# Nutritional Perspectives of Quality Protein Maize

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## INTRODUCTION

Despite the advances in nutrition science during the last decades, malnutrition is still a widespread problem in developing countries, where financial and human resources are scarce. Poverty is the ultimate effect of this situation. In Brazil, the most populous country of South America and the fifth largest in the world (United Nations, 1993), the prevailing condition of hunger and misery is not different from that seen in other developing countries.

A recent study on the socioeconomic status of the Brazilian population revealed that 32 million people live in condition of misery and hunger (Fundação Oswaldo Cruz, 1993). In accordance to this situation, the latest nutrition survey showed that 30% of the children under five years of age, show some degree of malnutrition (INAN, 1990). In addition, it is known that many others suffer from diseases caused or enhanced by an inadequate diet.

The World Declaration on Nutrition states that the nutritional well being of all people is a pre-condition for the development of societies and that all efforts should be made to promote nutritional well-being and health. It also states that these efforts are the responsibility of all segments of the population, governments, private institutions and community representatives (Pellet, 1994). Within this context, the generation and diffusion of technologies that help ensure increased production and improvement of food quality can make a great contribution to minimize hunger.

The genetic manipulation of traditionally consumed cereals and legume seeds targeting the enhancement of their nutritive value and processing characteristics has been the objective of many research institutes. The relatively recent development of Quality Protein Maize (QPM) is a result of this effort.

In this chapter, the importance of nutritive value of maize and the advantages of QPM genotypes for human nutrition, particularly in Brazil, will be briefly reported.

## IMPORTANCE OF MAIZE AS A HUMAN FOOD

Maize is a millennial plant originated in Central America. Its importance for Mayan, Aztec and Inca civilizations was such that the majority of their daily activities were related directly to this crop and it was treated with reverence in religious practice and artistic manifestations of these peoples.

Maize was already a part of the native Indian diet by the time of discovery of Brazil in 1500. By the influence of Portuguese settlers, whole maize meal, designated "fubá", was introduced, and it came to be the main item of the diet. Many preparations using fubá, such as cake, cookies, and porridge, became popular, and as a consequence its consumption increased. Although there are no available data, its importance in the diet was reduced during the 1950's, due to increased processing of wheat in the country. Despite this fact, in the 1970's the maize meal (fubá) contributed with 4.5% and 3.4% of the total ingested calories and proteins, respectively, remaining comparable to rice, beans, wheat and cassava as one of the five most important staple foods in Brazil, especially for the low income population.

Similar to other tropical countries, the volume of maize destined to human consumption has been increasing as a result of expanding production and industrialization frontiers. Today, maize is mostly consumed in the form of whole or degerminated meal, canned whole grain, grits, starch, oils and snacks. Minor amounts are consumed as a part of morning cereals and weaning food.

The average consumption of this cereal in Mexico/Caribbean Islands, Africa and in Andean countries is approximately 101, 31 and 29 kg/person/year, respectively, representing for some of them a contribution of 65% of the total calories and 53% of the protein intake (Bressani, 1991). Compared to these major consumers of maize, in Brazil the utilization of this cereal by humans is only 14% of the total production, but the consumption of 24.9 Kg/person/year is significant (CIMMYT, 1992).

Despite the fact that the percentage maize destined for human use has been stablely maintained during the last four years, there was an increase in direct and processed maize consumption. The difference was more significant in the processed form, reaching 24% in this period (Table 1) and representing an important item of the national economy.

Table 1. Evolution in the consumption of maize destined for food in Brazil

| | year | | | |
|---|---|---|---|---|
| | 94/95 | 93/94 | 92/93 | 91/92 |
| Human | 450* | 415 | 375 | 320 |
| Food industry | 4650 | 4395 | 4333 | 3750 |

* 1000t

Source: SAFRAS & Mercados, 1994

A dietary survey conducted in Brazilian state capital, in 1993, showed that maize figures among the three most consumed cereals. In Belém, a city in northern Brazil, its consumption exceeded twice that of rice. Surprisingly, consumption is also high in São Paulo and Porto Alegre, states known as great consumers of wheat (Table 2). Although these numbers confirm the importance of maize in the diet, they do not reflect the quantity consumed in the entire state. The data from a previous and more extensive survey (ENDEF, 1978), indicated that its consumption was higher in non-metropolitan and rural regions than in metropolitan areas.

## NUTRITIVE VALUE OF COMMON MAIZE

The maize kernel, like that of other cereal grains, includes pericarp (6%), endosperm (82%) and germ (12%) (Watson, 1987). The main structural component of the endosperm is starch, a complex carbohydrate that corresponds on average to 71% of the grain and is a source of concentrated energy.

Maize starch is composed of two fractions: amylose and amylopectin. In common maize, 70% to 80% is amylose and 20% to 30% is amylopectin. Some genotypes are composed of predominantly

Table 2. Human Consumption of Crops in Brazilian State Capitals.

| | grain equivalent | | | | |
|---|---|---|---|---|---|
| Centers of consumption | Rice | Common bean | Wheat | Soybean | Maize |
| Belém | 26.85 | 10.24 | 45.27 | 26.55 | 55.87 |
| Fortaleza | 45.62 | 16.88 | 40.56 | 26.19 | 6.31 |
| Recife | 19.14 | 12.78 | 50.02 | 24.17 | 10.13 |
| Salvador | 19.32 | 13.04 | 50.87 | 23.56 | 6.92 |
| Belo Horizonte | 55.25 | 12.44 | 36.52 | 56.05 | 10.65 |
| Rio de Janeiro | 45.71 | 13.63 | 44.07 | 47.87 | 9.86 |
| São Paulo | 52.29 | 10.72 | 46.52 | 58.79 | 22.97 |
| Curitiba | 38.61 | 8.28 | 52.05 | 48.00 | 12.29 |
| Porto Alegre | 38.31 | 9.42 | 53.87 | 51.18 | 22.89 |
| Brasília | 32.39 | 9.97 | 33.93 | 54.27 | 6.98 |
| Goiânia | 57.35 | 9.02 | 30.71 | 69.64 | 5.58 |

Source: Vieira (1994)

Table 3. Approximate Chemical Composition of Maize Kernel Parts.

| Chemical component | pericarp | endosperm<br>% | germ |
|---|---|---|---|
| Protein | 3.7 | 8.0 | 18.4 |
| Ether extract | 1.0 | 0.8 | 33.2 |
| Crude fiber | 86.7 | 2.7 | 8.8 |
| Ash | 0.8 | 0.3 | 10.5 |
| Starch | 7.3 | 87.6 | 8.3 |
| Sugar | 0.34 | 0.62 | 10.8 |

Source: Watson (1987)

one of these fractions, which imparts a differentiated behavior to the starch when processed. Those rich in amylopectin are designated as waxy and those rich in amylose, as amylose extender. Amylose extender genotypes are rich in starch resistant to digestion by the gastrointestinal enzymes (Granfeldt, 1993). Its main physiological effect is the alteration of colonic pH, resulting from the degradation of undigested starch by the colonic microflora. The beneficial effect of lowered ceco-colonic pH protecting the intestinal mucous has been the object of many recent studies (Roberfroid, 1993).

The average protein content of whole maize meal is approximately 9%, which is intermediary between that of rice and wheat. However, its quality is poor due to low contents of two essential amino acids, tryptophan and lysine, and the high concentration of leucine, which causes an imbalance of amino acids.

The majority of the studies on maize have focused on its protein quality. However, many other components may significantly contribute to the nutritional value in the diet. To illustrate this, some selected nutrients in whole maize meal are compared to those of wheat flour and polished rice (Table 4).

This comparison seems to be adequate, since polished rice and white non-enriched wheat flour are the forms most frequently consumed. Maize can be processed in many ways, as mentioned before, but its use as a whole meal is still frequent in some regions. Besides, it seems that this should be the preferential form to be used in feeding programs, because its nutritive value is higher than that of the degerminated flour. Whole maize flour contains on average, 0.38, 0.20, and 3.63 mg/100g, respectively of thiamin, riboflavin, and niacin, while the values for degerminated flours are 0.14, 0.05, and 1.0 mg/100g (United States Department of Agriculture, 1975).

Cornmeal has higher fat content than rice and wheat. It is a good source of unsaturated fatty acids, being particularly high in linolenic acid (2%), which is an essential fatty acid and needs to be provided by the diet. Due to its significant fat content, it is also a good source of pro-

Table 4. Energy and Selected Nutrient Content of Three Main Staple Cereals in Brazil[a].

| Nutrient | Wheat, all purpose non-enriched | Rice, raw, non-enriched | Whole cornmeal |
|---|---|---|---|
| Energy (Kcal)[b] | 364 | 363 | 355 |
| Protein (g)[b] | 10.5 | 6.7 | 9.2 |
| Carbohydrate (g)[b] | 76.1 | 80.4 | 73.7 |
| Fat (g)[b] | 1.0 | 0.4 | 3.9 |
| Vitamin A (mg)[c] | 0 | 0.0 | 47.0 |
| Vitamin E (mg)[c] | - | 0.13 | 1.8 |
| Thiamin (mg)[b] | 0.06 | 0.07 | 0.38 |
| Riboflavin (mg)[b] | 0.05 | 0.03 | 0.11 |
| Niacin (mg)[b] | 0.9 | 1.6 | 2.0 |
| Vitamin C (mg)[b] | 0.0 | 0.0 | 0.0 |
| Folate (mg)[c] | 26.0 | 9.2 | 47.8 |
| Calcium (mg)[b] | 16 | 24 | 20 |
| Iron (mg)[b] | 0.8 | 0.8 | 2.4 |
| Dietary fiber (g)[c] | 2.9 | - | 15.4 |

[a] On 100g basis. [b] United States Department of Agriculture. Composition of Foods. Agriculture Handbook n.8, Washington, D.C., 1975;
[c] Nutritionist IV, Version 3.5, N-Squared Computing First Data Bank Division. The Hearst Corporation, 1994.

vitamin A and vitamin E. The consumption of 100 g of cornmeal provides 50% or more of the average adult daily requirement of linolenic acid and 20% of vitamin E.

In regard to water soluble vitamins, cornmeal has relatively high concentrations of thiamin, riboflavin and folate. Similar to other cereals, it is deficient in vitamin C. Although the niacin content of cornmeal is even higher than that of rice and wheat, its availability is poor, and this deficiency is a serious nutritive problem in common maize. The low availability of niacin is further worsened by a marked deficiency of tryptophan, its precursor. In addition, the high amount of leucine in common maize is known to inhibit the conversion of tryptophan to niacin (Murray et al,1994). As a consequence, pellagra, the niacin deficiency disease, is associated with diets almost solely based on maize.

Similar to other cereals, maize does not contain considerable amounts of minerals, except iron. It may become an important source of iron for those who cannot afford better sources of this mineral such as meat and its derivatives. However, availability of iron from corn meal will possibly depend on the amount of fruits and vegetables rich in vitamin C present in the diet.

Maize contributes considerable amounts of dietary fiber which confers a significant physiological role to the grain. It has been demonstrated that fiber, particularly its insoluble fraction, helps normalize intestinal obstipation, accelerating and increasing the fecal bulk. Increasing fiber sources in school feeding programs should be of great value since it has been demonstrated that the prevalence of intestinal obstipation is high among school children (Maffei et al., 1993).

In summary, it seems that cornmeal contains higher amount of some of the essential nutrients when compared to polished rice and wheat flour. However, its nutritive value is affected by low availability of niacin, marked deficiency of its protein in tryptophan and lysine, and the presence of excessive amount of leucine.

The low nutritive value of maize can be corrected in genetically improved Quality Protein Maize (QPM). QPM protein contains 55% more tryptophan, 30% more lysine and 38% less leucine than common maize (Bressani, 1992). The remarkable increase in tryptophan and parallel decrease in leucine may favor the synthesis of niacin, resulting in improved niacin status of those who use maize as a main component of the diet.

## NUTRITIVE VALUE OF BRAZILIAN QPM CULTIVARS

In Brazil, two cultivars of QPM, namely BR 451 and BR 473 (Fig. 1) were developed by the Breeding Program of the National Maize and Sorghum Research Center (CNPMS - EMBRAPA). The variety BR 451 which was released in 1988, has been successfully used as a substitute for wheat due to its white color. Studies conducted at the Center of Food Technology (CTAA/EMBRAPA) in 1987 determined physical characteristics of the flour prepared from BR 451, such as yield, granulometry, and rheology. These analyses defined the ideal proportion of the wheat flour and BR 451 mixture to be used in industrial production of bread, cookies, and pasta (Peixoto et al., 1989).

In 1994, a yellow QPM variety, BR 473, was commercially released. Its yellow color resembles that of common maize, an important characteristic that determines the acceptability of this cereal for direct consumption by the population.

Whole cornmeal produced at the Experimental Farm of CNPMS/EMBRAPA, located in Sete Lagoas, Minas Gerais state, in 1993/1994 was used for chemical and biological evaluation of these cultivars.

### Chemical Composition

Samples of whole cornmeal were analyzed for total protein (%N x 6.25), carbohydrate, ether extract, moisture, some minerals and fiber contents (AOAC, 1985). Amino acid contents were determined by ion exchange chromatography according to Spackman et al. (1958) after acid and alkaline hydrolysis, except for lysine and tryptophan. These amino

Table 5. Chemical composition of QPM and common maize Brazilian cultivars.[a]

| Nutrients | Maize Cultivars | | |
|---|---|---|---|
| | BR 451 | BR 473 | BR 201(common) |
| | | g /100g | |
| Total Carbohydrate | 74.9 | 75.3 | 74.9 |
| Protein | 8.8 | 9.0 | 8.8 |
| Crude fat | 4.8 | 4.4 | 5.1 |
| Fiber | 1.5 | 1.5 | 1.5 |
| Phosphorus | 0.27 | 0.23 | 0.22 |
| Potassium | 0.35 | 0.27 | 0.30 |
| Calcium | 0.01 | 0.01 | 0.01 |
| Magnesium | 0.13 | 0.11 | 0.11 |

[a] dry basis

acids were determined according to the method described by Hernandez & Bates (1969).

The results obtained show that the chemical composition of QPM cultivars is similar to that of the common hybrid maize (Table 5). However, as expected, the concentrations of two limiting amino acids, lysine and tryptophan, are markedly higher in QPM cultivars when compared to common maize. The increment in lysine value is about 50% in white and 40% in yellow cultivars. The corresponding values for tryptophan are 40% and 35%, respectively. If compared to FAO/WHO standard protein, the QPM chemical score ranges from 90 to 100%, while that of common maize is 51. The QPM cultivars also present a sensible lower ratio of leucine to isoleucine when compared to common maize (Table 6).

Table 6. Essential amino acids and chemical score of common and QPM Brazilian maize cultivars.

| Essential Amino Acid | Maize | | | FAO/WHO Pattern 1989 |
|---|---|---|---|---|
| | Normal BR 201 | QPM Br 451 | BR 473 | |
| | | mgaa/g protein | | |
| Lysine | 29.8 (0.51) | 60.2 (1.03) | 51.6 (0.89) | 58.0 |
| Isoleucine | 38.1 (1.36) | 36.1 (1.28) | 40.1 (1.43) | 28.0 |
| Leucine | 137 (2.07) | 115.0 (1.74) | 112.6 (1.70) | 66.0 |
| Methionine + Cystine | 28.5 (1.14) | 31.6 (1.26) | 32.2 (1.28) | 66.0 |
| Phe + Tyrosine | 91.5 (1.45) | 93.7 (1.48) | 90.0 (1.42) | 63.0 |
| Threonine | 34.2 (1.00) | 45.4 (1.33) | 41.8 (1.22) | 34.0 |
| Tryptophan | 6.57 (0.59) | 11.2 (1.00) | 10.3 (0.93) | 11.0 |
| Valine | 52.7 (1.50) | 62.1(1.77) | 65.1 (1.86) | 35.0 |
| Histidine | 32.8 (1.72) | 62.2 (3.27) | 59.2 (3.11) | 19.0 |
| Leucine/isoleucine ratio | 3.59 | 3.20 | 2.80 | 2.35 |

Table 7. Composition of the experimental diets.

| | Diets | | | | |
|---|---|---|---|---|---|
| | Casein | BR 451 | BR 473 | BR 201 (common maize) | Protein free |
| | | | % | | |
| Casein | 9.7 | - | - | - | - |
| BR 451 | - | 90.1 | - | - | - |
| BR 473 | - | - | 87.8 | - | - |
| BR 201 | - | - | - | 89.8 | - |
| Soybean oil | 10.0 | 4.7 | 6.11 | 5.4 | 10.0 |
| Cellulose | 5.0 | - | - | - | 5.0 |
| Mineral mixture | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 |
| Vitamins[a] | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Coline bitartarate[a] | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| Starch | 70.6 | 0.5 | 1.39 | 0.1 | 5.0 |
| Total | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |

[a] Report of the American Institute of Nutrition ad Hoc Committee on Standards for Nutritional Studies. J. Nutr. 107: 1340-1348,1977

## Biological Assay

Biological evaluation of protein quality of these cultivars was conducted at the Department of Public Health of the Universidade Estadual Paulista in São Paulo, Brazil.

Male Wistar rats weighing 50-55 g were housed individually and kept in a room with controlled temperature and lighting. Net Protein Utilization (NPU) was determined by using the body nitrogen technique (Pellet and Young, 1980). Each group contained ten rats. During the ten days of the experimental period, water was provided *ad libitum*, but food was restricted to 15 g/day. The True Digestibility (TD) was determined by collecting feces during the last five days of the experiment (FAO/WHO, 1990). The diet composition is shown in Table 7.

Also, Relative Protein Value (RPV) of these cultivars was determined (Pellet and Young, 1980), by using three protein levels, 3%, 5% and 7%. Six rats were used for each protein level. The composition of these diets was similar to that used in NPU determination, except for the protein concentration.

The results of the biological assays are presented in Tables 8 and 9. There was no difference in digestibility between QPM cultivars and common maize. The protein quality of QPM cultivars was significantly higher than that of the common maize, as shown by both methods. Their value is about 80 to 84% of the casein and 15 to 20% higher than that of common maize. These results confirm the superiority of QPM proteins over common maize proteins.

Table 8. True Digestibility (TD) and Net Protein Utilization (NPU) of the QPM and common Brazilian maize cultivars (Means ± EP).

| | True Digestibility | NPU | NPUR |
|---|---|---|---|
| Casein | 90.4 ± 0.4 a* | 69.9 ± 3.0 a | 100 |
| BR 451 | 79,9 ± 0.9 b | 58.4 ± 2.7 b | 83.5 |
| BR 473 | 82,3 ± 0.8 c | 55.6 ± 2.2 b | 79.5 |
| BR 201 (common) | 79.1 ± 0.8 b | 47.9 ± 2.2 c | 68.0 |

* Means followed by the same letters are not significantly by the Tukey Test ($p < 0.05$)

Table 9. Relative quality protein for QPM and common Brazilian maize cultivars.

| Proteic font | RPV (%) | Regression Equation | $R^{2a}$ | $N^b$ |
|---|---|---|---|---|
| Casein | 100 | y = 4.01x - 0.494 | 0.95 | 18 |
| BR 451 | 86.3 | y = 3.46x - 0.769 | 0.96 | 18 |
| BR 473 | 85.0 | y = 3.41x - 0.704 | 0.93 | 18 |
| BR 201 | 65.6 | y = 2.63x - 0.394 | 0.91 | 18 |

[a] = correlation coefficient
[b] = number of the rats

## QPM in Feeding Programs

The value of QPM in fighting hunger and malnutrition has advantages over approaches using non-conventional foods that require changes in diet habits. QPM is not a new crop and Brazilians usually grow and eat maize as a part of their basic meals. The substitution of common maize by QPM will certainly improve the nutritional value of the final products, without altering the cost of processing. In addition, its sensorial and physical characteristics will be maintained with no interference to the consumers eating habits.

QPM may be also valuable in feeding programs, particularly for school Lunch Programs. Differently from other important staples in Brazil, such as wheat and rice, it can be grown on small scale in urban unused plot land or in rural areas because it is a crop adaptable to a wide range of environments. Local governments may become self-sufficient in providing an inexpensive high quality protein and energy source for combating malnutrition, with relatively low investment.

An example of the use of BR 451 and BR 473 in feeding programs is currently being conducted in Curvelo and Sete Lagoas, two small cities in the State of Minas Gerais. This program is under the coordination of CNPMS/EMBRAPA in cooperation with other local official and private institutions. The program, with the purposes of replacing common maize products with QPM and to formulate new recipes to further increase its consumption, was initiated in 1993 in eight out of 22 schools. In mid 1994, after the standardization of recipes of QPM products, two

Table 10. Initial nutritional status of school children ages five to six years, Sete Lagoas, State of Minas Gerais - Brazil, 1994[a].

| Nutritional Status | Elementary School Lucas Rodrigo | | Elementary School Pequeno Príncipe | | Total | |
|---|---|---|---|---|---|---|
| | N[b] | % | N | % | N | % |
| Wasted | 6 | 9.8 | 13 | 2.1 | 19 | 15.4 |
| Stunted | 6 | 9.8 | 5 | 8.1 | 11 | 8.9 |
| Wasted and Stunted | 1 | 1.6 | 1 | 1.6 | 2 | 1.6 |
| Normal | 48 | 78.7 | 43 | 69.3 | 91 | 73.9 |
| Total | 61 | | 62 | | 123 | |

[a] Evaluation according to WHO (1979) and classification according to Wateriow (1976)
[b] N = number of children

elementary schools and one day care center were selected and included in the project, with the objective to evaluate the impact of QPM on nutritional status. Before its introduction, the nutritional status of the children was evaluated by clinical examination and anthropometric measurements.

An inadequate nutritional status was seen in 25.9% of the total school children studied in Sete Lagoas (Table 10). The situation was even worse in Curvelo, where children, ages 0 to 7 years old, at the Tia Lourdes day care center were evaluated. From the total of 52 children, studied, 34.5% were undernourished.

In order to improve the nutritional status of these children, QPM was introduced in their diet in conjunction with the school vegetable garden program. The plain cow's milk consumed by the children under one year of age is being enriched with 60 g of QPM, which results in additional 226.8 Kcal and 5.28 g of high quality protein/child/day. The diet of older children is being complemented with many products of maize, including whole flour, degerminated flour, and the endosperm. Today, many preparations using these products such as corn bread, cakes, porridge, cream, and other typical dishes are consumed by approximately 4000 children.

The effect of including QPM in feeding programs will be evaluated in these three selected groups of children by the middle of this year. To date, the positive outcome of this type of program is the certainty that the acceptability of QPM is high, and that this type of intervention is feasible and can be extended to other regions of Brazil.

### Nutritional Perspectives for QPM

There is no doubt that QPM is nutritionally superior to common m aize. Nevertheless, additional gains in nutritive value of these genotypes should be attained. The search for cultivars with better yield, quality protein, and processing characteristics should also include nutritional improvement, such as better starch digestibility and higher concentrations of carotenes and others vitamins and minerals that could be of great value in reducing nutritional problems in developing countries. In food science and technology, efforts in developing low cost and easy to prepare products for infant nutrition may be achieved, for example, by the use of thermoplastic extrusion.

## CONCLUSION

Brazil ranks third in the world in maize production. Yet only 14% of this is destined to human consumption. If we take into account that 32 million Brazilians face starving every day, the important role that maize, particularly QPM, may play in combating hunger and malnutrition, seems clear. To promote the better use of this grain in alleviating malnutrition, it is necessary that agricultural and overall economic policies be strengthened to enhance the productive capacity, trading, maintenance of appropriate regional stocks and to ensure that the products will reach those that need them most. This can only be achieved with the involvement of all segments of the population, such as research institutions, universities, food producers, processors and marketers, health care system, educators of all levels, the media and non government organizations (NGO's).

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