QUALITY-PROTEIN MAIZE

Report of an Ad Hoc Panel of the
Advisory Committee on Technology Innovation
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in Cooperation with the Board on Agriculture
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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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- *Amaranth: Modern Prospects for an Ancient Crop (1983)*
- *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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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.

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[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]

[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.

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