Better diets from quality protein maize varieties can greatly improve the health of children, usually the most nutritional deprived segment of the population.

QUALITY PROTEIN MAIZE

Efforts at CIMMYT to produce maize varieties that have the opaque-2 gene and normal, hard kernels promise to pay off in better nutrition for millions in the tropics and subtropics.

In the concern over the current world food crisis, the importance of maize is often underestimated: hunger is commonly understood as a question of rice and wheat. Indeed, while maize is second in production only to wheat among food crops in the developed countries, by far the largest part of the harvest is fed to animals. The USA, for example, which annually harvests 140 million metric tons of maize, feeds 80 to 90 percent to animals, ultimately to be consumed as meat, milk, and eggs.

But in the poorer countries of the world’s hunger belt, where 70 percent of protein is provided by cereals eaten directly, maize is the third most important cereal; the staple food, and the major source of both total calories and vital proteins, for hundreds of millions of people. From its primeval native soil in Mexico, Central and South
PROTEINS AND/OR CALORIES?

In the 5 years since the U.N. urged action against an "impending protein crisis," substantial improvement has been made in the protein quality of maize, and the potential for similar improvement of other crops has been indicated. Meanwhile, however, the question has been raised whether protein improvement does not divert resources from a more urgent need to provide more calories by increasing crop yields.

Some of the considerations suggesting such a conclusion were forcefully presented in a 1974 paper by Ryan, Sheldrake and Yadav of the International Crops Research Institute for the Semi-Arid Tropics:

- The established minimum daily requirements for both proteins and calories overstate real physiological needs.
- Estimates of nutritional status based on the protein values of staples overlook the supplementary protein sources that complement the staples in actual diets.
- Available statistics indicate that protein deficiency is endemic only at the lowest income levels, and then only in the context of overall caloric deficiency.

The authors conclude:

Improvement in the quality and quantity of protein in the existing diets of the vulnerable groups... will not achieve as much as an increase in the size of their diets, which will supply not only much-needed calories, but also significantly augment the protein aspect.... Improved protein and lysine content, whilst desirable in themselves, should not rate a high priority.

Without denying the importance of total calories in nutrition, however, there is also persuasive evidence for the validity of improving protein quality.

- Minimum daily protein requirements, even adjusted to be more realistic, do not satisfy the special needs of certain groups. According to K.L. Blaxter of the Rowett Research Institute, England, "the minimal estimates of protein needs of young children...are about 50 percent greater than those of adults...." Pregnant and lactating women, as well as sick people, also require increased protein for the manufacture of tissue. It is precisely these groups, most vulnerable to protein malnutrition, that make up a disproportionate fraction of the populations of developing countries characterized by high rates of birth and disease. Moreover, these groups include increasing numbers of urban poor, for whom the improvement of nutrition through increased yields at the farm level is most problematical.

- The scattered data do not always confirm the assumption that the protein deficiencies of staples are compensated by other sources. Dr. Joaquin Cravioto of the Hospital del Niño, Mexico, cites a study of a rural Mexican village where only four of the 304 1-year-olds regularly received the beans that are commonly assumed to be the universal protein complement to maize.

Another study, by Cornell nutritionist Diva M. Sanjur, Joaquin Cravioto, and others, identifies "sociocultural" factors that result in protein deficits in vulnerable groups despite general nutritional standards. Thus, for example, "in most African households, the person having the first choice of food is the husband or father...often the mothers and toddlers are

America, maize has been transplanted successfully around the world. It has taken root as an important food crop in West Africa; in East Africa, where production is up to 6.7 million tons per year and rising, and four countries—Ethiopia, Kenya, Malawi, and Tanzania—have annual maize harvests of a million tons or more; in the Indian subcontinent and Asia; and in the island nations of the Pacific: "Maize grows over a wider geographical range and over a wider range of environments that any of the other cereals," Dr. Sprague points out. "Maize has excellent adaptation and capability."

Because maize is ubiquitous and so widely accepted as a staple, there is a cruel irony in the fact that it is deficient in both the quantity and the quality of the food it delivers. The high-yielding maize hybrids developed over the last half-century for the conditions of the U.S. corn belt do not perform well in the tropics and semi-tropics where maize is an important food. In these areas, the

traditional local varieties in farmers' fields yield only 20 to 30 percent as much as the best maize under ideal conditions. While the U.S. corn belt farmer harvests 6000 kilograms from each abundantly watered and fertilized hectare, his counterpart on his rainfed, nutrient-deficient fields in Latin America is lucky to scratch out 1000 kilograms per hectare. Except in a few countries, while populations continue to grow apace and the virgin land available for cultivation dwindles to none, average national maize yields have remained virtually unchanged over the last decade.

Meanwhile, even when available in sufficient quantity, maize is an inadequate staff of life. The protein content of the maize endosperm—the fleshy part of the kernel—amounts to only about 9 percent of the total weight, and of this only about half is the kind that can be metabolized by the human body to manufacture new tissue, for which protein is the essential raw material.
the last to be considered." Data from rural areas of Latin America and West Africa indicate that early weaning, an increasingly common practice, produces "a deficit that cannot be compensated as the child is not permitted a full participation in the foods available to the other members of the family."

Another study cited by these authors correlates the weaning time in various countries with peak mortality associated with "a sudden transfer of the child to a modified, deficient adult diet." Furthermore, in some cultures "when a child gets diarrhea...it is precisely those foods of high protein value...which must be omitted from the diet."

- A sufficiency of total calories does not always insure adequate balanced protein. A survey by K.O. Rachie and L.M. Roberts points out that in "Uganda, where carbohydrates are more than adequate (3000 to 4000 calories per day), but proteins are inadequate, there may be as many as five malnourishment deaths per 1000 population—primarily in post-weaning children." Even D.S. McLaren, in an article titled "The Great Protein Fiasco," concedes the efficacy of protein improvement for the tens of millions of people whose diets are based on starchy roots. Ricardo Bressani of the Institute of Nutrition of Central America and Panama has pointed out that at any level of total calories the typical diet of many Latin American rural residents, which includes 72 percent maize complemented by about 8 percent beans, "would be expected to be deficient in...amino acids," while "beans are supplying about 33 percent of the lysine needed."

- The ability of young children to get enough protein by eating more is ultimately limited by a child's capacity. Even while maintaining that "an energy gap rather than a protein gap is the crux of the matter," D.S. McLaren agrees that "how to match the intake of the child with its requirements remains a problem of puzzling complexity." Bressani notes that "the relatively low level of protein in maize becomes of nutritional significance in relation to the total dry-matter intake for children."

For a 14-month-old, 11.5 kilogram child, according to Cravioto, the daily protein minimum is 34.5 grams of protein; thus, the child would have to consume daily fully 820 grams of masa—the maize dough for tortillas, which is only 4.2 percent protein—in order to satisfy the requirement. This calculation, Cravioto adds, does not take into account either the low utility of normal maize protein due to its amino-acid imbalance; or the fact that many children get their masa diluted in 10 parts of water in atole, or gruel. He concludes, "You would have to feed the child constantly, a total of several liters of atole per day, in order to supply sufficient protein," while "if all that matters is total calories, you could give the child sugar."

Ideally, decisions to improve yield or protein quality, or both, would be based on precise definitions of physiological requirements and actual diets for specific populations in specific areas. Meanwhile, in the absence of such data, and encouraged by evidence that protein improvement need not be at the expense of yield, CIMMYT pursues a conservative, integrated strategy: the improvement of both yield and protein quality in maize varieties broadly adapted to the agricultural conditions and consumer demands of the maize-eating developing countries.

Especially for infants and young children, pregnant and lactating mothers, and the sick—those most in need of good nutrition but often the least well-fed of all in poor societies—the invisible protein deficiency of the only food they have to eat is perhaps the ultimate insult. It results in a syndrome, called kwashiorkor from its Ghanaian name, characterized by edema, potbelly, abnormal skin and hair, and severe diarrhea. Kwashiorkor is a leading cause of the high infant mortality in many parts of the world, and the proximate cause of many more deaths ascribed to other causes. Even the survivors do not always escape: stunted, often brain-damaged, they become the adults most in need of help and least able to help themselves.

The twin deficiencies of tropical maize—its depressed yield of total calories and the low quality and quantity of its protein—sometimes seem forced to compete for the attention and resources devoted to agricultural research. (SEE BOX) Meanwhile, at

Trainees learn how to separate quality protein kernels from normal kernels.
CIMMYT the two problems have been integrated into a coordinated effort to improve the total contribution of maize to world nutrition. The maize staff has been working for more than a decade to mobilize maize in the vanguard of the "green revolution," along with rice and wheat, producing high-yielding varieties tailor-made for the small-farm agriculture of the developing countries.

Then, in 1970, at the urgent initiative of the United Nations Development Programme, CIMMYT undertook to improve high-yielding varieties even further with the incorporation of a gene that promised maize with all the protein quality of milk. By 1974, CIMMYT was sufficiently encouraged by the progress in its experimental plots to hope that the first improved tropical maize varieties with the added virtue of quality protein, well adapted to local consumer tastes and farming conditions in developing countries, would be ready for worldwide introduction in national maize programs by 1976 or 1977.

The missing ingredients
The development of high-quality protein in otherwise normal maize is the climax of an agricultural detective story that began in 1914, when scientists at the Connecticut Agricultural Research Station demonstrated the inadequacy of Zea mays by inducing starvation in laboratory rats with generous helpings of a pure maize diet. The specific deficiency of maize was identified when the rats were restored to health with minute supplements of two protein constituents, the amino acids lysine and tryptophan. It became clear that there are at least two ways for rats—and people—to starve: from insufficient total food intake, or total calories; and from unbalanced protein, lacking the proper amount of essential amino acids.

Later, more sophisticated analysis revealed that the poor protein quality of maize is due to the fact that of the normal kernel's total protein—about 8 to 10 percent of the endosperm—fully half is locked up in the protein fraction zein, which is useful in the manufacture of textiles, plastics, and other products, but nutritionally useless to single-stomached creatures like people. In practical terms then, discounting the zein, the normal kernel is only about 4.5 percent effective protein.

More important, zein predominates at the expense of lysine and tryptophan, which are two of the 10 amino acids called "essential" because the human body cannot synthesize them itself and must obtain them from food. The protein in normal maize endosperm is only about 2 percent...
lysine and 0.5 percent tryptophan; while for the
growth and maintenance of body tissue these pro­
portions should be approximately doubled to 4
percent and 1 percent respectively.

The hope of finding or creating a maize with
more effective protein inspired researchers to de­
cades of fruitless breeding experiments and comb­
ing of the world’s maize catalogs. It was not
until the 1960’s that a team of Purdue University
investigators including Edwin T. Mertz, Lynn S.
Bates, and Oliver E. Nelson assayed a group of
curious mutants characterized by a soft, chalk­
white kernel that was not transluscent like normal
kernels.

These “opaque” varieties had been cataloged as
early as 1915 without exciting much scientific
interest as anything more than freaks. But to the
Purdue team, using newly improved methods for
amino acid analysis, the second of the mutants to
be tested—conveniently designated “opaque-2”—re­
vealed an unsuspected virtue: its lysine content
was 3.4 percent of the endosperm protein, 70 per­
cent greater than in normal maize, while the tryp­
tophan content was doubled, all at the expense of
the useless zein. It seemed the same abnormal
recessive gene that in the homozygous situation
produced the opaque kernel’s odd appearance and
texture also engendered elevated levels of glutelin,
the protein fraction rich in lysine, and depressed
levels of the prolamine fraction called zein.

Out of the laboratory
The first publication of the Purdue discovery did
not appear until the July 1964 issue of Science,
which reached Dr. Dale Harpstead, a maize geneti­
cist with the Rockefeller Foundation’s agricultural
program in Colombia, a month later. Dr. Harpstead
recognized immediately that the quality-protein
maize “could have a great and far-reaching impact”
on endemic protein malnutrition, but it took 2
more years to translate the laboratory discovery in
Indiana into a maize harvest in Colombia. From
Purdue’s small, precious experimental seed collec­
tion, Dr. Harpstead was able to get just 25 kernels
early in 1965. After increasing the seed, crossing
it into varieties adapted to local growing conditions,
and checking the resulting hybrids in the laborato­y, it was not until the January 1967 harvest that
Dr. Harpstead had enough maize to begin nutrition
tests on animals.

In the most striking demonstration of the new
maize’s nutritional potential, groups of weanling
pigs were put on diets in which all protein was
supplied by either normal or quality-protein maize.
The pigs receiving the improved maize gained 12
times as much weight per day, requiring only one
eighth as much feed per kilogram of body weight
gained, as their counterparts eating normal maize.
The overall physical development of the pigs on
quality-protein maize as only slightly inferior to
that of a control group fed on an optimum maize­
soybean mix.

The results of these and subsequent experiments
on animals (SEE BOX) encouraged the Columbian
scientists to proceed with tests on children. The
first human beneficiaries of quality-protein maize
were two brothers, Luis and Mario, who had been
brought to the University of Valle Hospital in Cali,
Colombia, in October 1967 in an advanced state of
protein starvation and third-degree malnutrition.
They manifested the classic symptoms—severe
diarrhea, edema, and brittle, bleached-out hair—
and, although they were 5 and 6 years old, neither
had attained the anthropometric development of a
normal 2 year-old. “They were in such a bad state,”
predicted Dr. Harpstead, “that they probably
wouldn’t have lived more than a month without
medical care.”

Under the supervision of Dr. Alberto G. Pradilla,
the two moribund brothers were put on a calorie­
sufficient, maize-based regimen that looked and
tasted much like the diet that had almost killed
PIG FEED

In the first Colombian experiments, under the supervision of Dr. Jerome H. Maner and the Colombian animal husbandry institute, weanling pigs weighing an average of 8.9 kilograms fared poorly on a diet of normal maize. Their average weight gain was only 21 grams per day over the 130-day experiment, and each kilogram of gain required 35 kilograms of feed. The animals manifested the symptoms of protein malnutrition. Some died shortly after, and autopsies revealed arrested development of vital organs and cessation of skeletal growth, as well as liver abnormalities.

In contrast, the weanlings getting quality-protein, opaque-2 maize gained an average of 254 grams per day—12 times as much as the group on normal maize—and used only 4.4 kilograms of feed to produce a kilogram of meat. The pigs were generally sound and suffered no gross symptoms of protein deficiency from the improved maize. With only slight protein supplementation, the opaque-2 diet achieved the optimal growth and development produced by control diets supplying a balance of essential nutrients and protein at the 16 percent level.

From the entire series of tests on pigs in all phases of growth, Maner concluded that “opaque-2 maize can be used as the only dietary source of protein during the finishing, pregestation and gestation periods of a pig’s life cycle without reducing pig performance.... For baby pigs, growing pigs, or lactating sows...as compared with the normal maize diet, the opaque-2 maize diet produced equal performance with less supplemental proteins.”

As the Colombian experiments were replicated and elaborated in other countries, it became clear that quality-protein maize would have its greatest and most immediate importance where low-cost protein supplements were not easily available for livestock. Elsewhere—in the USA, for instance, where soybean protein was cheap and abundant—the depressed yields of the early opaque-2 varieties would outweigh their nutritional advantage.

However, as a paper presented by J.W. Dudley, D.E. Alexander, and R.J. Lambert at a CIMMYT symposium suggests, “the economics of protein-calorie production may be changing. Soybean meal is now (November 1972) selling for $120/ton in the United States, an increase of 76 percent in the last year.” Such inflationary trends in the cost of protein alternatives, together with recent demonstrations that the inferiority in yield of quality-protein maize can be overcome, imply the more nearly universal acceptance of quality-protein maize as an animal feed in the future.

them. But this time the maize in their gruel and arepa contained the invisible quality-protein gene, supplemented by 25 percent additional protein from milk or vegetables. At the end of just 90 days, Dr. Pradilla reported, “the recovery of Luis and Mario was complete.”

Subsequent, more elaborate tests confirmed “that the protein supplied by the opaque-2 maize and sperm provided an adequate dietary base for the recovery of malnourished children, or could be used for normal infants when animal proteins are not available.” Drawing a less clinical conclusion, Pradilla declared that “we now have a potential source of low-cost, high-quality protein that can do much toward preventing malnutrition, This can mean the difference between life and death for millions of children.”

From further studies on children, Dr. Pradilla’s colleague Ricardo Bressani, of the Institute of Nutrition of Central America and Panama (INCAP) in Guatemala City, confirmed that “the nutritive value of the protein of the opaque-2 maize is high and its quality is about 90 percent of that of skim milk as tested in children.... “Bressani, too, was assured that “the inclusion of the opaque-2 gene in common maize appears to be a practical approach to the problem of improving the protein quality of human diets based on corn, thus improving the nutritional status of protein-deficient populations.”

The enthusiasm of the two nutrition investigators echoed the prophesy made 4 years earlier by Edwin T. Mertz at Purdue, that “mankind will have available—for the first time in history—a “super grain, which contains everything for complete human nutrition except a few inexpensive minerals and vitamins.” But since the initial success of the Colombian experiments in 1967, 7 more years have been spent in the effort to translate quality-protein maize from a diet for a few $100-a-day hospital
patients into a staple for hundreds of millions with average incomes closer to $100 a year. The problems were mostly scientific ones at first, to be attacked by patient, sophisticated breeding in experimental fields. As the agricultural answers have become imminent, or at least more clearly discernible, however, attention and effort have shifted to the less clear-cut problems of international organization, education, and social change that are involved in reaching people's stomachs through their minds.

**Made-to-order maize**

The immediate effect of the success of quality-protein maize in Colombia was to focus and accelerate efforts around the world to improve protein quality in maize and other crops. In 1968, the United Nations published a report whose very title urged “international action to avert the impending protein crisis”, and followed it with a check list of recommendations for strategic actions, including:

- Support increased production of conventional...sources of protein by all feasible means.
- Develop and support projects for the prompt introduction of improved varieties such as corn with higher lysine and tryptophan contents...

In response to this initiative, CIMMYT on August 4, 1969 submitted to the United Nations Development Programme a plan for a 3-year, coordinated effort to meet the U.N. twin objectives. CIMMYT proposed to integrate quality-protein-maize research with its continuing program for breeding broadly adapted, high-yielding tropical varieties. In addition, CIMMYT responded to the UNDP's call for the training of an international corps of specialists for “national programmes of nutritive maize production.” CIMMYT's proposal was approved by the UNDP Governing Council, and US$1,653,000 was appropriated for the 3 years beginning in March 1970.

By the early 1970's the staff of CIMMYT's maize program, under the direction of Dr. Ernest W. Sprague, had made considerable progress in overcoming many of the yield-limiting liabilities afflicting normal maize, a temperate-zone species, in the tropical agriculture typical of many developing countries. Instead of reaching for the sky under the tropical sun, the improved plant is as much as 1 meter shorter, saving growing time and photosynthetic energy for producing kernels instead of stalk and leaves. The shorter plant also stands better, resisting the tendency to “lodge” under the top-heavy weight of its mature growth. A full week has been cut from the time to flowering, leaving more time for fattening the kernels. The plant responds better than unimproved, locally adapted varieties to a wide variety of growing conditions typical of the tropics, and resistance to pests and diseases—the plant breeder’s greatest challenge—is slowly being improved. By 1972, after more than a decade of laboratory science and stoop-labor in its experimental fields, CIMMYT's maize staff was able to report that for its best elite varieties, “yields are up to 5500 kilograms per hectare in farmers' fields, within 10 percent of the corn belt average in the United States.”

But even while they were painstakingly revising the genetic endowment of normal maize, and with ultimate success still in doubt, the plant breeders accepted the risk of marrying their improved normal varieties to the quality-protein mutant, which had a list of inherited liabilities of its own to offset its nutritional assets. The key problem was the appearance and texture of the kernels. The gene that increased the kernels' content of lysine and tryptophan was also associated with their characteristic opacity, chalk-white color, and soft endosperm. While the telltale opacity afforded the scientist a convenient visual indicator of protein quality, it also made the maize unattractive to consumers accustomed to normal maize that was translucent, shiny white or yellow, and hard-textured; and maize that consumers will not accept, the market will not buy, and the farmers will not grow.

Moreover, the starch granules in opaque kernels were packed less densely than in normal kernels. Thus the kernels of opaque maize were lighter, **Quality-protein varieties which have normal, hard kernels and are high yielding will bring better nutrition within each of small farmers and their families.**
Quality protein experimental varieties yield well in international trials. At more than 60 percent of the locations in which they were tested in 1974 at least one of five quality protein varieties equaled the average yield of the check varieties.

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<th>(Ver 181 x Ant. Gpo. 2) Ven 1</th>
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<th>Compuesto K (H.E.) 02</th>
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Bold face indicates values not significantly different from the check average. Bold face with asterisk (*) indicates values significantly larger than the check average. a/Summer planting. b/Winter planting.

reducing farmers’ yields by an average of 10 to 15 percent. With no price differential to compensate for the disparity in weights between equal volumes of maize, the farmer would be understandably reluctant to pay a penalty for the humanitarian privilege of producing better protein. He would also be discouraged to discover his yield depressed still further by pest and disease attacks on the soft, vulnerable opaque kernels; and to find that the flour mill was docking him for the extra trouble of milling his non-standard maize.

For CIMMYT’s maize staff, the trick has been to retain the best qualities of both normal and opaque-2 maizes while suppressing their deficiencies. In practical terms, this has meant an attempt to locate “modifier genes” that would dissociate the quality-protein characteristic of the opaque maize from the texture that depresses yields and the appearance that deters consumers.

An approach to this problem was outlined at a recent CIMMYT symposium by two Indian investigators, Joginder Singh and V. L. Asnani. “Comparisons between opaque-2 maize and normal maize,” they cautioned, “should be viewed against the background of materials and procedures used in the development of opaque-2 maize varieties.” The donor opaque-2 stocks were not subjected to any rigorous selection; thus, the stocks would be expected to have low gene frequency for those genes conferring resistance to various diseases and transmitting high yield. The donor stocks in particular were very poorly adapted to the tropical maize-growing regions of the world.” Nevertheless, they contended:

Even though opaque-2 varieties, in general, have given 10 to 15 percent lower yield, several cases have been reported where opaque-2 varieties were equal to or even better than their normal counterparts. Variations in the relative susceptibility of opaque-2 varieties to ear-rot incidence, weevil attack, and borer damage has been observed. Modified opaque kernels with varying degrees and patterns of vitreousness are frequently found in backcross programs. But until recently, most backcross programs retained only completely opaque kernels, while modified opaques were discarded.

Supporting evidence was offered at the same symposium by researchers from the University of Illinois. After 6 years of selecting quality-protein maize for higher yield and improved agronomic traits, they concluded that “yields of opaque-2 maize hybrids need not be inferior to standard dent.” In 1966 “the opaque-2 yielded 85 percent of the normal counterparts at Illinois; but by 1972, after several generations of selection for yield, the best quality-protein hybrid was yielding only 7 percent less than the best dent maize in the U.S. corn belt.” In view of such experience, Singh and Asnani concluded that “the possibility of obtaining higher kernel weight—comparable to or higher than normals—plus low susceptibility to diseases and insect pests in certain genetic backgrounds suggests that wise selection of parental varieties to be converted to opaque-2 may provide a way to control the undesirable effects of the opaque-2 gene.”

At CIMMYT, the “wise selection of parental
CIMMYT's entire maize program draws on the rich collection of germ plasm kept in refrigerated storage. The CIMMYT germ plasm bank contains seed of 12,000 maize and related genera kept under refrigerated storage. Accessions are grown out from time to time to provide seed to breeders and to renew seed in the bank.

Dr. E.W. Sprague, director of maize improvement, exchanges ideas with some of CIMMYT's trainees. Each year CIMMYT trains about 50 young maize workers from developing countries. They learn modern methods of maize growing and how to bring new ideas to farmers.

Varieties' begins in the germ plasm bank, the largest maize-seed collection in the world, where the genetic variability of the species Zea mays and related genera is preserved. The bank's capital—currently including kernels of some 12,000 strains from 47 countries—is stored under refrigeration, cataloged by significant characteristics, and renewed by periodic small plantings. Further test plantings at several locations in Mexico, including the insect and disease nurseries, permit the identification of...
For vast numbers of persons in developing countries, maize is the staff of life. But because normal maize is low in certain essential amino acids, a heavy maize diet can lead to protein deficiency disorders.

materials with superior characteristics for the breeding program. The development of an improved variety proceeds through stages of increasingly sophisticated breeding, from the relatively crude evaluation in the germ plasm bank to more rigorous selection and precise fine-tuning, issuing finally in a maize plant that would never occur in an eternity of evolution, made to measure for the special needs of a specific national program (SEE BOX).

Since the inception of the UNDP-sponsored program in 1970, normal varieties in the breeding program have been systematically converted to include the quality-protein gene. Opaque-2 donors are specifically selected to obtain desirable endosperm characteristics. Vitreosity has been improved in each breeding cycle by harvesting only ears with the greatest percentage of hard kernels, and then segregating out only those kernels with the greater proportion of vitreous endosperm to become the seed for the next cycle. Meanwhile, in the absence of the characteristic opaque-2 kernel appearance as a guarantee of amino-acid balance, sample kernels from each segregated ear are sent to CIMMYT's protein quality laboratory for chemical analysis, and ears that score low in total protein or tryptophan—used as a convenient index for lysine as well—are rejected.

By this patient process, on May 10, 1972—9 years after the discovery of the opaque-2 mutant at Purdue and more than 4 years after the verification of its life-saving potential in Colombia—CIMMYT harvested the first crop of improved tropical maize combining opaque-2's quality protein with the translucent, hard kernel of traditional normal varieties. The total harvest: just 100 kilograms of seed.

By year's end that seed had been increased to 20 tons and distributed to collaborating national maize programs for field trials in 1973 under actual growing conditions around the world. Meanwhile, 45 more advanced populations, including materials adapted for tropical, temperate, and highland use, were converted to opaque-2 and grown through two generations. The early performance of these first improved, quality-protein maizes suggests that in each climatic zone, the best of them is already equal or superior in yield to normal local varieties.

Despite these encouraging results, however, the success of quality-protein maize cannot be weighed by the harvests from CIMMYT's field in Mexico. Even the development of quality-protein varieties adapted to the agriculture and consumer preferences of each maize-growing area of the developing world
will not finish the job. The ultimate proof of the breeding program is the dissemination of its improved seed and agricultural technology through national maize programs and their extension services into farmers' fields, and finally to millions of malnourished consumers. Having demonstrated the feasibility of custom blending a quality-protein maize with the appropriate genetic mix for almost any climatic or cultural condition, the CIMMYT maize staff still faces the more problematic challenge of getting their product into the hands—and stomachs—of the people who need it.

**Broadcasting seeds of change**

Following the encouraging results with the new materials at CIMMYT, little quality-protein maize has been grown commercially anywhere in the world. In the USA, Brazil, and Colombia, some original opaque-2 varieties with abnormal phenotype have been released to farmers in relatively small quantities, but even the little that has been planted is destined to feed pigs rather than people. Moreover, these are hybrids, dependent on elaborate systems for annual seed production and marketing, rather than varieties, which produce their own viable seed, suitable for poor countries where farmers must sow next year’s crop with this year’s kernels.

In 1972 in the USA, for example, where quality-protein maize competes with protein supplements, like soybean meal, that have been readily available and cheap until recently, Dr. D.E. Alexander of the University of Illinois told a 1973 CIMMYT symposium that “no more than 264,545 tons of commercial opaque-2 maize was produced...about 0.2 percent of the total crop. Based on their experience with the early, low-yielding materials, Dr. Alexander reported that “U.S. commercial producers of hybrid seed are not optimistic about the future of opaque-2 maize, although most apparently have adopted a ‘wait and see’ attitude....”

A more encouraging estimate was given at the same meeting by an official of Sementes Agroceres S.A., a major Brazilian seed producer. The company’s sales of opaque-2 materials, he reported, increased from an initial 100 tons in 1970 to 900 tons in 1972, representing about 4 percent of total production. “This may seem a rather modest start,” admitted the official, “but by comparison, it took Agroceres 6 years to match this amount in the early days of hybrid-seed-maize introduction in Brazil.”

The “different appearance” of the early opaque-2 maize he noted, “has a negative effect on commercialization,” which presumably will disappear when improved quality-protein varieties are available in Brazil. Meanwhile, Agroceres’ strategy has been to focus its early marketing effort on hog farmers. Two-thirds of Brazil’s 68 million hogs are fed almost entirely on normal maize, without protein supplements to provide balanced nutrition. According to its spokesman, “Agroceres is capitalizing on this situation by establishing opaque-2 maize feeding demonstrations at the farm level with Ex-

### THE COURSE OF ACTION

The development of improved maize varieties at CIMMYT begins in the germ-plasm bank, which in 1974 alone added 388 new seed samples to its collection already numbering close to 12,000. At the same time, 983 materials from the bank’s catalog were propagated in Mexico and another 284 by a cooperating university in Peru. Thus, in 1 year some 10 percent of the world’s maize collection, representing the genetic variability of the species, was rejuvenated with fresh seed and observed for promising characteristics.

From the germ-plasm bank, promising materials proceed through a process of initial classification and selection in the backup phase of the breeding program. Each is assigned to one of 34 genetic “pools” according to its climatic adaptation (tropical highland, tropical lowland, temperate), its maturing time (early, intermediate, late), its kernel color (white and yellow), and its kernel type (dent, flint, floury). Most of the pools are planted twice a year in several different climates at CIMMYT’s Mexican research stations.

The plants are evaluated and selected for yield, disease and insect resistance, and desirable agronomic characteristics. Superior materials are recombined and new candidates for the next breeding cycle are tested against the standard for the pool.

The superior performers graduate from the backup program to the advanced breeding phase, where they are subjected to even more rigorous selection under a wider range of growing conditions.

The few entrants that survive the ordeal are combined into “experimental varieties,” and their seed is increased and distributed for even further tests at 25 or more sites around the world. Only the most successful of these experimental varieties are dubbed “elite” and tested yet again under differing conditions at some 100 international locations.

Finally, the elite experimental varieties are fine-tuned in on-farm trials in the areas for which they are ultimately intended, and recombined if necessary with the best locally adapted maize. Only after running this gauntlet is a new maize variety ready to be released for distribution to farmers through national agricultural programs.
GETTING DOWN TO EARTH

In an essay on "Organizing for Agricultural Development," Cornell University sociologist William Foote Whyte asserts that "the fallibility of the extension agent is coming to be increasingly recognized." He cites a report by James Green of a program in Pakistan in which agents were asked to demonstrate the very techniques they were supposed to be transmitting to local farmers. "A number of the participants...confessed...that they did not feel confident enough...to demonstrate a single skill in their own technical field."

Green suggested that "the explanation was simple: they...had been trained in a lecture system and had never performed the skill or had done so only once or twice. There were veterinarians who had never castrated a bull calf; animal husbandrymen who had never culled poultry..." from similar testimony in a study by Coombs, Whyte quotes one official's explanation that "the typical extension worker in most Southeast Asian countries...has had little or no first-hand paddy experience...he cannot identify the problems in the farmer's field and thus cannot advise him on appropriate action. Consequently, he is reluctant even to approach the farmer to show him how things might be done."

Whyte is skeptical of the popular notion that extension workers fail to communicate with their clients because "getting their hands dirty" is beneath their dignity. Rather, Whyte suggests, lacking confidence in what he is supposed to do with those hands, "a man naturally prefers to be considered a snob rather than a fool."

In CIMMYT's in-service training program, the future extension agents, researchers, and technicians from developing countries get their hands dirty before they ever enter a classroom or hear a lecture. Immediately after a brief orientation session at the El Batan headquarters, the trainees are sent into farmers' fields and CIMMYT nurseries to plant experiments under the eyes of staff breeders, plant pathologists and entomologists.

Since 1973, the maize training program has also assigned to the trainees the layout of agronomic trials on private farms, in cooperation with CIMMYT staff agronomists and the Mexican extension service. The trainees are responsible for the trials from planning and planting right through to the field days, when farmers are invited to compare the performance of new materials with their local varieties. In the first year of this program trainee demonstrations in Veracruz State yielded 3.5 to 5.0 tons of maize per hectare where normal yields were 2.0 to 2.5 tons.

tension Service cooperation. The goal is to compare opaque-2 maize performance with that of normal maize when fed to hogs under local conditions and with the farmer's direct participation."

This selective introduction of quality-protein maize as an animal feed has stimulated interest from food companies serving institutional markets. In turn, it is hoped that the use of quality-protein maize products in institutional, officially sanctioned programs, will encourage their acceptance in the marketplace. Predicted Agroceres' official confidently, "The long-term possibilities for opaque-2 maize in Brazil are practically limitless."

The complex problems of realizing this "practically limitless" potential in all maize-eating countries require a sophisticated and strategic response from CIMMYT to translate scientific experiments into agricultural production. The aim of CIMMYT's "outreach" activities is the introduction of experimental varieties into national maize programs. In 1973, for example, the maize nurseries of 48 countries collaborated with CIMMYT in 289 international trials of breeding materials. Through this network, advanced populations were provided for further research, development, and release to almost every maize-producing country in the developing world.

Almost all international trials are grown under rainfed conditions, without supplemental irrigation, in order to closely approximate actual farm conditions for which the materials are intended. The exposure of CIMMYT-grown materials to differing conditions of daylength, temperature, moisture, insects, diseases, and soils provides invaluable feedback to CIMMYT's breeding effort. At the same time, the trials afford a practical training opportunity for students, technicians, and scientists in the participating national programs, while providing them with the most advanced breeding materials for fine-tuning under local selection pressures for eventual release to local farmers.

Other personnel from national maize programs are brought to Mexico for first-hand experience in a variety of programs. In-service training for students with a first degree in agriculture involves 6 or 7 months residence at CIMMYT's research facilities. From 1971 through 1974, the program has trained 171 young scientists from developing countries, in both field and laboratory skills, introducing them to the basic CIMMYT technique or working in interdisciplinary teams, and sharpening their insights into the process of agricultural development. (SEE BOX)

In 1974, CIMMYT's maize program was also host to degree candidates from 12 countries and doctoral students from two countries, as well as 11 postdoctoral fellows from eight countries. In addition, 15 visiting senior scientists from nine countries spent periods of 1 month to a full year at CIMMYT and 25 observers from 20 countries visited CIMMYT for shorter periods of study and consultation.
CIMMYT's Poza Rica, Mexico, experiment fields are one of several locations at which improved maize lines are being converted to quality protein.

CIMMYT scientists harvest lowland tropical maizes which are in the process of being converted to quality protein.
In CIMMYT’s protein quality laboratory, chemists analyze 8000 maize samples a year for protein and tryptophan and certain samples for lysine or all amino acids. The standard tests to evaluate quantity and quality of protein involves a 10-kernel or 15-kernel sample taken at random to represent each maize family undergoing improvement.

A PRIMER FOR NATIONAL PROGRAMS

According to Ernest W. Sprague, who ministers to many national maize-improvement efforts as Director of CIMMYT’s international maize program, most are afflicted by the lack of qualified maize research and production personnel, and by the lack of an effective organizational structure to transmit new technology to the farm level.

Sprague points out that it can take US$40,000 and 14 years to train a single agricultural Ph.D. for a national program. The staffing model Sprague recommends includes a minimum of six Ph.D.’s among 44 trained specialists to carry out a maize program for a small developing country short of both capital and trained talent for agricultural development. Even before a full staff is assembled, however, Sprague recommends the design of a simple, effective breeding and testing program to evaluate quality-protein maize from more advanced programs and promote the superior performers to local farmers through demonstration trials. More complex research and development activities can be undertaken as staff numbers increase and capabilities improve.

From the inception of a national maize program, Sprague suggests:

- Traditional agricultural systems organized around academic disciplines should be reformed into crop-oriented teams including all appropriate specialties.
- Research and extension should be integrated toward increased production. The common practice of staffing the extension service with the least qualified people, while the best go into research at higher salaries, should be abandoned.
- Maize breeding programs should turn out varieties rather than hybrids, which depend on advanced seed production and distribution systems that are unavailable in most countries, and which are less efficient in terms of development time and staff energies.

External factors affecting increased production must also be considered, cautions Sprague. Among them:

- The cost of essential inputs such as fertilizer and other chemicals must be in reasonable relation to the value of the crop. Thus, the assurance of a fair profit will give the farmer the incentive to reach for increased yield.
- Fertilizers, insecticides, and other inputs must be available at the right times and the right places as well as the right prices. Accurate and timely estimates of future needs, as well as good management of distribution systems, are both essential.

"Budgets for national programs, although extremely important," says Sprague, "are seldom the initial limiting factor; nor is credit. The quintessential element in developing effective national programs, Sprague insists, is the wholehearted support of national governments. "Government commitment is essential," he says. "Only with this support can effective national programs be organized."
Drilling out a small portion of the endosperm permits the tryptophan analysis on seeds, which if they prove to have high quality, will subsequently be planted.

There is heavy traffic in the other direction, as 10 members of CIMMYT's maize staff are posted as residents to the national programs of five countries—Egypt, Nepal, Pakistan, Tanzania, and Zaire. In addition, in 1974, members of CIMMYT's Mexico-based maize staff spent 875 man-days visiting national programs in Asia, Africa, and Latin America. In addition to observing and advising on the progress of CIMMYT nursery materials in local trials, the consultants surveyed national maize research and production needs and collaborated with national program staffs on future plans. They also spent time in farmers' fields investigating specific local problems, and in government offices advising policy makers on fertilizer needs, maize pricing strategy, grain storage and marketing, and other questions of national scope.

While such exhausting globe-hopping has served in the past to coordinate the expanding worldwide network of collaborating maize programs, CIMMYT has come to the belief that, for the future, efficiency and effectiveness would be better served by a system of intermediate, regional service centers. These would be linked to CIMMYT by a two-way flow of information and services, while maintaining closer relationships with nearby national programs than are possible under existing, long-distance arrangements.

Clearly, the national programs are crucial to the entire quality-protein-maize effort. Yet the establishment of effective national programs is perhaps the most complex and recalcitrant of the innovative technologies at CIMMYT. (SEE BOX) "Historically," notes Dr. Sprague, "governments have not placed a high priority on food production until their countries faced famine conditions, or until the cost of importing food reached a level that made self-sustained production the most attractive political and economic alternative."

Today, with these preconditions emerging as universal facts of life, Sprague insists that the most immediate challenge is to "convince government planners and policy shapers to make a firm, general commitment in support of agricultural research and production programs. Then, in appropriate countries, we should urge that high priority be given to planning and organizing maize programs."

Tony Wolff

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