristics. After each cycle, individual kernels from hard-endosperm ears were selected from among these families. The protein quality was checked constantly, with some 25,000 samples being analyzed each year.

In general, hard-endosperm traits were easier to find and accumulate in flint-type than in dent-type maizes. They were originally found mainly in yellow-flint varieties from the Caribbean, particularly in some samples from Cuba.

At first, chemical analyses were carried out just on the tiny bands of hard endosperm. Using a device reminiscent of a dentist's drill, almost microscopic samples were removed and their tryptophan and lysine levels checked. Those kernels containing the quality protein were replanted. The others were rejected. As the bands of hardness steadily increased, to eventually dominate the kernels' makeup, analyses were made on larger and larger samples, and later, when favorable modifiers had been accumulated in abundance, analyses were sometimes performed on the whole kernel. This is perhaps a more realistic process, but the ability in the early stages to remove portions so tiny that the seeds remained viable was the critical key to success.

In this way, by 1974 CIMMYT had developed four basic donor stocks that were broadly adapted to typical agroclimatic zones. Subsequently, it began systematically improving them in international trials.

Initially, one cycle of improvement was completed each year. Some 250 families would be generated and analyzed in Mexico's winter season (November to April); then, during the following season, they would be tested in six locations in both the northern and southern hemispheres, using six local maize varieties as checks.

While these trials were being conducted, the families were also grown in stress trials and analyzed in Mexico. In the stress trials, each was evaluated for its ability to withstand diseases, insects, and high-density planting. Specifically, families in the disease nursery were rated for their response to stalk rots and ear rots (under artificial inoculation); families in the insect nursery were rated for resistance to fall-army-worm (also under artificial infestation); and families were rated for yield, barrenness, and lodging (the inability to remain upright in windy or rainy conditions) when planted at high density.

Based on both the international trials and the stress trials, about 40 percent of the superior families were analyzed and selected each year. In the subsequent growing season, reciprocal crosses were made between individual plants of these families. And, at harvest, 250 pairs of ears were analyzed and selected for the next cycle of evaluation.

During more than 10 years of this massive and complex process, genetic modifiers that favor normal kernel appearance and density were accumulated.

Once this approach had served to gather the desired modifier genes, all the resulting germplasm was merged and reorganized. This was done by putting closely related materials together in individual "gene pools" or "populations."[2] By 1984, there were seven pools of QPMs for the lowland tropics, six pools for the subtropics, and seven pools for tropical highlands. In addition, there were six tropical and four subtropical populations. Pools were improved continuously, and superior selections from them were fed into the populations if and when needed.[3]

Today, QPM pools are constantly being improved and broadened by the addition of QPM families from other sources—carrying resistance to certain diseases, for instance. These serve as backups for the populations that are being advanced toward commercial applications.

KERNEL APPEARANCE AND DENSITY

Hardness (vitreousness) is distributed in the modified opaque-2 kernels in both irregular and regular patterns. In irregular types, the

[2] In CIMMYT terminology, populations are more advanced than pools. They are more uniform and genetically less variable.

[3] In each pool, 400–500 (half-sib) families are handled in an isolated half-sib recombination block. By 1986, most of the pools had gone through seven or more cycles of selection in a simple half-sib manner.

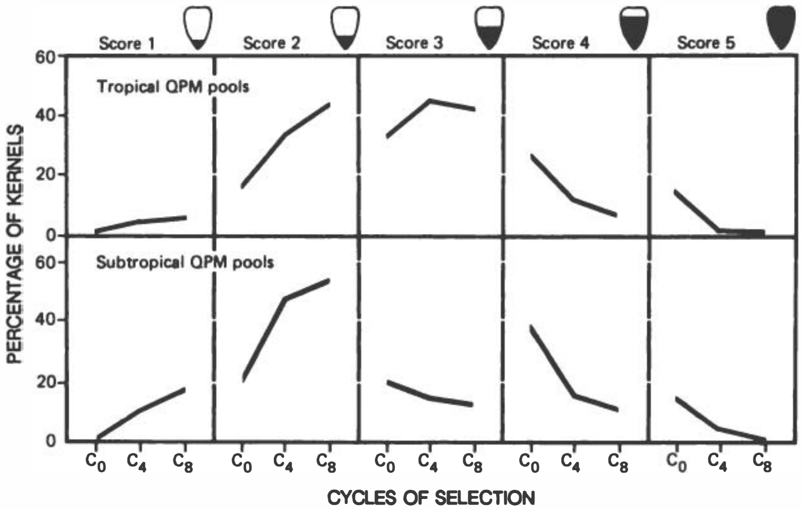

FIGURE 7.1 In converting opaque-2 maize to QPM, the main approach has been to select for greater kernel weight in segregating generations, carrying out recurrent selection, and hardening the endosperm by accumulating genetic modifiers. In addition, all ears that exhibited poor dry-matter accumulation were discarded.

The advances made in eight cycles of selection are represented in the chart by changes in the frequency of the various scores for kernel modification. A hardness rating of 1 indicates kernels that are completely hard (vitreous) and a rating of 5 indicates kernels that are completely soft (floury). During the conversion of opaque-2 to QPM, the scores have changed dramatically; the softness (4 and 5) has practically disappeared: the hardness (1 and 2) has increased to the point of complete dominance. (CIMMYT, 1985a)

hard endosperm forms bands, "bridges," scattered specks, or concentrations at the base of the kernel. It seems unlikely that this type of variation would be useful; therefore, it has received little attention. In the regular type, kernel hardness increases in a systematic way from the top of the kernel towards the base. Kernels showing this pattern are the ones that have been selected for improvement.

Steady progress in accumulating modifiers that increase kernel density has been achieved in every cycle of selection. But when the breeding first began accumulating hard endosperm, the ears of many genotypes developed gaps between the kernel rows. Consequently, CIMMYT researchers later selected ears with less and less inter-row space, until ears filled with normal-sized kernels and near-normal numbers were obtained.

This strategy led to the conversion of soft opaque-2 kernels into the hard QPM kernels (figure 7.1). Throughout the selection process, any kernels with a dull or chalky appearance were discarded. Accordingly,

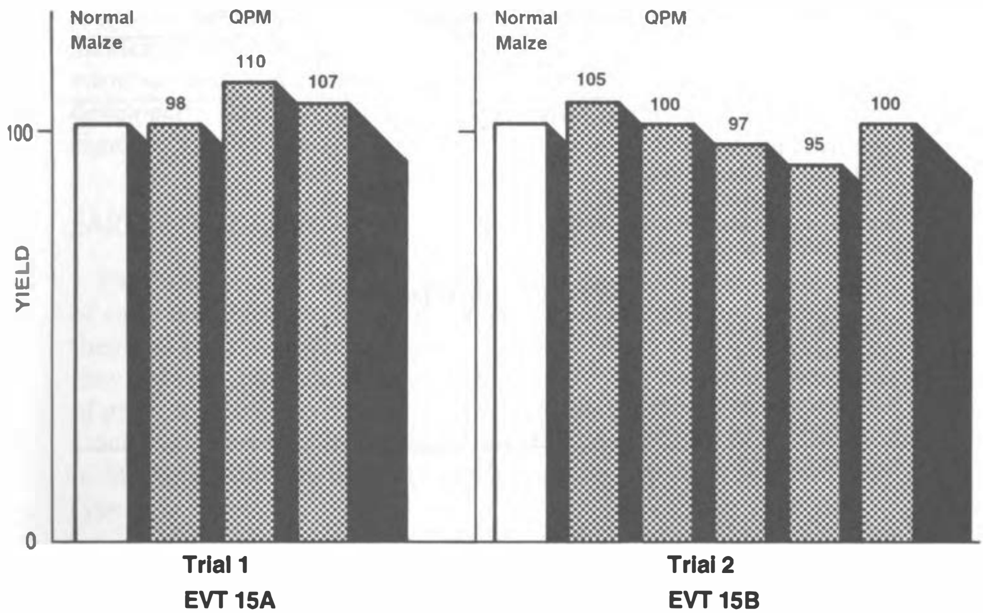

FIGURE 7.2 In many countries, QPM yields are indistinguishable from yields of the best normal-maize varieties. The results in the figure are from experimental stations in 33 locations in several countries. Local checks were the best yielding local variety of common maize. The figure shows that in results from two 1983 experimental trials, QPM performed as well as (and sometimes better than) its normal maize counterpart. The actual yield figures are given in table 8.2. (CIMMYT, 1985a)

the dull endosperm of opaque-2 maize gradually changed to the ''clear'' endosperm of normal maize. The resulting QPM has a shiny, translucent appearance.

YIELD

Perhaps the main reason that opaque-2 maize was abandoned in the 1970s was low yields. To overcome this trait has not been easy. Yield and kernel hardness are not usually correlated, so CIMMYT was forced to select for yield and kernel characteristics separately and concurrently.

Despite the complexities, steady progress has been made by recombining the highest yielding progenies. This has permitted the gradual accumulation of favorable genes (actually alleles) for yield. As noted, some of the recent selections have had yields similar to or better than their normal-maize counterparts (figure 7.2).

TABLE 7.1 Ear-Rot Data for QPM in Experimental Variety Trials, 1983.

Sample	Ear Rot (percent)
Test 1 (EVT 15A) (22 locations)	
QPM (Poza Rica 8140)	15.2
QPM (San Jeronimo (1) 8140	12.8
QPM check (Across 7940 QPM)	13.5
Normal maize check (Across 7926)	15.1
Local check mean (normal)	13.1
Test 2 (EVT 15 B) (7 locations)	
QPM (Tlatizapan 8141)	1.5
QPM (Across 8141)	1.4
QPM (La Platina 7941)	2.3
Normal check (Across 7845)	2.7
Local check mean (normal)	1.2

SOURCE: CIMMYT, 1985a.

One cause of low yield is that dry matter stopped accumulating in the grain approximately one week earlier than in normal-maize kernels. In the final stages of selection that trait was also overcome.

MOISTURE CONTENT

A problem requiring special attention was the higher-than-normal moisture content of the opaque-2 kernel (as measured at the time of harvest). It was observed that among genetically similar opaque-2 stocks a few ears lost moisture more quickly than the rest. By tagging plants that silked at the same time and then harvesting the crop 3–5 days earlier than usual, the fastest drying ears could be identified by measuring moisture content daily.

The physical causes of quicker drying are thought to be: a kernel "skin" (pericarp) that is thinner and more permeable, better compression of the starch against the pericarp, less husk cover, and perhaps hydrophilic compounds in the grain. However, so far, there are no strong data to determine which, if any, of these possibilities predominates.

FUNGAL INFECTIONS

The higher incidence of fungal ear rots in opaque-2 maize results, at least in part, from its soft kernels and higher moisture content. Hardening the kernels automatically reduced the incidence of ear rot. For most areas, the current QPM strains have shown adequate resistance to ear rots. Nevertheless, for hot and humid climates the incidence can be above normal (table 7.1). To reduce this, QPM varieties with tight husks that cover the entire ear are now being developed. This provides additional protection for such fungus-prone regions.

EARLY MATURITY

CIMMYT researchers use the number of days to silking as a measure of early maturation in a breeding pool. In selecting for quick maturity, they mark early-flowering plants, and after 70 percent have flowered, they detassel all plants in the male rows to eliminate any possibility of pollination by late-flowering types. This has helped to develop QPM stocks having earlier maturity. Today, the ''early QPM pools'' mature in 90 days from the time of planting, as do the early normal-maize types.

STABILIZING THE IMPROVEMENTS

Several breeders working on QPM materials have noticed that genetic modifiers can be unstable under different environmental conditions. For instance, QPM seed from the same source may result in different-looking kernels when grown in different locations. Even isogenic QPM materials grown at a single location can show inconsistent proportions of soft and hard kernels.

Experience, however, shows that it is possible to stabilize modifiers by carrying out six or more cycles of selection for stability as well as by ''shuttle-breeding,'' in which the plants are grown successively at two different sites and only those giving high yields at both are retained. After this, the materials attain a fairly high frequency of modifiers, and most appear to be stable over many environments. Today, the variation at the ear level has been reduced to a minimum, but variability within the ears persists. It, too, is diminishing with every successive generation.

GENETIC INSIGHTS

CIMMYT has demonstrated that significant progress in overcoming undesirable effects of otherwise desirable single genes can be made through the use of gene modifiers. The extent to which this is applicable to other species and other problems is as yet unknown. Nevertheless, the QPM experience has been a success and could become a model for the future.

8
Experiences Around the World

Although quality-protein maize (QPM) is still new, experiences with it are beginning to accumulate in various parts of the world. A number of them are summarized here.

LATIN AMERICA AND THE CARIBBEAN

Many countries of Latin America and a few of the Caribbean are now evaluating QPM at the farm level. The recent QPM entries have demonstrated yields comparable to those of normal maize (table 8.1).

Mexico

Numerous trials at Centro Internacional de Mejoramiento de Maíz y Trigo (CIMMYT) have evaluated tropical, subtropical, and highland QPM materials in various parts of Mexico.

A few varieties (most notably Composite I, Puebla opaque-2, and a highland modified opaque-2 composite) are now being grown on a small scale by farmers in the state of Michoacan. Other materials

TABLE 8.1 Performance of QPM in Experimental Variety Trials, 1983.

Entry	Mean yield (kg per ha)	Percent of normal check
Trial 1 (25 locations)		
Across 8039	4,077	98
Poza Rica 8140	4,546	110
Across 8140	4,443	107
Across 7726 normal (check)	4,145	100
Trial 2 (8 locations)		
Tlaltizapan 8141	5,195	105
Across 8141	4,978	100
Across 7941 (check)	4,809	97
Antalaya (1) 8141	4,711	95
Across 7845 normal (check)	4,967	100

SOURCE: CIMMYT, 1985a.

TABLE 8.2 Performance of Variety Nutricta in a Central American Regional Variety Trial, 1983.

	Yield (kg per ha)	Percent of check
QPM (Nutricta)	5,298	98
Normal maize (ICTA-B_1)	5,235	98
CENTA H_5 (check)	5,397	100
Los Diamantes 8043	5,248	97
Tocumen 7428	5,095	94
La Maquina 7727	4,780	88
ICTA HB-83	6,189	114
CENTA HE 20	6,008	111

SOURCE: CIMMYT, 1985a.

(Tuxpeño-1 QPM and Poza Rica 8140) are being multiplied for pig-feeding trials. Also, Mexico's biggest breadmaking company is testing QPM in snack foods and other products with an eye to commercializing them.

El Salvador

In farm-field tests, QPM has shown slightly higher yields than the hybrid that is currently the most popular farm variety in El Salvador (grown on 40 percent of the maize land). In lowland tropical areas, one QPM (CENTA M5B) showed a per-hectare yield of 5,534 kg compared with the common-maize hybrid (H-3) yield of 5,460 kg. In other trials, the top experimental QPM variety (HE 20) outyielded (at 7,390 kg per hectare) the best experimental hybrid in the country.

Guatemala

Guatemala, one of the leaders in QPM research, has been growing QPM varieties since 1981. In 1983, it became the first country to release a variety for commercial production. Named Nutricta, it is an open-pollinated, hard-endosperm QPM (known to CIMMYT as Tuxpeño-1 H.E.o_2). It has demonstrated a yield potential of more than 4 tons per hectare at the farm level (table 8.2). In 1986, Guatemalan farmers planted 140 hectares of it. Efforts are under way to produce enough seed for planting this variety on more than 1,000 hectares.

Building from the Nutricta source population, Guatemalan researchers have developed new varieties that seem to be more uniform, have better husk cover,[1] and have demonstrated even higher yields.

Guatemala is a model example of how a country may adopt QPM. Two institutions—Instituto de Ciencia y Tecnología Agrícolas (ICTA), and Instituto de Nutrición de Centro América y Panamá (INCAP)—

[1] Having husks that cover the tip of the ear tightly is important for reducing ear rots and bird damage.

FIGURE 8.1 A Guatemalan farmer shows to CIMMYT scientists ears of Nutricta, a QPM variety, harvested at a demonstration plot in the Salama area. (M. Castillo)

are introducing the crop. They have set up a joint board to hasten its adoption. The board, now known as the Nutricta Commission, is composed of representatives of the seed industry, the food industry, the government, ICTA, and INCAP.

From the beginning, there have been almost no problems in producing seed or in getting farmers to grow it. Indeed, there have been too many requests for seed. (As a result, in 1985, two Guatemalan farmers each produced 50 tons of QPM seed for sale to government agencies and other farmers.) There are high expectations that this spontaneous enthusiasm will remain and that QPM cultivation will continue to expand. The Nutricta Commission now forecasts that within five years some 10 percent of all Guatemala's maize will be QPM.

Demonstration plots (average size 0.5 hectares) have been established in 89 rural locations (figure 8.1). Although Guatemala has many microclimates, 60 percent of the area devoted to maize is in the tropical lowlands where the Nutricta variety is adapted. There, Nutricta has far outproduced the local variety. It has yielded as much as many of the superior normal-maize varieties included in agronomic evaluation trials.

Several pilot studies have tested QPM's acceptance in the poverty-stricken, maize-consuming populations who live on coffee plantations. In one, bags of QPM were distributed to more than 400 families, and the grain was accepted as well as, or better than, the varieties of maize usually available. In another, 636 tons of QPM were produced in various maize-growing areas of Guatemala over a period of three years. The producers included small landholders, landless laborers, and large-scale maize farmers. These experiences suggest that the varieties used posed no problems of lower yields or more sophisticated agricultural practices. This project also monitored QPM storage on the coffee plantations and in households, and was unable to detect any higher losses than with common maize.

Other Central American Countries

Costa Rica, Panama, Haiti, and the Dominican Republic are all evaluating inbred QPM lines with the goal of producing QPM hybrids. Costa Rica is a particularly promising target country because its government decrees that all tortillas must be nutritionally enriched. Currently, its tortilla flour is enriched with 8 percent soybean meal—a product that must be imported. QPM, by comparison, could be grown domestically.

Honduras has one QPM variety (Tuxpeño-1 H.E.o_2, locally called Nutridia) that is being multiplied on two hectares for on-farm trials.

Colombia

Colombia is testing progeny of QPM germplasm derived from CIMMYT QPM Populations 61, 62, and 63.

Venezuela

Venezuelan researchers are testing an experimental QPM variety (Across 7740). So far, yields have been good in the field and 40 tons of seed have been produced. The goal is to use QPM for *arepas*, a flat, unleavened, roasted maize product that Venezuelans eat at breakfast. Results show that food grits from QPM are 4–5 percent below normal in yield. Chances are good, however, that the latest QPM versions, with their more vitreous endosperms, will do better.

Peru

Peruvian researchers are working on experimental varieties derived from several QPM populations. Tuxpeño-1 QPM, Opaco Huascaran (Comp J), and experimental varieties from CIMMYT's population 40 have performed well and yielded more than 5 tons per hectare. Researchers are testing QPM as a part of a program to boost maize production in the coastal and forest areas of the country. Opaco Huascaran has been released to farmers.

Bolivia

Bolivia is growing about 15 hectares of two QPM varieties (Tuxpeño opaque-2 and Chuquisaca 7741) on a small scale in a subtropical area, primarily for pig production.

Brazil

Brazil ranks third in the world in maize production, with about 21 million tons produced annually. In addition, malnutrition in many of its urban slums and in the poverty-sticken Northeast is severe. So far, QPM has not been released for commercial use, but Brazilian maize breeders are testing CIMMYT QPM varieties extensively. Their goal is to create inbred lines from which hybrids adapted to local needs can be developed.

Paraguay

In 1985, Paraguayan researchers released one QPM variety, called Nutri Guarani V-241 (Population 66 from CIMMYT). Its yields are somewhat lower than normal maize, but it matures more quickly.

Argentina

Although extensive maize production does not necessarily make a country a candidate for QPM, Argentina produces more than 13 million tons of maize annually and it has a substantial swine industry. It is currently increasing some QPM materials for use in pig-feeding trials.

EUROPE

Europe is a significant maize-growing region. The Soviet Union's annual production averages about 14 million tons; Romania and Yugoslavia each average over 10 million tons; Italy (6.7 million tons) and Hungary (7.5 million tons) are also important producers. The crop is grown in France, West Germany, England, and other nations as well. There has been extensive work with the soft-endosperm opaque-2 varieties and, more recently, with QPM as well. Given the level of human nutrition in these countries, QPM should principally benefit the animal feed industries. However, the potential exists for marketing QPM-based snack foods, breakfast foods, and other consumer products in which enhanced nutritional qualities could be selling points.

AFRICA

QPM has particular promise for Africa, notably for Ghana, Ethiopia, Kenya, Zambia, Zimbabwe, Malawi, Mozambique, and other countries that have large concentrations of often malnourished refugees. In addition, Africa's livestock industry is increasing and QPM also has potential there.

In general, Africans prefer white maize, and it is noteworthy that some of the most promising QPM materials do indeed have white grain.

Senegal

In Senegal, seed of QPM materials (Obregon 7740 and Temperate White QPM) is being increased and evaluated in on-farm tests. It seems likely that they will be recommended for large-scale adoption.

Ivory Coast

Experiment stations at Serkessedougou and Bouaké have been testing CIMMYT QPM materials. Population 66 (late, yellow-dent QPM) was the best entry in the first test. Its yield was measured at 7,128 kg per hectare. The best normal-maize check measured at 6,466 kg per hectare.

South Africa[2]

In a research program conducted over a period of more than two decades, the South Africa Department of Agriculture has developed a commercial hybrid of opaque-2 maize. In 1987, the cultivar called "HL2" was released to seed companies. It is best adapted to Natal province, and trials conducted by the Summer Grain Centre demonstrate that it is agronomically comparable to many of the common-maize hybrids cultivated on a large scale in South Africa. Frequently, it even surpasses them in yield, resistance to disease, and other agronomical characteristics (table 8.3).

Of 49 commercial maize hybrids tested in the Department of Agriculture national cultivar trials in the 1983/84 season, HL2 achieved the second highest average yield. The trials were conducted at five locations in Natal. At three of them, it achieved the highest yield. In cases where it gave lower yields, any disadvantage was reduced or even cancelled out by its extremely good resistance to ear rot. Serious ear-rot epidemics broke out in parts of the maize-growing area during 1986 and 1987, and HL2 yielded a higher percentage of first-grade maize than did the common-maize cultivars. In the 1984/85 season, this hybrid also showed the highest resistance to streak disease.

In 1977 trials, the Animal and Dairy Science Research Institute substituted high-lysine maize for ordinary maize in standard diets for pigs. The results indicated a savings of 22 percent on the fish-meal component usually included in pig diets as a quality-protein source.

[2] This section based on information from H.O. Gevers.

TABLE 8.3 Performance of South African High-Lysine Maize.

Cultivar	Percent rotten cobs	Grain yield	Percent total lodging	Percent sprouting	Cobs per plant
QPM					
HL2	5.45	5.20	9.05	17.59	1.12
Normal Maize					
PNR 6549	6.20	5.56	9.37	16.57	1.15
RO 405	6.80	4.84	8.15	10.74	0.96
SSM 2045	7.19	5.00	12.62	12.89	1.05
RS 5206	7.23	5.13	12.51	10.92	0.98
PNR 6514	7.35	5.26	6.89	14.27	1.09

SOURCE: South Africa Summer Grain Centre. The normal-maize figures are for the top five cultivars out of 49 tested in the Centre's national cultivar trials (1986/87 season).

A feedstuff's amino-acid composition is less important to cattle, sheep, and other ruminants than it is to monogastric animals such as pigs. However, experiments at the Animal and Dairy Science Research Institute found that weanling calves fed HL2 in whole form increased their daily weight gain approximately 28 percent over those fed common maize.

ASIA

Asia is also promising for QPM. It has the largest population of swine in the world and has extensive maize-growing areas.

China

QPM materials have shown good prospects for cultivation in China, particularly in the southern regions. One (Tuxpeño-1 QPM) has already outyielded normal maize. From a small quantity of CIMMYT seed, breeders now have grown 15 hectares of this variety to produce seed for distribution to farmers.

QPM has also been evaluated in pig-feeding trials, with favorable results.

Chinese geneticists have, with CIMMYT help, set up their own populations of QPM. From these, they are selecting for modifiers. In northern China, with its temperate climate, inbred lines are being extracted from CIMMYT's tropical and subtropical QPM germplasm. One of these is already being used in an experimental hybrid.

India

India, too, is a promising target for QPM. It produces more than 7 million tons of maize each year, and the use of QPM could prove enormously beneficial. It may prove of particular local importance in the mountain and hill areas of the Punjab and the northwestern provinces where maize is a major food crop. Indian scientists are conducting trials using QPMs from CIMMYT, but so far none has been released for farm production.

Vietnam

Vietnam has recently released a QPM variety based on CIMMYT's Population 63.

9
Research Needs

As pointed out earlier, there is still much to be done before QPM can achieve its potential worldwide. Some general funding needs are:

- To sustain basic QPM research at Centro Internacional de Mejoramiento de Maíz y Trigo (CIMMYT);
- To extend and sustain the programs at other institutions collaborating with CIMMYT;
- To begin integrating QPM into national programs, including support for in-country adaptive evaluations (including postharvest handling);
- To create a "pipeline" for the tons of seed needed for commercial use; and
- To support national breeding programs to develop QPM for their individual conditions.

IN-COUNTRY RESEARCH

Overall, the next requirement is to intensify the testing and selection of QPM in suitable areas of need. This, in itself, is a demanding enterprise, and it is urgent that Third World countries develop national programs to collaborate with CIMMYT to evaluate QPM materials for local use.

Effective seed production is vital to the ultimate success of any new crop introduction, and even more so to QPM, in which the vital gene is recessively inherited. The effective delivery and marketing of seed, and the maintenance of genetic purity, are all critical in creating a local industry.

REGIONAL RESEARCH NEEDS

As previously noted, QPM should fit particularly well where diets are highly dependent on maize or root crops; for example, in parts of

Brazil, the Andean region, Central America, Mexico, coastal West Africa, Central Africa, Ethiopia, Kenya, Malawi, Mozambique, the outer islands of Indonesia, Vietnam, and the Philippines. Research to adapt the crop to these regions is needed.

In particular, to be useful in many areas of Africa, QPM must be improved for resistance to streak virus. (This is true of normal maize as well.) Resistance to downy mildew should also be developed in QPM to make it more beneficial for Asian countries where this fungal disease is serious.

FIELD STABILITY

Remaining questions about QPM's field stability, protein quality, and endosperm expression would best be answered by more definitive research, especially outside Mexico. Most of the work done so far has been in Mexico, where over the years the process of selection has produced QPM varieties that behave predictably year after year. In international testing, however, some QPM populations seem to be strongly influenced by climate and do not behave as expected. This is true of all crop varieties, but in the case of QPM, the instability of the gene modifiers adds an additional uncertainty to be studied, codified, and overcome.

The question of how to maintain QPM's genetic purity in commercial production is also a concern. More definitive evaluation should be made to establish the cheapest and easiest methods both for maintaining genetic purity in production fields and for monitoring protein-quality levels in commercial practice. A method under consideration is the introduction of yellow QPM in areas where white maize is used and white QPM where yellow maize is used. Also, there is the possibility of creating hybrid QPM varieties that would not be contaminated because of genetic incompatibility with other maize varieties.

GENETIC RESEARCH

More basic work on the genetics of modifiers is needed. The wide array of QPM germplasm can now be employed to improve understanding of their behavior. Efforts should also be made to identify simply inherited modifiers for inbred conversion programs. These (1- or 2-gene) simply inherited modifiers—if they exist—would make the process of creating and perfecting QPM much easier.

Another research area is to develop varieties of QPM that will not cross with normal maize, thereby eliminating the possibility of genetic contamination.

Molecular geneticists could benefit QPM's development enormously by resolving basic genetic uncertainties relating to the modifiers. Since modifiers are inherited quantitatively, it is important to know how many modifier genes are involved and where these are located. If the opaque-2 gene and its specific modifiers could be identified, their transfer to other genetic backgrounds would be greatly facilitated.[1]

HYBRIDS

In most maize-producing regions there is the opportunity to grow both hybrids and open-pollinated varieties; however, countries that now rely on hybrids would find the switch to QPM much easier if it is available in hybrid form. Indeed, for most such countries, QPM is unlikely to be successful unless hybrid performance is satisfactory.

Information on the combining ability of CIMMYT's QPM germplasm should be compiled to facilitate the development of QPM hybrids.

VARIETIES FOR TROPICAL HIGHLANDS

In some parts of the world, the soft-endosperm, floury maizes are preferred. This is particularly true in the highlands of Bolivia, Peru, and Ecuador. For such regions, work should be intensified to produce suitable germplasm having large floury kernels with good resistance to ear-rot pathogens.

MODIFYING AMINO ACID PROFILES

Opportunities exist for further increasing the proportions of proteins that carry the most desirable amino acid patterns. For example, the prolamine protein fraction in today's QPM stocks comprises approximately 30 percent of the protein. If this could be further decreased, the lysine, tryptophan, and biological value would rise to even higher levels than in today's QPM varieties.

Low levels of prolamines have been found also in high-oil, opaque-2 maize. For example, in one variety (designated R802, a high-oil opaque-2 inbred type) the percentage of prolamine (actually zein) in the whole-kernel protein is down to approximately 22 percent.[2] This suggests that further improvement in both protein quality and food

[1] A start on this has been made. See, for example, Schmidt et al., 1987.
[2] Alexander and Creech, 1977.

energy (from the high oil content) of the whole grain can be expected. Appropriate breeding schemes deserve to be directed towards that end.

NUTRITION RESEARCH

Some specific needs are:

- Testing QPM in local food products in the regions where they are consumed;
- Testing QPM in nutritional supplements, such as Incaparina;
- Testing QPM in refugee-feeding programs; and
- Testing the acceptability for human consumption and industrial use on a large scale.

Some general research needs follow:

Creating indigenous foods using QPM. A major feature, not yet adequately addressed, is the acceptance of QPM for preparing maize-based foods such as tortillas, *arepas*, porridges, and gruels in actual local situations. It is known that these products can be made, but whether they have subtle differences that will affect local preference is uncertain.

Fortifying foods with QPM. Using QPM to fortify baked products seems to be a good approach for maize-producing countries that now import protein supplements to fortify foods. This is a common situation in many Latin American countries.

Developing QPM concentrate. The production of QPM concentrate (from which the starch has been removed) deserves attention. The process has yet to be perfected. Also, comparisons with soybean meal need to be conducted. Foods that could be fortified include: weaning foods, instant tortilla flours, *tamalitos*, and foods for nursing mothers.

CHEMICAL ANALYSIS RESEARCH

There is a need to create simple tests for quality protein that can be used in the field or at checkpoints to identify adulteration with common maize. Dye-binding with Acilane Orange G shows some promise because there is a correlation between amino acid content and dye-binding value.[3] Also, extracting maize endosperms with alcohol might be developed into a visual method to determine the prolamine content.[4]

OTHER CROPS

QPM might be just the opening wedge in an overall upgrading of the nutritional quality of the world's major cereal crops. For wheat and rice, no equivalent genes have yet been found, but scientists working on barley and sorghum have found genes, like those in opaque-2 maize, that increase the protein quality. These are worth much more study than they are now receiving.

Danish researchers, for example, are developing a barley (mutant 1508) that has one of the highest levels of lysine ever measured in a cereal—5 g per 100 g of protein. From this they have selected a variety (called Piggy) that has 14 percent protein. In its agronomic development, this has reached the point of giving 90 percent of the yield of the best normal-barley varieties. When fed to pigs (without additional protein supplement) it gave growth rates as good as those of commercial swine diets containing protein concentrates.[5]

The first-discovered high-lysine sorghum has been tested on people in Lima, Peru, but proved to have poor digestibility (45 percent instead of 80 percent) due to its high levels of tannin. Recently, however, it has been noted that the people themselves appear to have overcome the problem by fermenting it with wood ash. This opens up important new possibilities because sorghum has one of the lowest protein qualities of any cereal. The new mutant raises sorghum to about the nutritional quality of wheat.[6]

[3] Information from O.E. Nelson, Jr.
[4] Information from CIMMYT's laboratory.
[5] Information from Lars Munck, Department of Biotechnology, Carlsberg Research Center, Gamle Carlsberg, Denmark.
[6] Information from E. Mertz.

Appendix A

QPM's Future in the United States

This report highlights the potential of quality-protein maize (QPM) for developing nations. However, maize (corn) is the largest crop in the United States, which each year produces more than 100 million tons—almost half the world's total. It seems probable, therefore, that any report on a nutritionally improved corn will stimulate considerable local interest. Accordingly, we include this brief appendix to outline some aspects of the crop's domestic promise.[1]

* * *

Although the discovery of opaque-2 corn's exceptional nutritive qualities was made at Purdue University in 1963, so far it has been put to little use in the United States. Moreover, the new, hard-endosperm forms that are known as QPM have not been used here at all.

Despite this lack of local recognition, however, QPM could become a noteworthy part of the North American corn industry. Any improvement in the fundamental nutritional value of corn is likely to create new, unique, and premium markets.

There is, for instance, distinct promise for breakfast cereals and snack foods, both of which are constantly criticized for their low nutritional value. For them, QPM might provide both a nutritious product and an important public relations breakthrough.

QPM, however, is not ready for immediate use in the United States. It was created in Mexico with the needs of malnourished people in Africa, Asia, and Latin America in mind. As a result, it is available at present only in open-pollinated types, not the hybrids mainly used in North America. Research is needed to tailor QPM to U.S. environments and farming needs.

A research group at Texas A & M University has begun such research with promising early results. In Florida and Texas, their various QPMs have grown well. In 1987, inbred lines with acceptable

[1] In this appendix, we use the units most meaningful to American readers involved in farming and agribusiness. For the same reason, we use the name "corn" instead of "maize."

agronomic properties were crossed to produce experimental QPM hybrids.[2]

QPMs suited to Corn Belt conditions are under development at Purdue University. Four temperate populations (NTR1, NTR2, ITR, and STR) have proved to be well adapted. Also at Purdue, a number of Corn Belt inbred opaque-2 lines are being converted to QPM types. These plants are suited to Corn Belt conditions and retain their nutritive qualities, but they are not yet in forms suitable for release to farmers.[3]

DRY-MILLING

Although QPM's progenitor, the soft-endosperm opaque-2 corn, has been known for 25 years, its poor milling qualities meant that it was inappropriate for dry-milling. (The soft endosperm breaks so easily that it produces poor yields of grits.) QPM, on the other hand, is of a hard-endosperm type and gives a good yield of grits. Thus, it seems promising for items such as snack foods and breakfast cereals.[4]

The Texas A & M research group has shown already that QPM can easily be processed into tortilla chips and other products without greatly modifying the normal process. Acceptable tortillas and tortilla chips with a 50–percent improvement in nutritional value resulted from QPM.[5,6]

The researchers report the following results:

- QPM had smaller, more dense, harder kernels than food-grade corn.
- QPM contained twice as much lysine, tryptophan, and albumins/globulins as food-grade corn.
- Rats fed QPM gained at least twice as much weight as those fed food-grade corn and consequently had improved feed:gain ratios.
- Tortillas and tortilla chips of both QPM and common corn had significantly higher dry matter and energy digestibilities but lower apparent protein digestibilities than their respective raw grains.

WET-MILLING

In wet-milling, the corn kernels are soaked before being processed to separate the starch, which is converted into dextrose, sweeteners, and myriad other products. The soak water is evaporated to recover

[2] Information from L.W. Rooney and A.J. Bockholt.
[3] Information from D.V. Glover.
[4] The processing might have to be slightly modified because QPM tends to have a larger germ than normal and may give an oily dry-milled products.
[5] Sproule, 1985.
[6] Sproule, et al., 1988.

"gluten meal." Although a by-product, gluten meal contributes importantly to the profitability of the process. If QPM were substituted for common corn, the gluten meal's nutritional quality, and therefore its selling price, would likely rise substantially.

The early opaque-2 corns were unsuitable for wet-milling because of their lower than normal starch yields—15 percent lower in some cases. However, the new QPMs essentially can equal the 71 percent starch yield of normal corn.[7] Thus, for them, the extra value of the gluten meal by-product may be economically significant.

ANIMAL FEED

Another area where QPM may have considerable domestic impact is the livestock industry. One U.S. company[8] offers for sale nutritionally improved corn hybrids based on soft-endosperm opaque-2 corn.[9] Reportedly, these hybrids can produce 97 percent of the yield of normal corn hybrids. Feeding trials employing them have shown good results and have stimulated their wider use in several parts of the country, primarily in feed for hogs.

These commercial hybrids of opaque-2 soft-endosperm corn have attained a small but avid following. Official figures are unavailable because farmers who raise these varieties feed them exclusively to their own livestock and never sell them to elevators. However, unofficial estimates place production at well over a million tons a year. Testimonials from farmers who feed opaque-2 corn silage along with opaque-2 corn grain to dairy herds claim that it increases the milk production.

Such claims remain unverified by controlled experiments, although careful studies at the Nebraska Experiment Station have given some preliminary supporting evidence of the value of nutritionally improved corn as livestock feed.[10] These experiments show that when opaque-2, soft-endosperm corn is fed in place of normal corn to all classes of pigs, from weaning to finishing, the farmer can reduce the total level of dietary protein supplement (soybean meal) by 2 percent. This is significant because soybean meal currently sells at about three times the price of corn.

In the University of Nebraska study, some of the newer opaque-2 corn varieties produced yields comparable to those of normal corn hybrids. When diets were formulated on an equal lysine basis, pig performance was similar for normal and opaque-2 corn, even though the normal-corn diets contained about 3 percent more soybean meal than the opaque-2 corn diets.

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[7] Information from D.V. Glover.
[8] Crow's Hybrid Corn Company (see Research Contacts).
[9] Commonly marketed under the name high-lysine corn.
[10] Asche et al., 1985.

Appendix B

Suggested Readings and References

This appendix is in two parts. The first, Suggested Readings, lists articles of general interest that lead deeper into the subject of QPM. The second, References, lists citations for the papers footnoted throughout the report.

A. SUGGESTED READINGS

Quality-protein Maize: Centro Internacional de Mejoramiento de Maíz y Trigo (CIMMYT) Bibliography. This bibliography, which lists 178 titles relating to quality-protein maize, is available from CIMMYT. It covers published literature as well as studies, conference proceedings, and unpublished reports. Requests can be sent to: Scientific Information Unit, CIMMYT, Apartado Postal 6–641, 06600 Mexico, D.F.

Photocopies of the items listed in the bibliography can also be supplied. Photocopies cost US$.10 per page for Latin America (MN$25.00 in Mexico) and US$.20 per page for all other countries.

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Appendix D

Biographical Sketches of Panel Members

WILLIAM L. BROWN, retired president and chairman of Pioneer Hi-Bred International, received his Ph.D. from Washington University (St. Louis) in 1942. He joined Pioneer in 1945 as a cytogeneticist and did research in maize genetics and breeding until 1965, when he was appointed director of corporate research. He was elected executive vice president in 1973 and president in 1975. He is a member of the National Academy of Sciences and currently serves as chairman of the Board on Agriculture, National Research Council-National Academy of Sciences. Dr. Brown's research has centered around maize genetics and breeding, racial relationships in maize, evolution of North American maize, and conservation and utilization of genetic resources.

RICARDO BRESSANI, head of the Divison of Food and Agricultural Science and research coordinator of the Institute of Nutrition of Central America and Panama (INCAP), Guatemala, received his Ph.D. in Biochemistry from Purdue University in 1956; an M.S. from Iowa State University, and a B.S. from the University of Dayton. He has been a member of the professional staff of INCAP since 1956 and visiting professor at the Massachusetts Institute of Technology and Rutgers University in nutrition and food science. His work has dealt with the nutritional quality of basic food crops and human nutrition research. After the discovery of opaque-2 at Purdue, he evaluated samples for nutritional quality, using children and demonstrating the exceptional qualities of this type of maize. During his career at INCAP, Dr. Bressani has been involved in the development of high-quality foods such as INCAPARINA, MAISOY, and others; in studying new sources of nutritents; in food processing and evaluation; in human and animal nutrition; and in nutrition-intervention studies. His current work is on amaranth grain and food grain legumes, particularly common beans. He has published many scientific articles and chapters and has edited a number of proceedings of conferences. He is editor of *Archivos Latinoamericanos de Nutrición* and of the *Amaranth Newsletter*. He is a foreign associate of the U. S. National Academy of Sciences, founding member of the Third World Academy of Sciences, and Doctor Honoris causa in Agriculture from Purdue University. Recently he was granted the World Prize "Albert Einstein Award," by the World Cultural Council.

DAVID V. GLOVER, professor of plant genetics and breeding, Department of Agronomy, Purdue University, received a B.S. in Agronomy in 1954 and an M.S. in Plant Breeding in 1959 from Utah State University. He received a Ph.D. in Genetics from the University of California, Davis, in 1962, and has served on the faculty at Purdue since that time. His research has centered around the genetics, cytogenetics, physiological genetics, and breeding of maize germplasm with major emphasis on improvement of carbohydrate, protein, and nutritional quality factors. He served as principal investigator and coordinator of the Purdue-U.S. Agency for International Development project on the inheritance and improvement of protein quality and content in maize. He was involved in consultancy activities on protein and nutritional-quality improvement in cereals.

ARNEL R. HALLAUER, research geneticist, USDA/ARS and professor of Agronomy, Iowa State University, Ames, received his Ph.D. from Iowa State University in 1960 and has been stationed at Ames since 1962. His research interests have emphasized basic research of maize relative to quantitative genetics and recurrent selection and the evaluation and adaptation of exotic germplasm for the U.S. Corn Belt. He has written one book, *Quantitative Genetics in Maize Breeding*, serves as an editor for four journals, and has written numerous articles for scientific journals.

VIRGIL A. JOHNSON is leader of wheat research, U.S. Department of Agriculture, and professor, University of Nebraska-Lincoln. He received his Ph.D. degree in plant breeding and genetics from the University of Nebraska in 1952. He coordinates the cooperative state-federal hard red winter wheat program in central United States and supervises an international winter wheat evaluation network in 38 countries. He has been active in numerous international wheat activities. His research has involved the development of improved wheat varieties for the hard red winter wheat regions of the United States and the genetics and physiology of high protein in wheat.

CALVIN O. QUALSET, director of the California Genetic Resources Conservation Program and professor of agronomy at the University of California, received a Ph.D. in Genetics from that institution in 1964. He has served on the faculty at the University of Tennessee and was a department chairman and later associate dean at U.C. Davis during the period 1975–1986. His research area is on the genetics, breeding, and genetic resources of cereal crops, especially focusing on wheat and triticale. He leads a team that has introduced numerous wheat and triticale varieties to California agriculture and has published extensively on the genetics of characters important in adaptation of wheat to specific environments. He has served on several consultancies in developing countries and was a Fulbright Scholar to Australia in 1976 and Yugoslavia in 1984.

NOEL D. VIETMEYER, staff officer and technical writer for this study, is a senior program officer of the Board on Science and Technology for International Development. A New Zealander with a Ph.D. in organic chemistry from the University of California, Berkeley, he now works on innovations in science and technology that are important for the future of developing countries.

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