E C O N O M I C S

Working Paper 00-02

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CIMMYT

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Abstract

Improvements in the production characteristics of quality protein maize (QPM) are currently leading to its reintroduction in various areas of the world, both for human and animal consumption. Although the improved QPM varieties produce yields that are highly competitive with other modern varieties, doubt still remains about the extent of protein deficiency as a nutritional problem in humans, as well as the feasibility of implementing the technology. This paper explores the pros and cons of adoption of QPM for human consumption and as animal feed, reviews where in the developing world it is most likely to have an impact, and discusses some important issues regarding its introduction.

Based on current data, the extent of protein deficiency as a nutritional problem among humans is unclear. Although it is not generally considered to be a widespread problem, it may be significant among certain populations, particularly young children during the weaning period. In addition, the technology faces production and distribution problems: genetic loss of the recessive, high protein gene remains a constraint, as does identification of QPM, which is now virtually indistinguishable from other maize. These problems greatly complicate the delivery of QPM to the target groups. QPM's nutritional impact as an animal feed is more straightforward, but it remains to be seen whether it is an economically viable alternative to synthetically produced amino acids.

Assuming that positive resolutions to these issues are found, QPM is most likely to have its greatest human nutritional impact in African countries with high maize consumption. It could also be important, however, in Central America and specific areas of South America and Asia. Its greatest potential for use as animal feed is in China, where it is already grown for this purpose. However, it has significant potential in other countries included in this study, with the exception of most of the African countries where pork and poultry consumption tends to be very low.

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Introduction

Although the prevalence of malnutrition has been reduced in many countries, it continues to persist and affect countless lives around the world. Its multiple causes make it a difficult problem to address; hence, many approaches have been developed to combat it. One approach now being explored is based on improving the nutritional value of cereal crops such as maize, wheat, rice, and other staples. Current work in this area is directed toward increasing the quantity of protein and utilizable micronutrients available in many of these crops. While considerable work remains for increasing micronutrient content in cereal crops, higher protein maize is here now and ready for introduction into maize consuming areas around the world.

Quality Protein Maize, or QPM, has been heralded as a possible protein source for both human and animal consumption in many countries. However, much debate remains concerning the magnitude and extent of protein deficiency, and consequently, questions arise about the overall nutritional impact of QPM. Targeting areas with the greatest potential need is therefore very important in order to maximize its impact. This paper looks at the potential role of QPM in 16 countries chosen as likely candidates for its introduction for human consumption, as animal feed, or both.

Maize, which originated in Mesoamerica, has become an important staple for many people, both in its center of its origin and many other areas around the world. Aside from being directly consumed by humans, it is also widely used in animal feed. As is generally true with cereals, maize is weak as a source of protein. Its utilizable protein content is limited by low levels of certain amino acids, particularly lysine, and to a lesser extent, tryptophan. Therefore, in areas or amongst populations where diets consist largely or totally of maize, protein deficiencies can occur.

Until the early 1970s, protein deficiency was believed to be the most serious cause of malnutrition. Based on this premise, many strategies were developed to decrease or alleviate protein deficiency. In 1963, scientists at Purdue University found a mutant maize variety with twice the normal levels of lysine together with elevated levels of tryptophan. Dubbed Opaque-2, this maize was heralded as a significant breakthrough in the global alleviation of protein deficiency. Studies carried out on rats, monogastric animals, and humans demonstrated the positive nutritional benefits of QPM (Bressani 1991; Graham et al. 1990; Graham et al. 1989; Valverde et al. 1981).

However, the Opaque-2 maize also possessed qualities that presented limiting factors to its widespread adoption, the most important being a lower yield potential than improved maize and the texture of the kernels. Opaque-2 had chalky, soft kernels that affected both the production and consumption qualities of the maize. It was much more susceptible than conventional maize to fungal attack due to its higher moisture content, and it had lower resistance to insects and higher storage losses. All these problems proved to be major obstacles to past attempts to implement adoption of Opaque-2 maize.

Interest in Opaque-2 maize received another setback in 1973, when the United Nations and the World Health Organization issued a report on revised recommended energy and protein levels. Whereas it was previously thought that overall protein was the most limiting factor in cases of malnutrition, newer research set much lower protein requirements while greatly increasing the importance of overall energy consumption (FAO / WHO 1973). The energy requirements of the human body were found to take precedence over its protein needs. Given shortfalls of both energy and protein, the body will convert protein into energy to cover its more immediate needs. As a result of this shift in nutritional thought, interest in increasing protein levels greatly diminished, and research has generally focused on increasing yields in crop production in order to reduce the overall energy deficit. Tradeoffs in quality have often been overlooked or justified on the basis of increased production.

Because of its undesirable production and consumption traits and the de-emphasis of protein requirements, interest in Opaque-2 maize had virtually vanished by the late 1970s. This was not the case for CIMMYT and a few other research sites, where work continued on refining the original Opaque-2 maize—the aim being to maintain its nutritional quality while making it competitive with conventional varieties of improved maize. These improved Opaque-2 varieties were renamed Quality Protein Maize, or QPM.

After many years of work, QPM has been improved to such an extent that breeders consider it almost indistinguishable from conventional maize varieties and now ready for widespread distribution. Various government programs have embraced it, especially in Africa, where dissemination efforts are proceeding under the auspices of Sasakawa-Global 2000 and CIMMYT,.

Although protein has been downgraded as a global nutritional problem, debate continues over its importance and whether resources should be diverted into reducing protein deficiency. It has been pointed out that some important population groups with special protein requirements—pregnant women, nursing mothers, very young children, the sick, and possibly the elderly[1]—may have difficulty receiving enough protein, especially when their diets lack sources of animal protein. High protein maize could help respond to their protein needs. Nevertheless, assuming that these groups lack adequate protein, questions remain as to the level of benefit that could be gained by introducing QPM, and whether it would be cost effective compared to other possible interventions.

[1] It is still not clear whether protein requirements increase or decrease with age.

This paper examines issues related to the targeting of QPM. What are the relevant factors in terms of need and adoption? Which countries are the best candidates for the introduction of QPM? Where would it have the most impact? Does a protein deficiency exist in the first place, and, if so, would the target group actually be affected by the introduction of QPM? Could QPM have an important role as an animal feed? Are pulses, such as soybeans, commonly added to feed? Or could amino acid deficiencies be supplemented more cheaply and efficiently through chemically produced amino acids, which are commonly used in developed countries?

Sixteen developing countries have been identified by members of the Maize and Economics Programs at CIMMYT as possible targets for the introduction of QPM. A key criterion for target selection was that the country be representative of areas with high utilization of maize where QPM could have an impact through either human or animal consumption. Selected countries include Bolivia, Brazil, El Salvador, Guatemala, Honduras, Nicaragua, Mexico, China, India, Vietnam, Ethiopia, Ghana, Malawi, Mozambique, Zambia, and Zimbabwe.

Ideally, an economic analysis should be conducted to determine the cost of introducing QPM *vis a vis* its potential health benefits. The scarcity of data and knowledge regarding actual impact on health precludes such an investigation at this time. In lieu of this approach, the author examines publicly available FAO data to obtain a general overview of the possibilities for QPM in the potential target countries. The data cover each country on an aggregate basis, and refer to available food supplies, not actual consumption. The data give no information regarding differences between economic groups or regions within the countries. Accuracy, particularly in respect to some of the African countries, is also a concern. Even given these shortcomings, however, the data can provide an overview for targeting countries that might be good candidates for QPM. Other sources of consumption and/or production data have also been incorporated into this review when possible.

Nutritional Background

Maize and Protein

It might be helpful at this point to describe briefly the protein “problem” with maize. Proteins are made up of amino acids, including nonessential amino acids, which the body can produce itself, and essential amino acids, such as lysine and tryptophan, which must be obtained from a dietary source. Since all the amino acids are needed to make protein, a shortage of any of them is a limiting factor. Animals provide the most complete and convenient sources of protein in the forms of meat, eggs, milk, and milk products. In the absence of animal proteins, the amino acids can be obtained from various vegetable sources, however, in general, a variety of different vegetables must be consumed in order to supply all of the essential amino acids.

Conventional maize lacks adequate levels of some essential amino acids, particularly lysine and tryptophan, thus reducing the overall biological value of its protein. However, when combined with pulses that carry those missing amino acids, the combined biological value of their protein approaches that of animal proteins. QPM has approximately twice the lysine and tryptophan levels of conventional maize and increased levels of histidine, arginine, aspartic acid, and glycine. On the other hand, it has reduced levels of the amino acids glutamic acid, alanine, and leucine. A lower leucine level, however, is considered an advantage because it results in a more balanced leucine-isoleucine ratio, which, in turn, helps liberate more tryptophan. These changes in amino acid composition increase the total amount of protein available from maize, without requiring the ingestion of other foods. Analysis of Opaque-2 maize in the 1960s found its protein quality to be as high as 90% of that of milk protein, which is often used as a protein of reference (Bressani et al. 1969). Nitrogen balance studies carried out on both children and adults found that although the nitrogen balance of Opaque-2 was lower than the protein of reference (either milk or casein), it was significantly higher than conventional maize (Bressani 1991).

It has also been hypothesized that higher tryptophan levels could help decrease the incidence of the nutritional disease pellagra, which is caused by niacin deficiency (Bressani 1991). When tryptophan, an important dietary precursor for the B vitamin niacin, is found in high levels concurrent with lower levels of leucine, niacin availability increases. It should be noted, however, that the oxidative conversion of tryptophan to niacin also requires three other B-complex vitamins—thiamin, riboflavin, and pyridoxin. Although pellagra is not currently considered a major problem, it still occurs, and QPM's possible role in its prevention is hypothetically considered to be an additional benefit.

QPM could also play an important role in meeting infants' protein requirements with less bulk. If solely breastfed, infants should be able to receive all the protein they need from breast milk, up to 4–6 months of age. The switch from breast milk to weaning foods is a very vulnerable time for children. Often, weaning foods do not adequately meet a young child's nutritional needs. Furthermore, the introduction of such foods is frequently accompanied by contamination from water and other foods. Very young children, consequently, are often afflicted with diarrhea and various illnesses, and so require even higher quality and greater quantities of foods to recover and for catch-up growth to occur. Without adequate nourishment, catch-up growth may never occur, leaving the children permanently stunted or worse. Even marginal malnutrition can cause deficits in behavior and cognitive performance, although these have been attributed to various micronutrient deficiencies rather than protein (Allen 1993).

Although experts advise against feeding weaning-age children a diet consisting solely of maize, all too often this is the case. In many areas, young children are fed only a maize gruel as a weaning food. Such children may not be able to consume enough bulk to satisfy their protein requirements (Ljungqvist et al. 1981). QPM could help meet their protein requirements with less bulk. It should not, however, be considered a complete solution as its increased lysine and tryptophan levels do not equal that found in animal protein and it does not overcome other important nutritional limitations. While QPM would be an improvement over plain maize gruel, care must be taken not to promote it as the sole source of nutrition for young children. Further research, sponsored by Sasakawa-Global 2000, on the role of QPM as a weaning food in Africa is currently underway.

Protein Requirements

Protein requirements vary widely among different members of the population depending on size, weight, activity levels, and individual differences in efficiency of utilization. Total daily requirements are higher for some groups, such as physical laborers and pregnant or lactating women, and lower for other groups, such as small children, who have a much lower body weight. The quality of the protein also affects protein requirements. Protein obtained from cereal, legumes, and vegetables are less bioavailable than protein obtained from animal sources, thus requiring greater intake (FAO / WHO 1985). This paper looks mainly at country-level aggregate data and uses the per capita intake of 50g / day recommended by the FAO and WHO (FAO / OMS 1992). This could be considered high for most people's needs, but it is meant to be adequate to cover the needs of almost any healthy individual.

As mentioned earlier this paper mainly relies on data from FAO food balance sheets for information regarding protein and energy availability. Admittedly there are problems with extrapolating consumption information with this type of data. Food balance sheets show availability of food, not actual consumption. They show, "for each food item – i.e., each primary commodity and a number of processed commodities potentially available for human consumption – the sources of supply and its utilization," (FAO, 1998). In 1980 FAO defined a food balance sheet as, "A national account of the annual production of food, changes in stocks, imports and exports, and distribution of food over various uses within the country,"(FAO 1980).

The use of food balance sheets as indicators of consumption has been questioned. It does not take into account distribution or seasonality of supply. When estimates from food balance sheets and actual home consumption surveys are compared, they seldom match. Generally, food balance sheets overestimate consumption when compared with actual consumption data, but not in all cases (Dowler et al. 1985). Nevertheless, it is being used in this case due to its accessibility for all the countries included in the study. The accuracy of the data for some of the specific countries will be discussed later in the paper. According to the FAO's 6th World Food Survey, the minimum (but not sufficient) per capita dietary energy supply needed by a country to lower food insecurity to 2.5% of the population is 2,770 Kcal / day (FAO 1996).

An Overview of the Target Countries

The countries examined in this paper represent areas of high maize use either for human consumption and / or animal feed. They provide a cross section of countries with different levels of development, ranging from the relatively well off, such as Mexico and Brazil, to very poor countries such as Malawi, Mozambique, and Ethiopia. Table 1 (following page) provides demographic background on the countries in this study. Several countries have relatively, high annual population growth rates, approximating 3%, which, if unabated, will lead to dramatic population increases. China, Brazil, and El Salvador stand out as having lower rates of population growth.[2] Central and South America are generally more urbanized, with Mexico and Brazil exhibiting the highest percentages of population in urbanized areas. Although the rate of growth of urbanization in many of the African countries is quite high, the actual percentages of populations living in urban areas range from low to medium. Mexico and Brazil have the highest levels of GNP, while the African countries and Nicaragua have the lowest levels, some of which are continuing to decline.

Children are likely to be the most important target group for QPM consumption. Table 2 provides some basic health and nutritional indicators to give a general idea of their status in these countries. Again, there is a wide range within this group of countries. Of 189 countries listed by UNICEF, Malawi and Mozambique had the eighth and ninth highest rates of under-five mortality, while Mexico ranked 102nd. The African countries in our study (with the possible exception of Zimbabwe), India, and Bolivia have the highest infant and under five mortality rates, Mexico the lowest, and the other countries range somewhere in between. Life expectancy

Table 1. Demographic data and GNP on the targeted countries

	Total population (1000s) 1996	Population annual growth rate (%) 1980 - 1996	% of population urbanized 1996	Average annual growth rate of urban population (%) 1980 - 96	GNP per capita (US$) 1995	GNP per capita average annual growth rate (%) 1985-95
Bolivia	7,593	2.2	62	4.1	800	1.8
Brazil	161,087	1.8	79	2.9	3,640	-0.8
El Salvador	5,796	1.5	45	2.1	1,610	2.8
Guatemala	10,928	2.9	39	3.2	1,340	0.3
Honduras	5,816	3.1	44	4.6	600	0.1
Nicaragua	4,238	2.6	63	3.6	380	-5.4
Mexico	92,718	2.0	74	2.6	3,320	0.1
China	1,232,083	1.3	31	4.2	620	8.3
India	944,580	2.0	27	3	340	3.2
Vietnam	75,181	2.1	19	2.2	240	4.2
Ethiopia	58,243	2.9	16	5.6	100	-0.3
Ghana	17,832	3.1	36	4.1	390	1.4
Malawi	9,845	2.9	14	5.6	170	-0.7
Mozambique	17,796	2.4	26	8.6	80	3.6
Zambia	8,275	2.3	43	2.8	400	-0.8
Zimbabwe	11,439	3.0	33	5.3	540	-0.6

Source: *The State of the World's Children 1998*

2 All growth rates in this paper are exponential growth rates either given by FAO or UNICEF, or calculated using the semilog model:

$\ln Y = a + Bx + u$

where:

ln Y = the natural logarithm of variable Y,
x = time period (year),
a = a constant of B,
B = growth rate of Y,
u = error term, and
Y = a constant, proportional rate of growth or decay.

Table 2. Health and nutritional indicators for the targeted countries

	Infant Mortality Rate 1996*	Under Five Mortality Rate 1996**	Under Five Mortality world ranking 1996**	Life expectancy 1996	% under 5s (1990-1997) suffering from: Underweight mod.+ severe	Underweight severe	Wasting mod. + severe	Stunting mod. + severe
Bolivia	71	102	51	61	8	2	1	29
Brazil	44	52	79	67	6	1	2	11
El Salvador	34	40	88	69	11	1	1	23
Guatemala	43	56	74	66	27	6	3	50
Honduras	29	35	97	69	18	3	2	40
Nicaragua	44	57	73	68	12	- -	2	24
Mexico	27	32	102	72	14x	- -	6x	22x
China	38	47	82	69	16	- -	- -	- -
India	73	111	46	62	53	21	18	52
Viet Nam	33	44	85	67	45	11	12	47
Ethiopia	113	177	19	49	48	16	8	64
Ghana	70	110	47	57	27	8	11	26
Malawi	137	217	8	41	30	9	7	48
Mozambique	133	214	9	47	27	11	5	55
Zambia	112	202	13	43	28	9	6	53
Zimbabwe	49	73	65	49	16	3	6	21

x indicates data that refer to years or periods other than those specified in the column heading, differ from the standard definition, or refer to only part of the country.
- - Data not available.
***** Probability of dying between birth and exactly one year of age expressed per 1000 live births.
****** Probability of dying between birth and exactly five years of age expressed per 1000 live births.
******* Rank of country within world for level of under five mortality
Underweight – moderate and severe – below minus two standard deviations from median weight for age of reference population; severe – below minus three standard deviations from median weight for age of reference population.
Wasting – Moderate and severe – below minus two standard deviations from median weight for height of reference population.
Stunting – Moderate and severe – below minus two standard deviations from median height for age of reference population.
Source: *The State of the World's Children 1998.*

also is generally lower in the African countries and malnutrition tends to be high. The rates of malnutrition, especially stunting (a measure of long-term malnutrition) were high in the African countries as well as several countries in Central America and Asia.

Pathways to Nutritional Impact

The countries in this study present a range of conditions within the maize consuming world that allow the exploration of different QPM targeting options. These options address 1) improving human nutrition and/or welfare through using QPM to increase human protein consumption or 2) using QPM in animal feed.

As seen in Fig. 1 (following page), the most direct route to improving human nutrition using QPM is if it is grown by and fed directly to the target groups. We could envision this happening with subsistence or small-scale maize farmers, but there are also other possibilities. The maize could also be sold to gain more income with which to purchase higher quality food or health care. In this instance, its impact would not differ from selling any other improved variety, unless it could be sold at a premium (which is unlikely). Selling QPM at a higher price for human consumption would probably require government subsidies in order for the target consumers, the poor, to be able to purchase it. Selling it at a higher price for animal feed is different option, which will be examined later.

Another possibility is the large-scale production of QPM on commercial farms for sale to the target populations. This option could be especially promising as part of a program aimed at the urban poor, although it could also be extended to any areas where maize is mainly purchased and home production is minimal. An advantage to this option is that large, commercial producers would probably use hybrid QPM seed, thus resolving the problem of maintaining QPM's genetic purity. However, once QPM leaves the farm, be it a commercial operation or a smallholder plot, the problem of differentiating it from normal maize arises. These issues will be addressed later in this paper.

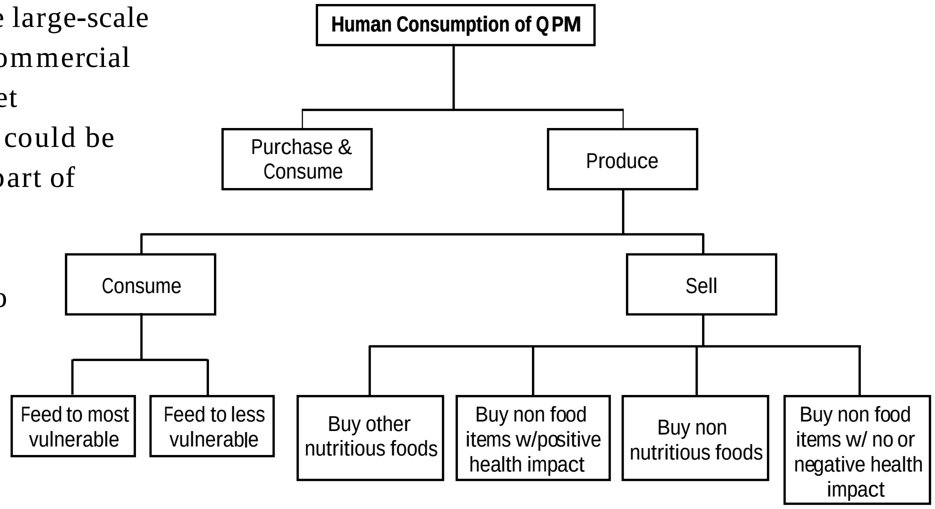

Figure 1. Routes of nutritional impact through human consumption of QPM.

As Figure 2 shows, the potential routes of QPM to affecting human welfare, when used as animal feed, may be primarily as a source of income. In terms of QPM's impacts on nutrition when used as feed, they are likely to be indirect at best. In large part, because members of the target groups are poor, they are the least likely to own animals; indeed, if they owned and consumed animals, they would probably not be suffering from protein deficiencies and hence not be in the target group. It is possible to hypothesize that cheaper feed would result in more economically accessible meat products, if one assumes that the savings are passed on. However, this would be unlikely to have an impact on the target populations. If people cannot afford to buy and eat legumes, they probably cannot afford to buy meat, even at reduced prices.

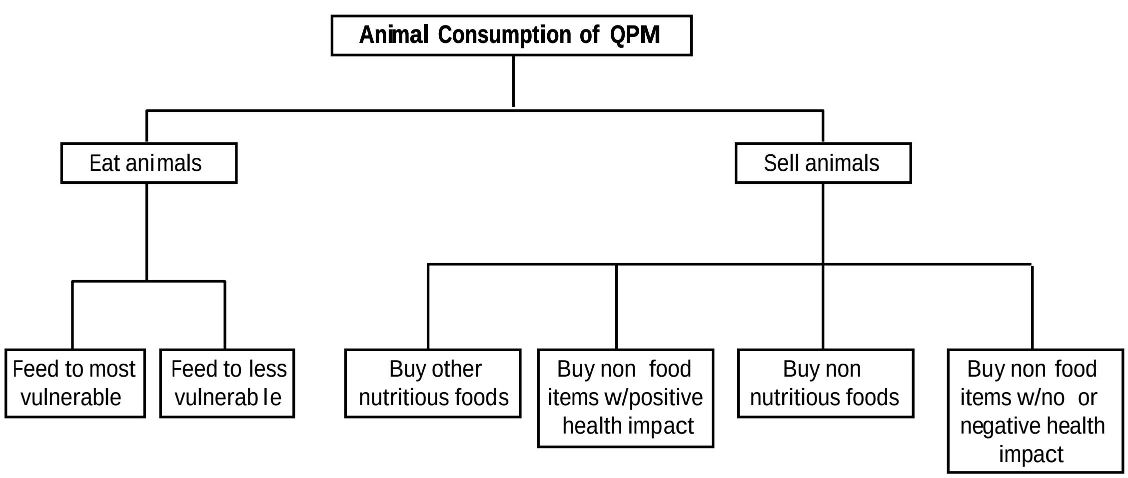

Figure 2. Routes of human nutritional impact through use of QPM in animal feed.

Another possibility is for poor farmers to sell QPM for use in feed at a premium price. In this scenario, their incomes would be higher than if they sold conventional improved maize varieties, and they might possibly reap benefits through its direct consumption as well. To sell QPM at a premium, however, would require that it be easily identifiable or certified in some way.

Although it would be difficult to measure an impact of QPM use for animal consumption on human nutrition, this is not to say that using QPM in animal feeds is not an important option for savings in the feed industry. This will be discussed further in the section on animal feed.

QPM for Human Consumption

The Protein Question: Are Deficiencies a Problem?

One of the main arguments against further investments aimed at introducing QPM is the belief held by many nutritionists that little protein deficiency problem actually exists. As mentioned earlier, interest in QPM waned substantially following the issuance of the revised protein requirements in 1973 (FAO / WHO 1973), and since then, protein deficiency has not been considered the threat that it once was. A study carried out in Mexico, Kenya, and Egypt seems to confirm this stance, as no protein or amino acid deficiencies were found, in either adults or children, in any of the communities studied (Beaton et al. 1993). Today it is generally believed that overall energy deficiency and micronutrient deficiencies such as iron, Vitamin A, zinc, and iodine, are more important. Some nutritionists, however, strongly believe that protein deficiency remains an important dietary problem, especially among high risk groups, due to the low quality of protein that is often consumed when animal products are not a part of the diet. Illnesses and severe intestinal parasites also can reduce the body's ability to absorb and use protein.

Assuming that protein deficiency is a problem, many aspects of QPM's actual potential nutritional impact on humans are still unclear. Several studies carried out under controlled conditions show an increase in nitrogen retention and weight gain with Opaque-2 or QPM, versus normal maize (for an overview, see Bressani 1991). Most studies to date have been controlled feeding trials comparing groups consuming different sources of protein (usually Opaque-2, normal maize, and a reference protein such as milk or casein). Few community level studies on adoption and impact under normal conditions have been carried out.

Among the few community-based studies were a six-month, supplementation trial with preschool children in India (IARDI 1977; Singh et al. 1980), and a maize replacement study on a coffee plantation in Guatemala (Valverde et al. 1983). The Indian study consisted of a control group and groups of children supplemented with normal maize, Opaque-2 or skim milk. The results of the performance of Opaque-2 appeared to be promising, with the children involved showing gains in weight, height, and arm circumference comparable with or just below the group receiving milk. However, no statistical analysis was shown for the study, and the study itself concluded that its time frame was too short for its results to be authoritative (Singh et al. 1980). Furthermore, supplementation trials provide little information regarding adoption and impact under normal dietary conditions.

The Guatemalan study also showed some promising preliminary results, but it was not completed due to loss of funding. Several other interventions such as the introduction of medical care, an improved water supply, and an increase in the minimum wage make the results difficult to interpret. However, the data suggests that, taking into account the impact of other interventions, children in communities receiving Opaque-2, versus those receiving normal maize, had greater improvements in weight and height in children under 19 months of age, after which improvement was not found. In the case of older children, growth stunting had, most likely, already occurred, and it was hypothesized that an increase in protein consumption alone was not enough to make a difference without an increase in energy consumption as well. It was not ruled out that the same results could have been obtained with only an energy supplement.

Both studies, and particularly the Guatemala study, looked to some extent at the issue of adoption, although the exact methodology was not described. Although it was concluded that Opaque-2 was acceptable for consumption purposes, the more serious production related and storage problems were not adequately dealt with, as is evident from its lack of widespread adoption at the time.

More recent studies were carried out after the introduction of QPM into Ghana. In 1993, a group of 444 farmers were given either QPM or another type of maize to cultivate, and three-day assessments were carried out at six-month intervals on children in the two groups. In a second study two groups of a total of 120 children between 0 and 15 months of age were given supplements of maize dough made with either QPM or other maize. It was reported in a paper by Tsumasi-Afriyie et al., (1998), that, “The studies and observations indicated that QPM-fed children were healthier, suffered less fatalities and had better growth rates.” Unfortunately, these studies are unpublished and details and actual results are unavailable.

Assuming that QPM is acceptable to consumers and that protein deficiency is a problem, the biggest question is whether QPM is the most desirable or cost-effective method for addressing the problem. Although providing for a range of nutritional needs in one staple crop seems to be a convenient solution, is it the best one? How many people enjoy eating such a monotonous diet? Would not another approach involving a more varied diet better address nutritional deficits as a whole, be more agreeable, and possibly more efficient in the long run? Although growth faltering among preschool children is directly caused by inadequate intake of energy, nutrients, or both as well as infectious diseases, these are affected by complicated interactions between a variety of biological, social, and economic factors and relationships. These relationships vary between different locations, time periods, and population groups, making the problem difficult to address. (Pinstrup-Andersen et al. 1995). Given the complexity of the problem, is allocation of resources to QPM, in terms of money and effort, the most cost-effective approach to the problem?

The other side of the argument is that a more varied diet may be out of reach to many people who are already eating diets consisting mostly of maize. Although a balanced diet may be the best option, animal products, the most efficient source of protein, are generally expensive and unaccessible to many. Fresh fruits and vegetables also tend to be expensive and they are seasonal. Although legumes are a good source of protein when combined with cereals, consumption levels have dropped in many areas, and they are often not used in weaning foods.

Furthermore, since improved versions of QPM are already available, have no known negative side effects, and will probably help some people, why not introduce it? If people are already consuming a maize-based diet, why not make it as nutritionally complete as possible to offset dietary deficiencies. Although protein deficiency has been downgraded as a nutritional constraint, some at-risk populations could still benefit from it. Regarding QPM's cost effectiveness, most of the money needed to develop QPM has already been spent and a marketable product has been produced. This does not discount the fact that introducing and promoting QPM would still entail considerable expenditures.

Protein Availability in the Targeted Countries

Is there adequate protein available to feed the populations of the countries included in this study? Based on 50g / day and total per capita protein available, most countries seem to have enough available protein to feed their populations, although the margin for some countries is minimal (Table 3). Ghana and Mozambique, however, fail to meet the FAO / WHO minimal standard. Ghana comes close with 49 g / day, but Mozambique falls quite short at 35 g / day, providing 98% and 70% of the daily per capita protein recommendation for these countries, respectively. Zimbabwe, Zambia and Nicaragua are on or just above the daily per capita recommendation. Some of the data may be suspect, especially those from Mozambique, as the exceedingly low figure for per capita protein availability is not consistent with reported levels of malnutrition for the country.

Table 3. Overview of available energy and protein, and nutritional contributions of maize – 1996

	Total kcal available per capita per day	Total protein available per capita per day (g)	Daily avail. per cap. kcal supply as % of requirements*	Daily avail. per cap. protein supply as % of requirements **	Per capita maize consumption (kg/year)	% kcal from maize of total kcal per cap/ day	% available per cap RDA for kcal provided by maize*	% protein from maize of total protein per cap/day	% available per capita RDA for protein provided by maize**
Bolivia	2,170	56	94	112	44	15	14	13	14
Brazil	2,938	74	128	148	20	6	8	5	8
El Salvador	2,515	63	109	126	87	32	35	33	42
Guatemala	2,191	56	95	112	102	45	43	46	52
Honduras	2,368	55	103	110	89	35	36	40	44
Nicaragua	2,328	52	101	104	52	21	21	25	26
Mexico	3,137	82	136	164	129	35	47	34	56
China	2,840	76	123	152	11	3	4	3	4
India	2,415	59	105	118	8	3	3	3	4
Vietnam	2,502	58	109	116	16	5	6	5	6
Ethiopia	1,845	59	80	118	36	19	15	14	16
Ghana	2,560	49	111	98	43	14	16	20	20
Malawi	2,097	56	91	112	149	62	56	61	68
Mozambique	1,799	35	78	70	54	26	20	34	24
Zambia	1,939	51	84	102	143	59	50	59	60
Zimbabwe	2,083	50	91	100	118	45	41	50	50

*Recommended daily per capita energy requirement = 2,300 kcal/day (FAO/WHO 1992).
**Recommended daily protein requirement = 50 g/day (FAO/OMS 1992).
***Protein to energy conversion ratio = 4 kcal/g protein (FAO/OMS 1992).
Source: FAOSTAT, FAO. December,1998.

Protein deficiency is not the only, or the worst, nutritional deficit in these countries. Low levels of energy consumption, generally accompany it. This is true for all the countries in this study. Based on the FAO/WHO recommended per capita energy intake of 2,300 kcal/day (FAO/OMS 1992), many countries have less than the recommended available energy supply needed to feed their populations. These include Bolivia, Guatemala, Ethiopia, Malawi, Mozambique, Zambia, Zimbabwe, and Mozambique, which again registered the lowest level of the group. In fact, using the threshold mentioned earlier of a minimum per capita energy supply of 2,770 kcal, only Mexico, Brazil, and China meet this criterion. This does not even take into account all the micronutrient deficiencies, which will not be discussed specifically in this paper. As noted, it has been argued that energy is a more important priority than protein and that an overall increase in food supply would probably also take care of most protein deficiencies. If QPM yields as well as other high-yielding varieties, however, no energy tradeoffs would be involved.

Figure 3 shows the growth rate in energy and protein availability over a ten-year period ending in 1996. It is clear that while some countries have made fairly large gains (Ethiopia, Ghana, China, and Vietnam), others have been losing ground (Zambia, Zimbabwe, Guatemala, and Nicaragua). Note that the protein gains in China far outweigh the energy gains, probably reflecting the increased consumption of animal products. Ghana, on the other hand, has experienced the reverse; although there have been energy and protein gains, the much larger energy gains probably reflect an increase specifically in cereal consumption.

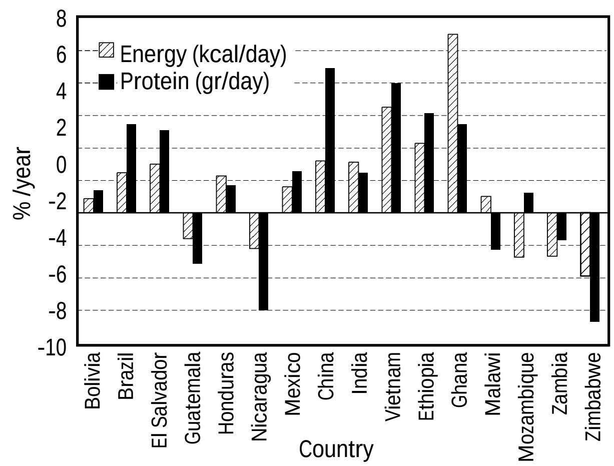

Figure 3. Growth rates of energy and protein availability 1987-96.
*Not significantly different from zero.
Source:FAOSTAT, FAO.March, 1998.

Brazil, China, and Mexico stand out as having more than enough kcal and protein available to feed their populations, however, these are aggregate figures and there can be significant in-country variation.

The National Nutrition Survey in Mexico, undertaken by the Instituto Nacional de Nutrición Savador Zubiran (INNSZ), shows a gradient of malnutrition from north to south, with malnutrition gradually increasing as one moves south, but with pockets of malnutrition and poverty in other areas, most notably Guerrero (INNSZ 1997). The FAO data for the overall amount of energy available in Mexico is quite high at 3,137 kcal, or comparable to that found in the USA. On the other hand, the National Nutrition Survey based on household level consumption, found per capita daily consumption to be 1,910 kcal outside of Mexico City and 2,016 kcal within Mexico City. Protein consumption was 61 g/day outside of Mexico City and 70 g/day within the city (INNSZ 1997, 1995), compared to the figure of 82g/day from FAO. According to the INNSZ data, no region of the country suffered from protein deficiency, although many states show fairly high rates of malnutrition (INNSZ 1996). This does not necessarily indicate that protein deficiency does not exist in some areas of the country, or within some populations, but that it does not appear at a regional level.

In Bolivia, the FAO data show per capita energy and protein availability at 2,170 kcal and 56g / day, respectively. Government surveys have shown energy consumption during 1990–1994 to be 2,045 kcal / day. However this varies widely between urban and rural areas, and by state, ranging from 1,226 kcal to 2,314 kcal / day. Protein consumption ranged from 33g to 76g / day in various parts of the country (Haquim 1995). Overall protein availability seems adequate based on the FAO data, but protein intake from actual consumption data was well below the recommended 50 g / day in some areas of the country. Given these discrepancies, it is quite probable that the FAO data also overestimates actual consumption figures in some other countries and that assumptions of protein adequacy may not be accurate.

In contrast, the data used here for some other countries probably underestimate real consumption. According to Alderman and Higgins (1992), actual consumption generally exceeds the balance sheets, and they assume this is the case in Ghana and probably other African countries. This may be the case for Mozambique, which reported very low available per capita protein.

Table 3, which shows per capita availability levels of maize for human consumption, provides useful information regarding which countries would be good candidates for QPM. Malawi and Zambia are strong prospects with around 60% of their total kcal and protein supplies coming from maize. Guatemala, Mexico, El Salvador, Mozambique, Ghana, and Zimbabwe also exhibit high percentages of total energy and protein supplies coming from maize, which may make them suitable for QPM deployment. On the other hand, maize in China, India, and Brazil provides less than 10% of total available protein and energy, although this does not provide an accurate picture of the overall situation in these countries. India and China especially have large regions of high maize use, and although the contribution of maize to people’s diets in these countries appears small in percentage terms, it does contribute to the food intake of a large number of people.

According to these data, Mozambique is also a good candidate for the introduction of QPM based on an overall deficiency of protein available, despite its relatively lower proportion (26%) of total calories that come from maize. Naturally its introduction could have the most impact in those regions of the country with the highest levels of maize consumption.

Figure 4 shows differences in the proportion of available protein provided by maize between 1987 and 1996. With the exception of Bolivia, the role of maize in providing protein has generally dropped in the Latin American countries. China shows a drop of almost 60%

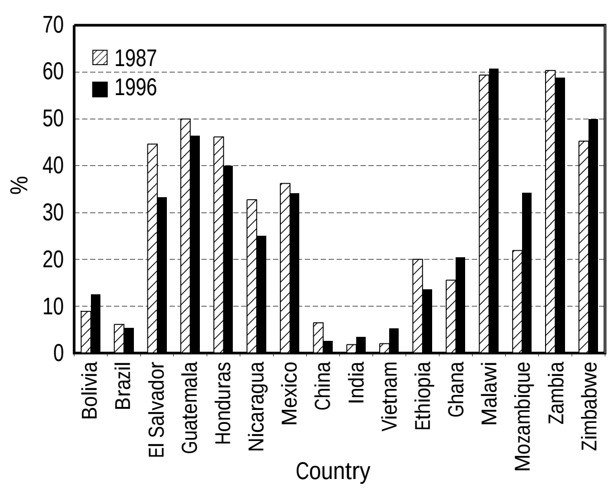

Figure 4. Proportion of available protein provided by maize, 1987 and 1996.
Source: FAOSTAT, FAO.February, 00

in the proportion of available protein coming from maize, while in India and Vietnam, the contribution of protein from maize, although low to begin with, has increased substantially, by 86% and 159%, respectively. With the exception of Ethiopia, the importance of maize as a protein provider has also increased in all of the African countries, most notably in Mozambique.

In summary, the importance of maize in the national food supply is very high in many African countries and in Central America, and somewhat less important in South America. The lowest contribution of maize is in Asia, although its importance is increasing in India, Vietnam, and several other countries, especially in Southeast Asia, that are not included in this analysis. China appears to be lowering its per capita use of maize as a food crop as its economy improves, although maize consumption is still important in certain areas of the country.

Pulses as a Protein Source

When considering the protein situation in the potential target countries, we must consider the role played by pulses in the diets. Many traditional diets provide a large portion of their protein by combining cereals with pulses (which contain a more complete set of essential amino acids, including higher levels of lysine and tryptophan).

However, with changes in traditional diets, pulse consumption has dropped in several countries, often without being replaced by another protein source. In some countries, for instance China, the drop in pulse consumption is an indication of prosperity and a switch to animal proteins. People become better off and consume more animal products and fewer beans. In other countries, pulses have been dropped from the diet, because of high prices and/or unavailability, and not replaced by alternative sources of protein, thus leading to potential protein deficits.

Table 4 reviews the in-country correlations between annual per capita supply of pulses and protein from 1961 through 1996. Countries with growing per capita meat supplies, such as China and Brazil, decreased their levels of pulse supply while increasing their overall protein supply. Mexico, India, and Zimbabwe also showed negative, though statistically insignificant, correlations between protein and pulse availability. Correlations between pulse and protein availability were positive, and in most cases statistically significant, in the other countries included in this analysis. This positive correlation does not necessarily indicate whether availability is increasing or decreasing, however, it is noteworthy that the targeted African countries and Nicaragua showed negative growth rates for both pulse and protein availability. Bolivia, El Salvador, Guatemala, and Vietnam all showed low but positive growth rates for these variables during this time frame[3]. Although cause and effect cannot be demonstrated by correlations, the data imply that pulses continue to play an important role in the diet of many countries, and that reduced consumption, without a replacement source of protein, can leave an important dietary gap. This is particularly true in Africa, where QPM may help fill this gap. Studies examining the dietary combinations of QPM or conventional maize and beans suggest that with QPM, the absence of beans does not affect protein quality (Bressani 1991); this is not the case with conventional maize. Therefore, it appears that, in the absence of increased pulse consumption, QPM provides a viable option for increasing protein consumption.

[3] Data for growth rates for pulse consumption not shown for this time period. It is available at FAOSTAT.FAO.April, 1999.

Table 4. Availability of pulses

	Correlation between per capita supply of pulses (kg/y) and per capita supply of protein (g/day) 1961-96	Per capita pulse supply (kg/y) 1996	% protein from pulses of total available per cap/day 1996	% RDA for protein* available from pulses 1996	Growth rate of pulse production 1987 - 96
Bolivia	.663**	2.5	3.6	4	-0.5
Brazil	-.443**	17.8	14.9	22	3.3
El Salvador	.428**	9.0	7.9	10	5.6
Guatemala	.566**	9.8	10.7	12	-1.0
Honduras	.449**	8.8	9.1	10	0.9
Nicaragua	.626**	13.8	15.4	16	7.0
Mexico	-.065	15.7	9.8	16	4.4
China	-.808**	1.7	1.3	2	-2.5
India	-.195	12.7	11.9	14	2.1
Vietnam	.666**	2.4	1.7	2	2.4
Ethiopia	.837**	16.7	16.9	20	7.6
Ghana	.264	0.9	2.0	2	2.3
Malawi	.672**	16.5	17.9	20	0.9
Mozambique	.246	6.9	11.4	8	4.0
Zambia	.562**	2.2	2.0	2	8.4
Zimbabwe	-.181	3.6	4.0	4	-1.1

*Recommended daily protein requirement = 50 g/day (FAO/WHO 1992).
**Correlation is significant at the 0.01 level (2-tailed).
Source: FAOSTAT, FAO. December,1998.

Table 4 also shows the contribution of pulses to protein availability, and production trends for pulses. Pulses continue to be an important source of protein in several of the countries included here, most notably Ethiopia, Malawi, and Brazil, where 20% or more of the recommended protein requirement can be supplied by pulses.

It is generally true that from 1961 to 1996 pulse availability has declined in most of the countries in this study. There have been shifts, however, within this overall trend. While the growth rates for pulse use from 1961 to 1986 were generally negative or near zero, between 1987 and 1996, some countries have increased their pulse supply (Figure 5), including Brazil, El Salvador, Honduras, Mexico, Malawi, Vietnam, and most notably, Ethiopia and Zambia. In Ethiopia, however, the increase in pulse supply was accompanied by a decrease in meat supply. Increases in both meat and pulse supply should indicate increases in overall protein availability, although it is highly unlikely that such increases are evenly distributed throughout a population.

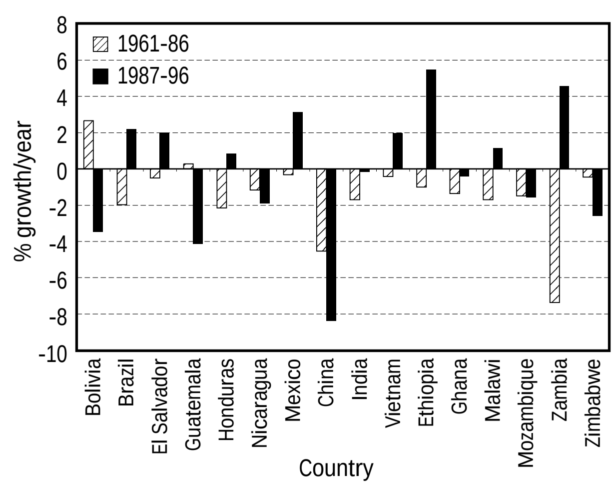

Figure 5. Growth rates for per capita availability of pulses.
Source: FAOSTAT, FAO November, 1998.

In some cases, when pulse supply drops, so does protein supply, because no alternative protein source is found or provided. This loss appears to leave a gap in traditional diets, which in many cases is only being filled by increased dependence on maize or other cereal crops. Given the poor quality of protein in conventional maize and cereals in general, protein deficits can only increase in countries where this trend is not reversed.

Genetic Loss of the High Protein Gene

An important agronomic shortcoming of QPM is that a recessive gene controls its high lysine levels. Because maize is an open pollinated crop, this gene can be easily lost through cross-pollination unless hybrid seed is purchased every year. This problem will be more pronounced where QPM is planted in small patches surrounded by non-QPM maize, the practice of planting multiple varieties in close proximity being common among many small landholders. Several possible solutions have been suggested, but none appear ideal for most poor or subsistence farmers. The most reliable way to maintain high lysine levels is to purchase and plant hybrid seed each new season, however, this solution may not be feasible for small-scale farmers who are not accustomed to, or economically capable of, purchasing seed on an annual basis.

Another proposed solution is to blanket an area with QPM, so that no crossbreeding with other maize occurs. It is unlikely, however, that this would prove sustainable. Maize populations are dynamic, with farmers continuously introducing new varieties with different characteristics, either to ensure against total crop loss (i.e., maize with different growing seasons, tolerances to drought or insects), for use under various cropping conditions, and / or for different consumption purposes. Experimentation at the farm level is constant (Bellon and Brush 1994; Louette et al. 1997). Therefore, even if an area were planted solely to QPM one year, it is unlikely that it would continue to be so within a few years time. Furthermore, in some circumstances, blanketing a large area with QPM could be undesirable because of the potential negative impact on genetic diversity.

Loss of the high lysine gene can also be controlled to a certain extent by careful management practices, such as selecting seed from the center of the field. This practice, however, would probably require special training of farmers. Furthermore, since QPM appears virtually identical to conventional maize, it would be difficult to tell when the gene was actually lost and new seed must be purchased. Making QPM a different color from other maize consumed in the area (i.e. white versus yellow) could alleviate the latter problem. However, this could cause problems with consumer acceptance. Biotechnology could offer a solution in the future by changing the gene from recessive to dominant, but such work has not yet been undertaken, and could also cause problems with acceptance.

Finding an appropriate solution to the loss of the high quality protein trait depends very much on the targeted group, its cultural traditions, and its cropping conditions. Certainly, large-scale farmers growing hybrid seed would be the easiest way to ensure maintenance of genetic purity.

The Adoption Question

Regarding acceptance of QPM, policy- and decision-makers should address several basic questions. Do people in the proposed target country or region actually have protein deficiency? Is maize consumed in sufficient quantities in those areas for it to have an impact on overall protein consumption? And, is QPM an acceptable substitute for foods already consumed by target groups?

A thorough analysis of factors affecting the acceptance of QPM is beyond the scope of this paper. However, one can pose several reasonable hypotheses based on past history and anecdotal information. One such hypothesis is that acceptance will more likely pose a problem in the center of origin for maize, Mesoamerica, given its ancient traditions regarding maize consumption—many types of maize are grown for very specific uses. The Museo Nacional de Culturas Populares reported 605 different maize dishes in Mexico (Museo Nacional de Culturas Populares 1982). People in these areas with a long tradition of using specific varieties for different preparations might be less likely to accept substitutes. CIMMYT work on maize diversity management and utilization in Oaxaca, Mexico found that the traits most frequently cited by farmers as important were consumption related and included taste and suitability for special preparations such as atole, tejate, pozol, and nicuatol (Bellon et al. 1998). QPM may or may not be acceptable for these preparations. This could prove problematic if it was widely viewed as unacceptable for dishes consumed by the target groups, such as weaning foods. Such preferences can vary from region to region and even from village to village.

One could also hypothesize that QPM may be more readily acceptable in Africa or Asia than in Mesoamerica. Although maize has been in Africa since the sixteenth century, it has only become a staple crop of real importance within this century; therefore it does not have the extensive history and traditions that are found in Mexico or Guatemala. Substitution of one type of maize for another with similar color and general consumption characteristics may not be overly problematic. In Ghana, for example, QPM seems to have been well accepted, and most households make no distinction between it and other improved varieties (Morris et al. 1999).

However, even in Africa, further research on QPM acceptance and adoption is warranted in order to avoid any deployment missteps. Breeders often use a different set of criteria for judging a variety than consumers. For instance, breeders may concentrate on improving production characteristics such as yield, while paying little attention to consumption characteristics. For example, national research programs in Malawi, concentrating on increasing yield, released improved dent maize varieties. Although farmers appreciated the increased yield, they preferred their local flint varieties for their personal consumption, because they could be more easily processed into the flour used for everyday consumption. As a result, they produced local varieties for home consumption and improved dent varieties for sale (Smale and Heisey 1994). The fact that breeders did not take milling characteristics into account had an important impact on the adoption of the new varieties.

Although breeders consider current versions of QPM to be virtually indistinguishable from conventional maize, this may or may not be so. Maize breeders and consumers may be using different criteria to judge the maize. These differences are often not apparent until it is grown and consumed by the target populations. However, fairly widespread adoption in Ghana (Morris, et al 1999) would appear to justify claims that in Ghana at least, current versions of QPM are as acceptable as other maize.

Another important adoption issue is the identification of target recipients. Raising QPM as a cash crop to be targeted for consumption by the urban poor in the form of tortillas, for example, could be a valid approach, especially with the large urban populations found in Mexico and Brazil. As seen in Table 1, large percentages of the populations of Central and South America are already urbanized and those figures are rising. However, the maize characteristics that could be successful in an urban-based deployment strategy, may not necessarily be accepted in a setting of rural poverty, where maize is grown for self-consumption.

Female Education—A Key Factor in Adoption

Malnutrition is affected by a number of factors including the demographics of the affected group. With preschool age nutrition, a large body of research indicates that maternal education is a very important variable. Maternal education includes specific education on nutritional issues, as well as levels of formal education. A 1997 study conducted in nine countries and the Indian state of Kerala on the impact of health interventions found that health; nutrition, water, and sanitation all had significant positive impacts on health indicators. Education, however, had the greatest health impact, including improved rates of infant and under-five survival, life expectancy at birth, and total fertility (UNICEF 1999).

Another study, conducted by the International Food Policy Research Institute (IFPRI), looked at the determinants of nutritional status of children in 179 developing countries and found that women's education was the most important determinant, followed closely by per capita food availability. In fact, improvements in women's education was found to be responsible for 43% of the total reduction in child malnutrition between 1970 and 1995; that percentage climbs to more than 50% of the reduction when combined with women's relative status. However, in cases in which per capital food availability was less than or equal to 2,300 kcal, food availability ranked first, followed by education (Smith and Haddad 2000). Given the importance of education, it is worth examining some educational statistics from our sample countries (Table 5).

The lowest levels of adult literacy are found in India and Africa; however, some countries appear to be responding to the problem. Malawi in particular, with a 56% literacy rate, is apparently making an effort to rectify the situation. Between 1993 and 1997 it claimed 100% enrollment of primary school age children. Educational improvements in some countries, notably in India, Ethiopia, Malawi, and in the past Mozambique, have been distributed inequitably between male and female children. The educational situation for women in Mozambique is particularly bleak; only 40% of the total adult population and 23% of adult females are literate. The situation of the next generation will not be much better as only 45% and 35% of elementary school age boys and girls, respectively, were enrolled in school during the cited time period. The situation is not much better in Ethiopia with a female literacy rate of only 25%. Guatemala and Ghana are a little better with around half of the female population in these countries literate. In general, the remaining countries in this study take a somewhat more egalitarian approach to education in regards to gender (Figure 6).

Low levels of female education are detrimental to these countries for many reasons. Not only do these countries fail to capitalize on the human resource potential these women offer, they also neglect the key players needed to combat health and nutritional problems. Women control most aspects of eating and childcare. Poor understanding of an intervention can lead to lack of, or improper, adoption. Furthermore, women with less education tend to have lower social status,

Table 5. Education levels

	Adult literacy rate 1995		Primary school enrollment ratio (net) 1993-97		% primary school children reaching grade 5 1990-95	Secondary school enrollment ratio 1990-95		Enrollment ratios females as a % of males 1990-95	
	total	female as a % of males	male	female		male	female	Primary school	Secondary school
Bolivia	83	84	90y	89y	60	40	34	91	85
Brazil	83	100	93y	94y	70	- -	- -	96x	116x
El Salvador	72	95	78	80	58	27	30	101	111
Guatemala	56	78	61y	55y	- -	25	23	88	92
Honduras	73	100	89	91	- -	29	37	101	128
Nicaragua	66	103	82	85	47	40	47	103	118
Mexico	90	95	- -	- -	85	57	58	96	102
China	82	81	99	98	92	60	51	97	85
India	52	58	75y	61y	62	59	38	81	64
Vietnam	91	94	- -	- -	- -	- -	- -	95x	93x
Ethiopia	36	54	28	19	51	11	10	64	91
Ghana	65	71	70y	69y	80	45	29	84	64
Malawi	56	58	100	100	94	6	4	90	67
Mozambique	40	40	45	35	47	10	6	72	60
Zambia	78	83	76	75	- -	31	19	93	61
Zimbabwe	85	89	91y	90y	90	49	39	93	80

y Indicates that survey data were used for estimating net primary school enrollment.
- - = Data not available.
Gross secondary school enrollment ratio: The number of children enrolled in secondary school, regardless of age, divided by the population of the age group which officially corresponds to the same level.
Net primary school enrollment ratio: The number of children enrolled in primary school, who belong to the age group that officially corresponds to primary schooling, divided by the total population of the same age group. Data from household surveys on children attending school have been used to fill blanks and to replace UNESCO reported data that are three years or more, older than the survey data. Such data are identified by 'y'.
Source: *The State of the World's Children1998.*

therefore, even if they understand the benefits of an intervention, they are less likely to have the power to act on it. Such problems would probably extend to the adoption of QPM for use in weaning or children's foods by a population of largely uneducated women. The Ghana experience is a case in point. As mentioned earlier, Ghana had a large-scale campaign to promote the benefits of QPM. Despite its local name, Obatanpa, "the good nursing mother," a recent survey found that few farmers knew that it possessed any special nutritional benefit and women constituted a minority of the "knowledgeable" group (Morris et al. 1998).

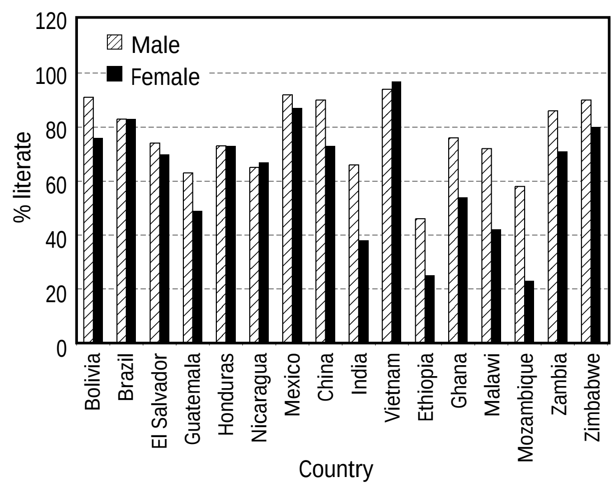

Figure 6. Adult literacy rate, 1995.
Source: UNICEF, 1998.

Assuming that one of the most important QPM objectives is its adoption for weaning foods, mothers must understand that; 1) there is a nutritional difference between QPM and conventional maize, 2) have access to it, and 3) be willing to use it. Constraints regarding these points have been addressed earlier in this paper. That said, the importance of maternal education should be taken into account when addressing these points and in the broader context of implementing programs aimed at introducing QPM for human consumption. Such programs, ideally, should be part of integrated nutrition and development programs that include an educational component aimed at women. This approach should greatly increase the possibility of adoption and impact, although researchers may find it difficult to ferret out the respective impacts of QPM and education in their impacts assessments.

Giving QPM Another Chance

Despite the controversy over its potential value, many now feel that QPM is worth a second look, both for human consumption and as animal feed. It was introduced into Ghana in 1992, and has been promoted on a fairly large scale. However, its nutritional impact is unclear because no baseline nutritional studies were carried out on which to base a comparison. A 1997 survey found that farmers identified about 15.9% of the area planted to maize in Ghana as planted to QPM. A further 18.5% was identified as "agric," a name that farmers used as a catch all category for various improved varieties. It can be assumed that a fair, but unknown proportion of the "agric" was also QPM. Despite the fairly widespread adoption, must farmers were unaware of its nutritional properties and knew of no difference between it and other improved varieties issued by the government. Even when farmers were aware of the existence of a nutritionally improved variety, they did not always correctly identify it (Morris et al., 1999). On the positive side, adoption does not seem to be a problem since farmers apparently found it indistinguishable from conventional, improved maize. QPM appears to be functioning similarly to an enrichment program, in that people growing or purchasing QPM are receiving the added protein without necessarily being aware of it. Therefore, if QPM were widely grown and its lysine levels could be maintained, it could reach a large proportion of the population.

QPM is currently being grown in China, Brazil, Ghana, Viet Nam, India, South Africa, and the United States. It is in the process of being released in Mexico, El Salvador, and Guatemala. Verification trials are being held in several countries in Asia, Africa, and Latin America. Sasakawa-Global 2000 is actively introducing it in several African countries including Ethiopia, Guinea, Burkina Faso, Mali, Mozambique, and Nigeria.

QPM as Animal Feed

The other important use of QPM is as a less expensive source of high protein animal feed for monogastric animals, such as pigs and poultry. Unlike multiple ruminant animals (i.e. cattle, sheep, goats), monogastric animals require a more complete protein than cereals alone can generally provide. The nutritional protein limitations of conventional maize extend to monogastric animals, insofar as it lacks sufficient lysine and tryptophan. These amino acids are usually supplemented in animal feeds by soybeans, pulses, or commercially produced synthetic amino acids. QPM presents another option. Studies have documented improved growth in pigs and poultry when QPM is substituted for conventional maize, thereby increasing bioavailable protein (Sullivan et al 1989; Asche et al. 1985). As a result, some have suggested that the biggest impact of QPM could from its use in commercial feeds.

Use of Pulses and Synthetic Amino Acids

Traditionally, the protein content of feed has been increased through the addition of pulses and/or soybeans. However, with the exceptions of China, India, and to some extent Mexico, this is not a widespread practice in the countries found in this study (Table 6).

In recent years, the supplementation of feeds with commercially-produced synthetic amino acids has become more common in developing countries, and it remains an important option for the commercial feed industry. When available, synthetic amino acids can be inexpensive and easy to add to animal feed, especially when used in bulk. Some countries, such as Mexico, Brazil, and China, now produce their own synthetic lysine and tryptophan, while others can easily import it. This solution to the protein problem, however, may not necessarily be available to all developing countries, or if it is, it may not be within reach of their small-scale farmers. QPM could still provide savings on the price of feed, depending on its price and the price and availability of synthetic lysine.

The Role of QPM

A 1992 CIMMYT study analyzed the possible economic benefits of QPM for the commercial feed industries in Brazil and El Salvador (López-Pereira 1992). By using QPM, the study found that soybean meal could be reduced by approximately 50% and imports of synthetic lysine eliminated or substantially reduced. Furthermore, the savings in the cost of producing feed from using QPM would be 4–5% for pig feed and 3–4% for poultry feed in Brazil and 3–4% for both pig and poultry feed in El Salvador.

It appears that there may be a role for QPM in the commercial feed industry, although its advantages depend on its price and availability versus those of the alternatives. Its role as feed for small-scale or home livestock production and consumption is less clear. Small-scale farmers

Table 6. Pulse and soybean availability for use in animal feed – 1996

	Soybeans used as feed (1000 MT)	% total soybeans used for feed	Soybean/ cereal in feed ratio	Pulses used as feed (1000 MT)	% total pulses used for feed	Pulses/cereal ratio
Bolivia	1	0.17	0.004	- -	- -	- -
Brazil	1,251	5.65	0.048	1	0.03	4E-05
El Salvador	- -	- -	- -	- -	- -	- -
Guatemala	1	2.32	0.005	- -	- -	- -
Honduras	- -	- -	- -	- -	- -	- -
Nicaragua	- -	- -	- -	- -	- -	- -
Mexico	500	16.09	0.037	23	1.41	0.221
China	1,900	13.66	0.015	2,082	45.72	0.017
India	- -	- -	- -	1,233	8.43	5.825
Vietnam	- -	- -	- -	- -	- -	- -
Ethiopia	- -	- -	- -	- -	- -	- -
Ghana	- -	- -	- -	- -	- -	- -
Malawi	- -	- -	- -	6	2.39	0.002
Mozambique	- -	- -	- -	- -	- -	- -
Zambia	- -	- -	- -	- -	- -	- -
Zimbabwe	- -	- -	- -	- -	- -	- -

Source: FAOSTAT.FAO. November, 1998.

often do not have the resources to provide special feeds for their livestock. If QPM is grown on the farm or is readily available, then these animals could possibly benefit from its use. It seems unlikely, however, that backyard pig and / or poultry raisers that are not currently purchasing feed will start purchasing QPM for their animals. Even when small-scale farmers can afford to purchase such inputs, they could encounter the problems cited earlier associated with identifying and purchasing QPM for human consumption.

Most of the benefits of using QPM as an animal feed are likely to be through economic savings to commercial feed producers or to larger pig and poultry operations that purchase commercial feed containing QPM grown from hybrids on commercial farms. Any analysis of possible impact of QPM on human nutrition through animal feed is tenuous at best. However, to give a clearer picture of its possible impact, the author will review the role of pig and poultry production and supply, and the current state and future of the pig and poultry industries in the countries examined in this paper.

To examine the possible dietary impact on humans of QPM used in animal feed, it is important to determine the role pig and / or poultry meat plays in the diet. The per capita meat supply in several of the surveyed countries was so low that we can deduce that pig and poultry meat has little impact on the diet. In other countries, animals that would not benefit from QPM (such as cattle or sheep) might be more important meat sources. Availability was quite clearly discerned by region. Overall meat availability in India and the African countries in 1996 was quite low (Figure 7). India, Malawi, and Mozambique had per capita meat supplies of less than 5 kg / y, compared to 48 kg / y for Europe and 71 kg / y for the USA and Canada (FAO 1998).

Other countries, including China, Mexico, Bolivia, and especially Brazil, had fairly high per capita levels of meat supply. Although pigs or poultry taken independently were not necessarily the most important sources of meat (beef is more important in Bolivia and Brazil), combined, they represent at least half of the meat consumed in these countries. In China and Vietnam, pig and poultry meat together represent 86% of the total meat supply.

Increases in pig and / or poultry use in some countries, most notably China, have been dramatic. Per capita availability of pig meat in China and poultry meat in Brazil have increased by more than 1000% since 1961 (FAO 1998). The average annual growth rate of the per capita supply of meat in China (1987–96) exceeded 8%, with growth rates of 5.7% and 16.3% for pig and poultry meat, respectively. Poultry availability in Bolivia, Honduras, and Nicaragua has also increased more than 10% annually during this period (Table 7).

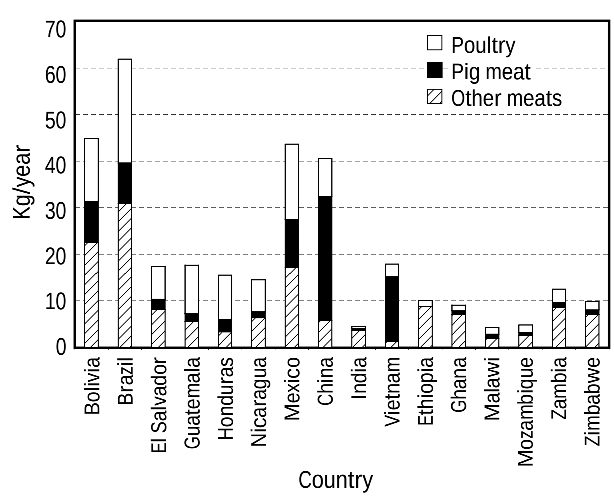

Figure 7. Per capita meat availability (kg/year) 1996.
Source: FAOSTAT, FAO March, 1998.

Annual availability of pig meat from 1987–96 dropped, or increased only minimally, in Bolivia, most of Central America, Mexico, and particularly in the African countries. Nicaragua shows an especially large drop. Poultry in Ghana, is one exception to this trend among these countries.

Table 8 shows the 1996 contribution of pig and poultry meat to available protein intake within each country. Clearly, pig and poultry meat are not important protein contributors at the national level to diets in India or any of the African countries in this analysis, with the exception of a small contribution by poultry meat in a few of the African countries. In fact, meat

Table 7. Pig, poultry and meat available for human consumption, 1987-1996

	% total meat availability provided by pig and poultry meat	Growth rate of per capita pig supply (kg/yr.) 1987 - 1996	Growth rate of per capita poultry supply (kg/yr.) 1987 - 1996	Growth rate of per cap total meat supply (kg/yr.) 1987 - 1996
Bolivia	49.8	-1.3	16.1	1.8
Brazil	50.1	1.2	7.7	3.2
El Salvador	53.6	-3.3	1.1	2.1
Guatemala	68.7	0.6	5.7	2.6
Honduras	78.6	-0.1	11.4	0.9
Nicaragua	56.3	-13.0	14.6	1.0
Mexico	60.7	-0.3	8.1	2.5
China	85.9	5.7	16.3	8.1
India	21.4	1.8	8.7	1.3
Vietnam	86.3	3.6	-.01	2.6
Ethiopia	12.6	0	-1.2	-0.8
Ghana	22.0	-2.3	8.1	-0.7
Malawi	55.2	-3.5	1.8	-1.4
Mozambique	49.0	-1.9	-1.5	-2.5
Zambia	32.2	1.3	2.4	0.1
Zimbabwe	27.2	-3.8	1.7	-3.5

* 1995 data.
Source: FAOSTAT, FAO.November,1998.

Table 8. Contribution of pig and poultry meat to protein supply – 1996

	% protein from pig meat of total per capita/day	% recommended* protein provided by pig meat*	% protein from poultry of total per capita/day	% recommended* protein provided by poultry*	% protein from all meats of total per capita/day	% recommended* protein provided by meat
Bolivia	3.6	4	7.1	8	26.8	30
Brazil	2.7	4	9.5	14	28.4	42
El Salvador	1.6	2	3.2	4	9.5	12
Guatemala	0	0	5.4	6	10.7	12
Honduras	1.8	2	5.5	6	9.1	10
Nicaragua	0.0	0	3.9	4	9.6	10
Mexico	3.7	6	6.1	10	18.3	30
China	10.5	16	4.0	6	17.1	26
India	0	0	0	0	3.4	4
Vietnam	6.9	8	1.7	2	10.3	12
Ethiopia	0	0	0	0	6.8	8
Ghana	0	0	0	0	8.2	8
Malawi	0	0	0	0	3.6	4
Mozambique	0	0	2.9	2	5.7	4
Zambia	0	0	2.0	2	9.8	10
Zimbabwe	0	0	2	2	8	8

*Using 50g protein/day as recommended by FAO/WHO, 1992.
Source: FAOSTAT, FAO. November, 1998.

availability is generally quite low, providing only a small percentage of the average recommended daily allowance for protein.

Available protein intake from poultry and especially pig meat is somewhat higher in the Central American countries than in the African countries or India, although growth rates have actually been negative over the past ten years in many countries (Figure 8). In fact, in some African countries the per capita supply of meat in general has been declining.

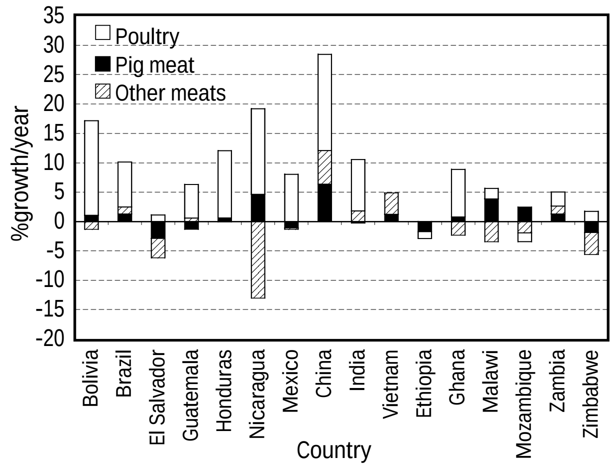

Figure 8. Growth rates for pig, poultry, and other meat availability 1987-96.
Source: FAOSTAT, FAO. April, 1998.

The extremely low availability of pig and poultry meat in the African countries suggests that, at this time, there would not be a large market for QPM as feed. Meat availability there as a whole provides only a small percentage of the FAO / WHO recommended daily intake of protein (FAO / WHO 1992). In India, Ethiopia, Ghana, and Zimbabwe, not only is overall availability of meat low, but combined pig and poultry meat represent less than 30% of the meat available. In Ethiopia it is only 12.5%. Beef, mutton, and other meats are more commonly consumed in these countries, where grazing animals are a traditional part of life (FAO 1998).

Analysis of data on pig and poultry production provides similar and consistent results. Of the countries in this study, China has the highest production growth rates (over the 10-year period) for pig meat and the second highest for poultry (Table 9), with Vietnam close behind. In a few cases, specifically Malawi and Zimbabwe, there has been a general increase in pig production occurring simultaneously with fairly large drops in availability for human consumption. This discrepancy can be somewhat accounted for by high annual population growth rates, and in the case of Zimbabwe, the exportation of much of its pig production. In 1996, Zimbabwe exported 20.8% of its pig production and from 1987 to 1996 exports grew at an annual rate of 35.7%. (FAO 1998). Generally, however, production growth rates in a country reflect similar supply growth rates.

A review of the import and export figures shows that El Salvador, Guatemala, and especially Ghana import a large percentage of their total domestic supply of pig meat (Table 10). Ghana also imports a large amount of poultry. With pig production dropping, low levels of per capita supply, and much of what it does consume imported, Ghana appears to be an especially poor candidate for QPM use in feed production.

Inexpensive feed could, of course, make pig and poultry production more attractive, especially in countries where pig meat and poultry account for a large percentage of the total meat consumed. Conversely, where consumption of pig and poultry meat is minimal because of low overall consumption and / or preferences for other meats, and commercial feeds are less commonly used, the prospects for QPM as animal feed are probably not good.

Furthermore, in several cases (mainly India, and the African countries) only small percentages of the available maize have been used for feed (Table 11, following page). However, it should be noted that with India's large population, even a low percentage of maize used for feed translates into a fairly large quantity. In fact, India uses more maize in feed, by quantity, than most of the individual Central American countries. In Africa, although only a small percentage of the total

Table 9. Changes in pig and poultry production, 1989–98

	Growth rate of pig production (%/yr.) 1989 - 98	Growth rate of poultry production (%/yr.) 1989 - 98	Growth rate of total meat production (%/yr.) 1989 - 98	% pig meat of total meat production 1998	% poultry meat of total meat production 1998	% pig + poultry meat of total meat production 1998
Bolivia	1.8	15.1	4.7	19.2	31.5	50.7
Brazil	5.4	9.2	5.2	13.7	40.4	54.1
El Salvador	0.5	2.9	2.2	13.1	54.9	68.0
Guatemala	2.6	7.8	3.8	8.9	60.9	69.8
Honduras	2.6	11.9	1.9	16.6	60.0	76.6
Nicaragua	-9.7	21.4	3.2	6.1	37.9	44.0
Mexico	3.1	9.7	4.8	23.5	39.0	62.5
China	6.0	8.4	16.7	67.3	19.5	86.8
India	3.4	6.5	2.6	6.5	8.7	15.2
Vietnam	6.1	3.1	5.1	10.3	11.5	21.8
Ethiopia	2.9	-0.6	-0.3	72.7	13.7	86.4
Ghana	-2.7	4.6	0.2	0.2	12.4	12.7
Malawi	2.3	2.9	2.3	24.2	28.0	52.2
Mozambique	0.7	0.9	0.0	15.2	34.7	50.0
Zambia	0.2	6.3	2.0	8.4	28.4	36.8
Zimbabwe	2.3	5.0	0.1	9.5	17.7	27.2

Source: FAOSTAT, FAO. December, 1998.

Table 10. Imports and exports of pig and poultry meat -1996

	PIG MEAT			POULTRY		
Country	Total domestic supply (1000 MT)	Imports as % of total domestic supply	Exports as % of total production	Total domestic supply (1000 MT)	Imports as % of total domestic supply	Exports as % of total production
Bolivia	66	0.9	0.1	103	0.1	2.7
Brazil	1,425	0.2	6.1	3,601	0.0	13.8
El Salvador	13	17.8	1.0	40	0.4	0.6
Guatemala	19	16.7	3.8	114	4.8	0.6
Honduras	15	4.9	0.0	55	2.9	0.0
Nicaragua	5	6.5	2.1	29	3.3	0.8
Mexico	952	8.2	4.0	1,501	14.1	0.5
China	32,363	0.0	0.7	9,831	3.2	3.9
India	434	0.0	0.3	478	0.0	0.1
Vietnam	1,046	0.0	0.6	204	0.0	0.3
Ethiopia	1	0.0	0.0	73	0.0	0.0
Ghana	14	34.4	0.1	22	45.6	0.0
Malawi	9	0.0	0.0	14	1.3	0.0
Mozambique	13	0.7	0.0	29	2.5	0.0
Zambia	10	1.1	0.0	24	0.1	0.0
Zimbabwe	10	0.0	20.8	21	0.4	1.5

Source: FAOSTAT, FAO. November, 1998.

Table 11. Maize use as feed or food – 1996

	Total domestic supply (1000 Mt)	Total maize used as feed (1000 MT)	Total maize used as food (1000 MT)	% use of total domestic maize supply as feed	% use of total domestic maize supply as food	Maize as % of total cereal used in feed	Maize as % of total cereal used as food
Bolivia	613	116	335	19	55	45	39
Brazil	32,140	25,266	3,260	79	10	96	18
El Salvador	820	270	502	32	61	82	55
Guatemala	1,374	180	1,113	13	81	85	74
Honduras	699	120	517	17	74	66	69
Nicaragua	350	90	222	26	64	46	40
Mexico	23,807	5,390	11,925	23	50	40	73
China	132,639	103,082	13,411	78	10	84	6
India	9,377	205	7,119	2	76	8	5
Vietnam	1,534	250	1,206	16	79	9	9
Ethiopia	2,525	200	2,119	8	84	78	24
Ghana	1,008	60	759	6	75	100	53
Malawi	1,801	100	1,463	6	81	96	90
Mozambique	1,102	60	961	5	87	89	61
Zambia	1,403	70	1,180	5	84	94	88
Zimbabwe	1,801	275	1,349	15	75	99	72

Source: FAOSTAT, FAO. November, 1998.

maize crop is used for feed, maize is the cereal most often used for that purpose (maize accounted for 89–100% of the total cereal used in feed in the African countries in this study). These figures on African maize use indicate, in turn, that these countries simply do not use very much animal feed. Nevertheless, should a more viable feed industry develop in these nations, given the preference for maize as a feed ingredient, a future role for QPM for animal feed in Africa should not be ruled out. China and Brazil, on the other hand, use the highest proportions of their maize for animal feed; in the case of China especially, this accounts for a huge amount of maize.

The average annual growth rates for maize use as feed and food during 1987–96 are shown in Figure 9. Clearly, maize use as feed has been increasing substantially in many countries. The highest percent increase is in Nicaragua, although the amount of maize involved is actually fairly small. Increases in maize use as feed can similarly be seen throughout Latin America, with the exception of Bolivia. China uses the largest quantity of maize as feed, and has a 10-year annual growth rate of 10.94%, which corresponds to a drop in the growth rate of maize for human consumption of –9.11%. Overall maize use also rose substantially in Vietnam. In the African countries, the growth rate for maize use as animal feed ranges from zero to negative figures, with the exception of moderate growth in Ghana and Malawi.

In looking at these statistics, it should be noted that increases in poultry, and particularly pork consumption might also be restricted in several countries because of religious and / or cultural

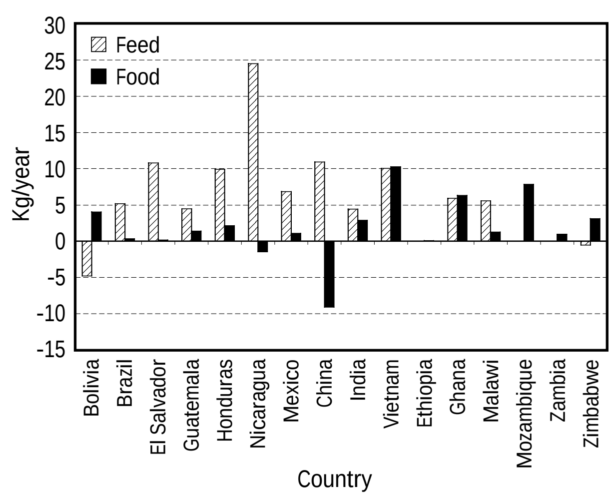

Figure 9. Growth rates of maize for feed and food use, 1987-96.
Source: FAOSTAT, FAO. December,1998.

reasons. Although diets tend to change and diversify as incomes rise, it is not likely, for example, that Muslim areas of Africa or India are likely to become major pork consumers, no matter how low the price of feed.

Conclusions

With the reintroduction of QPM into various countries around the world, it is important to take a fresh look at the problems encountered in the past and those likely to be encountered in the future. To ignore these problems is to run the risk of once again being stymied by them, and after great expenditure of money and resources, failing to have any substantial impact on the nutritional problems of the developing world.

There are two distinct important options for use of QPM: 1) as a staple food crop for human consumption and 2) for pig and/or poultry feed. Different groups of people benefit from the different options. With human consumption, the pathways toward improving human nutrition can be fairly direct, however, this holds true only if QPM is consumed by the target groups. On the other hand, any benefits from QPM to the poor through its use in animal feed will probably be quite tenuous and indirect. QPM as feed will probably not significantly decrease human protein deficiency simply because people with access to animal protein are probably not protein deficient. The main benefits would be economic and would probably accrue to pig and/or poultry producers and the feed industry.

The original and arguably more important goal of QPM is to help the poor by decreasing malnutrition through direct human consumption. Despite various deployment attempts in the past, QPM has not been widely adopted, and therefore its impact on human nutrition has been minimal. However, given the prevalence of maize in the diets of Africa and Mesoamerica, the improved QPM varieties could serve as an important weapon in fighting protein deficiency in targeted populations.

QPM's greatest potential impact would probably be in Africa, due to the continent's high levels of poverty and malnutrition, as well as high levels of maize consumption. Its fairly widespread acceptance in Ghana may indicate that current QPM varieties are as acceptable as other types of improved maize. Within each country, it is critical to target the populations in which protein deficiency is most likely to be a problem and regions where QPM can be easily obtained and consumed by those populations. The latter could be either rural areas, where maize is grown and consumed at home, or urban areas, under circumstances in which the legitimacy of the QPM supply can be assured.

The potential for QPM as animal feed is probably highest in China, Brazil, and Mexico, because of the high levels of pig and poultry production and consumption and extensive use of maize as feed in those countries. Other Latin American countries, as well as Vietnam, are also fairly good candidates for its use as feed, while its potential for this use in Africa and India appears to be quite low.

Further nutritional studies and assessments of protein deficiency in the developing world will be required to resolve the debate over whether QPM could provide widespread health benefits. However, a drop in traditional pulse consumption, unaccompanied in many cases by an increase in the use of an alternative source of protein, may be creating an important nutritional gap that, in many areas, is not being filled.

Furthermore, little study has been dedicated to determining whether QPM would be adopted and consumed by the target groups most likely to benefit from it. In the past it was not, however, with improvements in the production and storage qualities of QPM, the response from target groups could change. The recessive gene for high protein levels remains a problem, as does the lack of adequate research to assess its impact in areas where it has been adopted. The failure to educate women, both on nutrition issues and in general, may also impede QPM adoption and keep it from reaching its target groups. It is critical that QPM be introduced in concert with education, both for farmers, regarding the best ways to maintain its genetic purity, and for women, regarding its benefits and proper use.

QPM may not be the ultimate answer for our nutritional problems. And it may not have the widespread impact of other interventions, such as better education for women and improving economic conditions. However, in maize-consuming regions of the world, QPM could make an important contribution toward reducing protein deficiency, and, in conjunction with other nutritional and educational interventions, it could help improve the overall nutritional picture for many resource poor people in the developing world.

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