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Processing of whole maize: lime-cooking

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Lime-cooking in rural areas

A number of researchers have described how maize is cooked in rural areas of countries where tortillas are eaten. Illescas (1943) first described the process as carried out in Mexico. It involves the addition of one part whole maize to two parts of approximately I percent lime solution. The mixture is heated to 80C for 20 to 45 minutes and then allowed to stand overnight. The following day the cooking liquor is decanted and the maize, now referred to as nixtamal, is washed two or three times with water to remove the seed-coats, the tip caps, excess lime and any impurities in the grain. The addition of lime at the cooking and steeping stages helps to remove the seed-coats.

The by-products are either thrown away or fed to pigs. Originally, the maize was converted into dough by grinding it a number of times with a flat stone until the coarse particles were fine enough. Today the initial grinding is done with a meat grinder or disc mills and the dough is then refined with the stone. A portion of about 50 g of the dough is patted flat and cooked on both sides on a hot iron or clay plate.

In Guatemala a similar process (described by Bressani, Paz y Paz and Scrimshaw, 1958) uses either white or yellow maize, but the lime concentration varies from 0.17 to 0.58 percent based on the weight of maize, with a grain-to-water ratio of 1:1.2, and the maize cooking time varies from 46 to 67 minutes at a temperature of 94C. The rest of the process is essentially the same, except that the dough is prepared with a disc mill and is cooked for about 5 minutes at a temperature of about 170C at the edges and 212C in the centre.

Tamalitos, for which the dough is steamed, are softer and keep longer. For recently harvested maize less lime is used and cooking time is decreased; the procedure is modified conversely when the grain is old and dry. The dry matter losses are about 15 percent, but they can vary between 8.9 and 21.3 percent.

Industrial lime-cooking

Factors such as the migration of people from rural to urban areas created a demand for ready-cooked or pre-cooked tortillas. Equipment for processing raw maize into lime-treated maize and then into a dough and tortillas was developed and industrial production of tortilla flour began in Mexico and other countries. Mechanized production in Mexico became important soon after the Second World War. Two types of industry are found in urban areas. One is the small family-owned home tortilla industry, where the process is as described above but with larger and mechanical equipment used to supply a larger market. This development became possible through the introduction of rotary mills and the tortilla maker designed by Romero in 1908. This equipment was later replaced by a more efficient type in which the dough is passed through a rotating metal drum where it is cut into tortilla shapes. These fall onto a moving belt or continuous cooking griddle, dropping into a receptacle at the end of the belt. This small industry may use whole maize, in which case the dough is cooked in large receptacles, or it may start with industrial tortilla flour.

The second type of industry is the large industrial conversion of maize into an instant precooked tortilla flour. The process has been described by various workers (e.g. Deschamps, 1985). It is based for all practical purposes on the traditional method used in rural areas. More recently, the process of producing the flour has been expanded to produce tortillas.

Maize is bought after the buyer has inspected its quality and sampled it. Batches of maize with a high percentage of defective grains are rejected. Those that are accepted are paid for according to the defects found in the raw material. Maize is also selected according to its moisture content, since very high moisture will result in storage problems. During the cleaning stage, all impurities such as dirt, cobs and leaves are removed. The cleaned maize is sent to silos and warehouses for storage.

From there it is conveyed to treatment units for lime-cooking. There it is converted into nixtamal, using either a batch or a continuous process. After cooking and steeping, the lime-treated maize is washed with pressurized water or by spraying. It is ground into a dough (masa) which is then transferred to a dryer and made into a rough flour. This flour, consisting of particles of all sizes, is forced through a sifter where the coarse particles are separated from the fine ones. The coarse particles are returned to the mill for regrinding and the fine ones, which constitute the final product, are sent to the packing units. Here the flour is packed into lined paper bags.

One complete unit must have equipment for lime treatment, milling, drying and sifting and a daily production capacity of 30 to 80 tonnes of flour. These figures are the minimum and the maximum; to increase its production capacity, a commercial enterprise must install several parallel units. The use of such units seems to be more a tradition than a technical necessity, since it would be perfectly feasible to design plants with a capacity lower than 30 tonnes or higher than 80 tonnes per day. Plants that are very large or very small are apparently not considered viable.

The industrial yield of alkali-cooked maize flour fluctuates between 86 and 95 percent depending on the type of maize, the quality of the whole kernels and the lime-treatment conditions. Industrial yields have been reported to be higher than those at the rural and semi-industrial levels, possibly because of the quality of the grain processed.

Tortilla flour is a fine, dry, white or yellowish powder with the characteristic odour of maize dough. This flour when mixed with water gives a suitable dough for the preparation of tortillas, tamales, atoles (thick gruels) and other foods. All maize flours made in Mexico must conform to the specifications of the government's Department of Standards and Regulations.

When the flour has a moisture content of 10 to 12 percent it is stable against microbial contamination. If the moisture content is over 12 percent it is easily attacked by moulds and yeast. The problem of bacterial attack is almost nonexistent since the minimum of moisture required for bacterial growth is so high that flour with this moisture content would already be transformed into masa. Another matter related to the stability of flour is rancidity, which is normally not a problem unless the flour is packed at high temperatures. The minimum time required for the flour to spoil in Mexico is four to six months during the winter and three months during the summer. Nevertheless, it is usually sold to the consumer within 15 days of being sold to retailers and wholesalers, while its shelf-life is one month (Delvalle, 1972).

Tortillas made from lime-treated maize flour can be made at home or in factories. Such flour has been a great advantage for households and for factories both large and small, although its use in rural areas is not widespread.

In Guatemala, about 3 000 metric tons of maize are produced yearly for tortilla flour production. This amount is significantly lower than that in Mexico; the population is smaller and there are few small tortilla factories. About 90 percent of the production is sold in urban areas and 75 percent goes into tortilla making. Other countries where lime-treated maize flour is produced are Costa Rica and the United States. In Costa Rica tortilla consumption per person is about 25.6 kg per annum. Approximately 62 percent of the production is commercial, 30.6 percent is home-made from commercial flour and 7.4 percent is home-made from grain.

Modifications of lime-cooking

The traditional method of cooking maize with lime to make tortillas at the rural level is both time-consuming (about 14 to 15 hours) and hard work. The cooking and soaking operations take up 70 to 80 percent of the time, which in a sense may be acceptable to the rural housewife. Nevertheless, the availability of an instant tortilla flour offers many advantages such as convenience, less labour and lower use of energy, for a safe, stable and nutritious product. At the industrial or commercial level, grinding and dehydration are large factors in the cost. Lime-cooked maize contains about 56 percent moisture, which must be decreased to 10 to 12 percent in the flour. Therefore, any method that would decrease both time and cost and still yield acceptable tortillas would be advantageous.

Efforts in this respect have been made by a number of workers. Bressani, Castillo and Guzmn (1962) evaluated a process based on pressure cooking at 5 and 15 lb pressure per square inch (0.35 and 1.05 kg per cm) under dry and moist conditions for 15, 30 and 60 minutes, without the use of lime. None of the treatments had any effect on chemical composition and true protein digestibility, but all reduced the solubility of the nitrogen. Pressure cooking at 15 lb per square inch (1.05 kg per cm) under dry conditions reduced the nutritional quality of the product, particularly when carried out for 60 minutes. The pressure cooking method without lime did not reduce crude fibre content, which is one of the particular effects of lime, and the calcium content was significantly lower than in dry dough (masa) prepared by the traditional method.

Khan et al. (1982) conducted a comparative study of three lime-cooking methods: the traditional way, a commercial method and a laboratory pressurecooking procedure. For each process maize was undercooked, optimally cooked and overcooked to measure some of the physical and chemical changes that might occur. Although the traditional method caused the greatest loss of dry matter from the grain, it gave the best tortillas in terms of texture, colour and acceptability. The pressure-cooking procedure yielded a sticky dough and undesirable tortillas. The commercial method was the least desirable. This study allowed the authors to propose a method to evaluate the completeness of cooking.

Bedolla et al. (1983) tested various methods of cooking maize and sorghum as well as mixtures of the two grains. The methods tested included the traditional one, steam cooking as tested by Khan et al. (1982) and a method using a reflux (condensing) system. They found that the methods of cooking affected the total dry matter lost during processing into tortillas.

Variation of cooking conditions can result in lower processing times. For example, Norad et al. (1986) found that a 40 percent reduction in cooking time could be achieved by pre-soaking the grain before alkali cooking. In these studies dry matter losses, water uptake, calcium content and enzyme susceptible starch increased, whereas amylograph maximum viscosity decreased in both presoaked and raw maize upon cooking. The decrease in viscosity and increase in the other parameters was faster in the pre-soaked maize.

Dry-heat processes have also been studied. Johnson, Rooney and Khan (1980) tested the micronizing process to produce sorghum and maize flours. Micronizing is a dry-heat process using gas-fired infrared generators. Rapid internal heating takes place, cooking the product from the inside out. The authors used this process to produce tortilla flour, claiming that it would be quicker and more economical than the traditional method.

Molina, Letona and Bressani (1977) tested production of instant tortilla flour by drum drying at the pilot plant level. Maize flour was mixed with water at a ratio of 3: I with 0.3 percent lime added on the basis of maize weight. After mixing, the dough was passed through a double-drum dryer heated with steam at 15, 20 or 25 lb per square inch (1.05, 1.40 or 1.75 kg per cm2), 93, 99 and 104C surface temperature and 2, 3 or 4 rpm. The process produced an instant tortilla flour with physico-chemical and organoleptic characteristics identical to those of the reference sample prepared by the traditional method but different from those of a commercial product.

Extrusion cooking has also been evaluated as an additional technology for producing tortilla flour. Bazua, Guerra and Sterner (1979), using a Wenger X-5 extruder, processed ground maize mixed with various lime concentrations (0.1 to 1.0 percent). The dough and tortillas made by extrusion were compared with those made by the traditional process for their organoleptic properties as well as lysine tryptophan and protein content. No appreciable differences were noted at comparable use levels of calcium hydroxide. Both the traditional process and the extrusion modification induced losses of tryptophan related to the amount of lime added. With a 0.2 percent addition 8 percent of the tryptophan was lost, while with 1 percent lime more than 25 percent was lost. Some lysine losses were also observed. The organoleptic results suggested that it is possible to make culturally acceptable tortillas using extrusion as an alternative to the lime-heat treatment.

Maize for tortillas

Grain quality is a concept now growing in importance in breeding programmes aimed at increasing acceptance of genetically improved seeds by farmers as well as by consumers and food processors. The grain quality characteristics include yield, technological properties and, when possible, nutritional elements as well. Technological properties include stability during storage, efficiency of conversion into products under given processing conditions and acceptability to the consumer. The technological aspect of maize quality for tortilla preparation is of little importance to small farmers in the least developed countries, who seldom use seed other than that kept from harvest to harvest. Furthermore, the rural housewife knows how to adjust cooking conditions to the type of maize she will process for consumption. But maize is now being converted into a tortilla flour using industrial processes, where the grain being used may be of different varieties from various producers and different environments. It may have a variety of structures or may have been poorly handled after harvest, factors which influence the yield and physico-chemical and organoleptic as well as culinary properties of the product. This would appear to be of growing importance in countries such as the United States where the maize tortilla is becoming a very popular food.

That physical characteristics of maize are important became clear some time ago, when Bressani, Paz y Paz and Scrimshaw (1958) showed that the yield of dry matter in the form of dried-maize dough or flour was affected by the maize cultivar. In their rural home studies dry matter losses from white maize averaged 17.2 percent with a variability of 9.5 to 21.3 percent. Dry matter losses from yellow maize averaged 14.1 percent, with a range from 8.9 to 16.7 percent.

Cortez and Wild-Altamirano (1972) conducted a series of measurements on 18 cultivars of maize produced in Mexico. These included kernel weight, colour and lime-cooking time using a standard cooking procedure with 1.5 percent lime at 80C and a steeping time of 12 hours. Cooking efficiency and time were measured by the ease with which the seed coat could be removed. Evaluations of the cooked maize included measurement of the volume of I kg of maize, the yield of dough from I kg of grain and the moisture content of the dough. The dough was further evaluated by measuring its strength and water absorption. The dehydrated dough was then ground to 60-mesh size and evaluated for moisture, colour, specific volume and other physical characteristics using a mixograph. The tortillas made from the dough of each maize sample were further evaluated for extensibility, volume, plasticity, softness and roughness of the surface.

From this extensive study, the authors reached several conclusions. Maize varieties or cultivars of higher weight per volume, a harder endosperm, more moisture and a high protein content produced the best tortillas. Two cultivars of popcorn maize were among the best types for tortillas. The Swanson mixograph was useful in establishing differences in maize types. The time required to cook the samples ranged from 30 to 75 minutes, and dry matter losses ranged from 10 to 34 percent. Rooney and Serna-Saldivar (1987) found that maize with hard or corneous endosperm required a longer cooking time. Bedolla and Rooney (1984) stated that the texture of the dough was affected by the endosperm texture and type, drying, storage and soundness of the maize kernel. MartnezHerrera and Lachance (1979) established a relationship between kernel hardness and the time needed for cooking. They reported that within a maize variety, higher calcium hydroxide concentration slightly decreased cooking time. Furthermore, knowing the initial hardness of a variety made it possible to predict the time required to cook it. Khan et al. (1982) and Bedolla and Rooney (1982) measured a parameter termed nixtamal shear force (NSF), an indication of kernel hardness. The measurement was related to both cooking time and processing method. These authors showed that the NSF measurement could reveal small differences in maize with similar endosperm texture and could be used to predict optimum cooking time.

Dry matter losses resulting from lime-cooking constitute a good index of maize quality for tortilla preparation. Jackson et al. (1988) reported that greater losses resulted from stress-cracked and broken kernels than from sound kernels. Therefore they concluded that any system for assessing maize for alkaline cooking should include measures of broken kernels, the potential for breakage and ease of pericarp removal. Specific studies on the effects of drying and storage on quality of maize for tortilla making are not readily available. Bressani et al. (1982) reported on QPM storage as related to tortilla quality. The Nutricta QPM variety was stored under a number of field or rural conditions. Containers made of cloth not treated with insecticides allowed insect infestation and therefore higher dry-matter losses during cooking; but the protein quality was not affected.

Possibly the most interesting feature of the process of converting maize into tortillas is the use of an alkaline medium, and particularly calcium hydroxide. The most obvious effect of adding lime is the facilitation of seed coat removal during cooking and steeping. According to Trejo-Gonzlez, Feria-Morales and Wild-Altamirano (1982), added lime maintains an alkaline pH, which is needed to hydrolyse the hemicelluloses of the pericarp. Lime uptake by the kernel follows that of water, but the rate is lower than that of water. Norad et al. (1986) showed that soaking the kernels before cooking led to a higher calcium content in the grain. Calcium content of masa was affected by lime levels and also by cooking-steeping temperatures. Several other authors (e.g. Pflugfelder, Rooney and Waniska, 1988a) have shown in one way or another that lime uptake during alkaline cooking is affected by physical and chemical characteristics of maize dough.

Martnez-Herrera and Lachance (1979) found that higher calcium hydroxide concentrations slightly decreased cooking time, but the differences were not statistically significant. These authors also reported an interaction between maize variety and calcium hydroxide concentration. However, the coefficient of variation was high (29.1 percent); this was attributed to inherent variability in the kernels of the different varieties.

Bedolla and Rooney (1982) reported that increases in cooking time, cooking temperature, lime concentration and steeping time produced lower viscoamylograph peak viscosities at both 95 and 50C, which was interpreted to mean a greater degree of starch gelatinization. Trejo-Gonzalez, Feria-Morales and Wild-Altamirano (1982) showed that calcium was fixed or was bound in some way to the starch of the maize kernel. Other effects included greater solid losses with increasing amounts of lime; changes in colour, aroma and flavour; and a delay in the development of acidity, which extends shelf-life. If added in exceedingly large amounts, lime affects organoleptic properties of the food; this effect is often observed when maize has been stored for a long time.

Ogi and other fermented maize products

Acid porridges prepared from cereals are eaten in many parts of the world, particularly in developing countries, where they may form part of the basic diet. Some examples of acid porridges include pozol in Mexico and Guatemala, ogi in Nigeria, uji in Kenya and kenkey in Ghana. These porridges are usually made from fermented raw or heat-treated maize, although sorghum and millet are often used.

Ogi manufacture

The traditional process of making ogi has a number of slight variations described by several authors. Ogi is traditionally prepared in batches on a small scale two or three times a week, depending on demand. The clean grain is steeped in water for one to three days to soften. Once soft, it is ground with a grinding stone, pounded in a mortar or ground with a power mill. The bran is sieved and washed away from the endosperm with plenty of water. Part of the germ is also separated in this operation. The filtrate is allowed to ferment for 24 to 72 hours to produce a slurry which when boiled gives the ogi porridge. Ogi is usually marketed as a wet cake wrapped in leaves, or it may be diluted to 8 to 10 percent solids in water and boiled into a pap or cooked to a stiff gel.

Akinrele (1970) reported that the souring of the maize took place spontaneously without the addition of inoculants or enzymes. He identified the organisms involved in this unaided fermentation and investigated their effects on the nutritive value of the food. He identified the moulds as Epholosporium, Fusarium, Aspergillus and Penicillium species and the aerobic bacteria as Corynebacterium and Aerobacter species, while the main lactic acid bacterium he found was Lactobacillus plantarum. There were also yeasts: Candida mycoderma, Saccharomyces cerevisiae and Rhodotorula sp.

Although ogi is supposed to have an improved B-vitamin content, the results observed are quite variable, at least for thiamine, riboflavin and niacin. Banigo and Muller (1972) identified the carboxylic acids of ogi fermentation. They found 11 acids, with lactic, acetic and butyric acids being the most important.

The ogi-making process is quite complex, and the porridge can also be prepared from sorghum, rice, millet and maize. Therefore, laboratory procedures have been developed to learn more about the process and introduce changes to convert the grains to food more efficiently. These have been described by Akingbala, Rooney and Faubion (1981) and Akingbala et al. (1987), whose studies have been useful also in evaluating varieties of cereal grains for their efficiency in making ogi. The authors also reported on the yields of ogi from whole maize kernels (79.1 percent) and dry milled flour (79.8 percent).

The commercial manufacture of ogi does not differ substantially from the traditional method. Modifications have been introduced, such as the dry milling of maize into a fine meal or flour and subsequent inoculation of the flour-water mixture with a culture of lactobacilli and yeast. In view of the importance of ogi in the Nigerian diet, large-scale production is indicated. The material could be dried and packaged in polythene bags for a good shelf life. There is some problem in achieving a controlled fermentation with pure cultures. Some modifications include spray-drying the slurry or drum drying.

Other fermented maize products

Ogi has a number of other names such as akamu or ekogbona, agidi and eko tutu. These, with the Kenyan uji and Ghanaian koko, are substantially the same preparation with changes in the grain used or some modification of the basic process. For the Mexican pozol, maize is processed with lime as for tortillas. The nixtamal, or cooked maize without the seed-coat, is ground to a coarse dough which is shaped into balls by hand. The balls are then wrapped in banana leaves to avoid drying and are allowed to ferment for two to three days, or more if necessary. The micro-organisms involved are many.

Arepas

Another major food made from maize, used daily in Colombia and Venezuela, is arepa. Mosqueda Suarez (1954) and Cuevas, Figueroa and Racca (1985) described the traditional preparation method as practiced in Venezuela. De Buckle et al. (1972) defined the Colombian arepa as roasted maize bread without yeast, round in shape, prepared from maize that has been degermed. Whole maize is dehulled and degermed using a wooden bowl called a pilon and a double-headed wooden mallet. The moistened maize is pounded until the hulls and part of the germ are released from the endosperm. The hulls and germs are removed by adding water to the mixture containing the endosperm. The endosperm is cooked and then stone-milled to prepare a dough. Small portions of this dough are made into balls, then pressed into flat discs which are cooked rapidly on both sides.

The traditional method of preparing arepas has been substantially modified by the introduction of precooked maize flour, which reduces the time from 7 to 12 hours to 30 minutes (Cuevas, Figueroa and Racca, 1985). There are two stages in the industrial process. The first is the preparation of maize grits by cleaning, dehulling and degerming the maize; the second is the processing of the grits to produce precooked flour. Efforts have been made to modify the process even further by extrusion cooking.

Other maize preparations

In Latin America there are many maize-based foods besides tortillas and arepas. Some of these are drinks like colados, pinol and macho, basically suspensions of cooked maize flour. These three products have a very low protein quality. The production of humitas, a tamale-like food consumed in Bolivia and Chile, was described by Camacho, Baados and Fernandez (1989). Made from immature common or opaque-2 maize to which is added a number of other ingredients, humitas is produced from precooked maize flour which resembles the lime-treated masa. Other products include mote, made from cooked maize and cheese, pupusas, made from lime-treated maize and cheese, and patasca, which is like a lime-treated maize kernel. From immature maize a sweet, tasty atole of high nutritive value is made; Khan and Bressani (1987) described the process, which consists of grinding the maize in water followed by filtration and cooking. Immature maize, either common or opaque2, and sweet maize are also extensively consumed. Chavez and Obregon (1986) reported on the incorporation of the opaque-2 gene into sweet maize to provide a food of high nutritional quality.

Maize has also been used as a substrate for fermented beverages called chicha. Cox et al. (1987) have reported on the microflora of these fermented products, which are made by basically the same process but using a variety of additives.

Milling

The maize kernel is transformed into valuable foods and industrial products by two processes, dry milling and wet milling. The first yields grits, meal and flours as primary products. The second yields starch and valuable derived products.

Dry milling

The dry milling of maize as practiced today has its origins in the technologies used by the native populations who domesticated the plant. The best example is the method used to make arepa flour or hominy grits. The old technology was soon replaced by a grinding stone or stone mill, followed by the grits mill and finally by sophisticated tempering-degerming methods. The products derived are numerous, with their variety depending to a large extent on particle size. They are classified into flaking grits, coarse grits, regular grits, corn meal, cones and corn flour by means of meshes ranging from 3.5 to 60. Their chemical composition has been well established and their uses are extensive, including brewing, manufacturing of snack foods and breakfast cereals and many others.

Wet milling

The largest volume of maize in developed countries such as the United States is processed by wet milling to yield starch and other valuable byproducts such as maize gluten meal and feed. The starch is used as a raw material for a wide range of food and non-food products. In this process clean maize is soaked in water under carefully controlled conditions to soften the kernels. This is followed by milling and separation of the components by screening, centrifugation and washing to produce starch from the endosperm, oil from the germ and food products from the residues. The starch has industrial applications as such and is also used to produce alcohol and food sweeteners by either acid or enzymatic hydrolysis. The latter is done with bacterial and fungal alpha-amylase, glucoamylase, beta-amylase and pullulanase. Saccharides of various molecular weights are liberated yielding sweeteners of different functional properties. These include liquid or crystalline dextrose, high-fructose maize syrups, regular maize syrups and maltodextrins, which have many applications in foods.

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Chapter 5 - Physical and chemical changes in maize during processing

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Lime-treated maize (part I)

Chemical changes

The conversion of maize into tortillas involves a process in which water, heat and calcium hydroxide are used. All three influence the chemical composition of processed maize, causing changes in nutrient content. The changes that take place are caused by both physical losses of the kernel and chemical losses. The latter may result from destruction of some nutrients and chemical transformation of others.

The proximate composition of maize and of home-made and industrially prepared tortillas is shown in Table 16. Changes in fat and crude fibre content are shown, and in some cases an increase in ash content. The values for homemade and industrially produced tortillas are similar for most major chemical components with the exception of fat, which is higher in industrially produced tortillas.

Dry matter losses

From studies on maize cooking by rural housewives using their own traditional method, Bressani, Paz y Paz and Scrimshaw (1958) reported a loss of solids (17.1 percent for white maize and 15.4 percent for yellow maize) when maize was made into dough. Bedolla and Rooney

(1982) have reported losses of 13.9 and 10 percent respectively for white and yellow maize using the traditional process and losses of 7 and 5.7 percent in steam cooking. In other studies where variations in the processing technique were evaluated, Khan et al. (1982) found losses of 7 to 9 percent in commercial processing, 9 to I I percent in pressure cooking and 11 to 13 percent using the traditional method. These workers also reported that dry matter loss increased as cooking time increased.

TABLE 16 - Proximate composition of raw maize and home-made and industrially produced tortillas

Product	Moisture (%)	Protein (%)	Fat (%)	Ash (%)	Crude fibre (%)	Carbohydrates (%)	Calories per 100 g
Maize							
White	15.9	8.1	4.8	1.3	1.1	70.0	356
Yellow	12.2	8.4	4.5	1.1	1.3	73.9	370
White	13.8	8.3	-	1.2			
Tortillas							
While	47.8	5.4	1.0	0.8	0.7	44.5	204
Yellow	47.8	5.6	1.3	0.8	0.6	44.4	212
White	41.9	5.8	-	0.9	-	-	-

Industrial	40.5	5.8	0.9	1.1	1.4	50.3	226
Industrial	44.0	5.3	3.4	1.2	0.7	42.8	215
Industrial	45.2	5.2	3.1	1.4	1.1	41.1	206

Sources: Bressani, Paz y Paz and Scrimshaw, 1958; Cravioto et al., 1945; Ranhotra, 1985; Saldana and Brown, 1984.

Likewise, the integrity of the maize kernel influences losses. Jackson et a/. (1988) reported that dry matter losses in the traditional cooking procedure were higher (10.8 to 12.1 percent) with broken kernels then with undamaged ones (6.3 to 8.9 percent). Besides the integrity of the kernel and the heating process used, other factors such as length of steeping influence dry matter losses. Long steeping caused larger losses than a short steeping time. Dry matter losses of QPM with a hard endosperm are similar to those of common maize. Recently, Bressani et al. (1990) reported losses of 17.1 percent for the Nutricta QPM variety as compared with 17.6 percent from a white tropical maize. Sproule e! al. (1988) found a 9.6 percent dry matter loss from QPM as compared with a 10.4 percent loss in common maize.

Dry matter losses depend, then, on a number of variables such as the type of maize (hard or soft endosperm), kernel integrity (whole or broken kernels), cooking procedure (traditional, steam cooking, pressure cooking, commercial), the levels of lime used, cooking time and steeping time, as well as other operations such as rubbing to eliminate the seed-coat during washing of the kernels. This process also eliminates other parts of the kernel: the tip cap and

possibly the aleurone layer and small amounts of germ. Paredes-Lpez and Saharopulus-Paredes (1983) used scanning electron microscopy to show that the outside surface of lime-treated maize had important structural deterioration. They indicated that the aleurone layer was retained as well as some pericarp layers and that the germ remained attached to the endosperm. Gmez et al. (1989) noted that important structural changes took place in maize during "nixtamalization". The alkali weakened the cell walls, facilitating the removal of the pericarp. It solubilized the cell wall in the peripheral endosperm, caused swelling and partial destruction of starch granules and modified the appearance of the protein bodies. The dough contained fragments of germ, pericarp, the aleurone and endosperm, as well as free starch and dissolved lipids. Thus some of the chemical changes that have been observed can be accounted for by the chemical compounds present in these three or four parts of the kernel. The dry matter content has been analysed by Pflugfelder, Rooney and Waniska (1988a), who reported 64 percent non-starch polysaccharides (fibre), 20 percent starch and 1.4 percent protein.

Nutrient losses

Studies on the losses of nutrients during the transformation of maize into tortillas are not abundant, even though significant changes due to processing do take place (Cravioto et al., 1945; Bressani, Paz y Paz and Scrimshaw, 1958). Ether-extractable substances are lost, 33 percent in yellow maize and 43 percent in white maize. This is difficult to explain, although it could be partially accounted for by the loss of the pericarp, the aleurone layer, the tip cap and some of the germ, parts of the kernel containing ether-extractable substances. Losses in crude fibre were reported to be about 46 percent in white maize and 31 percent in yellow maize.

Lime treatment at 96C for about 55 minutes hydrolyses the pericarp, which is removed during washing, pulling the tip cap with it, and this would account to a large extent for fibre loss. Nitrogen losses amount to about 10 and 5 percent for white and yellow maize, respectively. Again, this may be partly due to the physical loss of the pericarp and tip cap. Even though tortillas may have a slightly higher protein content than the original maize on an equal moisture basis, as has been reported by various workers, this may be caused by a concentration effect, since soluble sugars from the kernel are lost. Ash content increases because of the absorption of lime, which significantly increases calcium content (Saldana & Brown, 1984; Ranhotra, 1985). Significant losses take place in thiamine (52 to 72 percent), riboflavin (28 to 54 percent) and niacin (28 to 36 percent). In yellow maize 15 to 28 percent of the carotene was lost (Cravioto et al., 1945; Bressani, Paz y Paz and Scrimshaw, 1958).

***Fat and fatty acids*. Ether-extractable substances of 33 and 43 percent were reported by Bressani, Paz y Paz and Scrimshaw (1958) from yellow and white maize respectively, as processed in Guatemalan rural homes. Pflugfelder, Rooney and Waniska (1988b) found losses of 11.8 to 18.1 percent and suggested that these could be partly due to the vigorous handling of cooked maize at the industrial plant. Of the total masa lipid, 25 to 50 percent was free and partially emulsified. Bedolla et al. (1983) found ether extract values of 5.0, 3.1 and 3.6 percent in raw maize, cooked maize and tortillas respectively, or about a 28 percent change. This loss has not been fully explained; however, it may result from the loss of the seed-coat, the tip cap, the aleurone layer and possibly part of the germ, and also from ether soluble substances, not necessarily fat. Even though ether-extractable substances are lost in the process of converting maize into tortillas, the fatty acid make-up of the fat does not change in common maize or**

QPM, as shown in Table 17. Differences between maize samples, either raw or processed, are larger than those between raw maize and tortillas, suggesting that the alkaline cooking method does not alter the fatty acid make-up of the fat.

TABLE 17 - Fatty acid content of common and quality protein maize and tortillas (%)

Product	C16:0	C18:0	C18:1	C18:2
Common maize	12.89	2.92	37.08	47.10
Opaque-2 maize	15.71	3.12	36.45	43.83
Common maize tortilla	13.63	2.95	37.14	45.76
Opaque-2 tortilla	15.46	3.25	35.84	43.03

Source: Bressani et al., 1990

Fibre content. The crude fibre content of maize - as determined by the Association of Official Analytical Chemists (AOAC) methodology decreases as the kernel is converted into tortillas. Various investigators (e.g. Saldana and Brown, 1984) have explained how and why such a loss takes place. With newer methodology to determine fibre, Reinhold and Garcia (1979), using the Van Soest method, reported that the neutral detergent fibre (NDF) and acid detergent fibre (ADF) in tortillas (6.60 and 3.75 percent, respectively, on a dry weight basis) were significantly

higher than those found in the dough (an average of 5.97 and 2.98 percent, respectively). No difference was reported in hemicellulose, with dough containing 3.18 percent and the tortillas 2.89 percent. Using the same method, Bressani, Breuner and Ortiz (1989) found 10.8 percent NDF in maize and 9 percent in tortillas, as well as ADF of 2.79 and 3 percent respectively. Hemicellulose averaged 8 percent in maize and 6 percent in tortillas, while the values for lignin were 0.13 and 0.15 percent. These values and others are shown in Table 18. Using the method of Asp et al. (1983), Acevedo and Bressani (1990) detected a decrease in insoluble fibre from raw maize (13 percent) to the dough (6 percent) and an increase in tortillas (7 percent). Soluble fibre increased from 0.88 percent in raw maize to 1.31 percent in the dough, and further increased to 1.74 percent in tortillas. Fibre decreases from raw maize to dough are due to the losses in seed-coat described previously. Increases from dough to tortillas, however, may be due to the browning reaction, as has been reported in baked wheat products (Ranhotra and Gelroth, 1988).

TABLE 18 - Dietary fibre in common and quality protein make and tortillas (%)

Product	Insoluble dietary fibre	Soluble dietary fibre	Total dietary fibre	Neutral detergent fibre	Acid detergent fibre	Hemicellulose	Lignin
Raw common maize	11.0	1.4	12.4	10.8	2.8	8.0	0.13
Common							

maize tortilla	9.5	1.4	10.9	9.0	3.0	6.0	0.15
Raw QPM	13.8	1.1	14.9	-	-	-	-
QPM tortilla	10.3	1.9	12.2	-	-	-	-
Other tortilla	3.4	-	-	6.6	3.7	2.9	-
Other tortilla	4.1	-	-	-	3.8-5.0	-	-

Sources: Acevedo and Bressani, 1990; Bressani, Breuner and Ortiz, 1989; Bressani et al., 1990; Krause, 1988; Ranhotra, 1985; Reinhold and Garcia 1979.

***Ash*. Changes in ash content have not received much attention from researchers. Most findings, however, have shown an increase in total ash content from maize to tortillas, which may be expected because of the lime used for cooking. Along with this increase in ash there is a significant increase in calcium content. According to Pflugfelder, Rooney and Waniska (1988b), calcium content in the dough is influenced by lime levels, cooking and steeping temperatures and maize characteristics. The changes in other minerals are variable and may depend on the purity of the lime used as well as on the type of grinding equipment. In one study (Bressani, Breuner and Ortiz, 1989; Bressani et al., 1990) the magnesium content increased from 8 to 35 percent from maize to tortilla; there was no change in sodium and a small decrease in potassium. Iron content also increased; however, the increases may have resulted from contamination. Phosphorus content also increases from maize to tortilla (Table 19). One aspect of nutritional interest is that the calcium-to-phosphorus ratio, which is about 1:20 in maize, changes to approximately 1:1 in the tortilla.**

TABLE 19 - Mineral content of raw maize and home and industrial samples of tortillas (mg/100 9)

Product	P	K	Ca	Mg	Na	Fe	Cu	Mn	Zn
Maize	300	325	48	108	54	4.8	1.3	1.0	4.6
Home-made tortilla 1	309	273	217	123	71	7.0	2.0	1.0	5.4
Home-made tortilla 2	-	-	202	-	-	2.7	0.3	-	3.4
Home-made tortilla 3	294	-	104	72	-	3.5	1.3	-	4.6
Industrial tortilla 1	315	-	182	106	-	4.0	2.5	-	3,2
Industrial tortilla 2	240	142	198	60	2	1.2	0.17	0.41	1.2
Industrial tortilla 3	269	185	205	63	9	1.5	0.19	0.40	1.1

Sources: Bressani et al., 1990; Krause, 1988; Ranhotra, 1985; Vargas, Munoz and Gmez 1986

***Carbohydrates*. Maize and tortillas contain significant amounts of soluble carbohydrates, but very little is known on how they change during alkaline processing. Starch losses of about 5 percent have been reported; these are recovered in the solids lost. A decrease in sugar from 2.4**

percent in maize to 0.34 percent in tortillas was also found. Robles, Murray and Paredes-Lopez (1988) found that alkali-cooking and soaking of maize caused large increases in viscosity and that cooking time had a significant effect on pasting properties, although there was no extensive gelatinization of the starch. Differential scanning calorimetric studies yielded similar gelatinization endotherms for untreated maize and nixtamal flours. In the process enzyme-susceptible starch increases as cooking time lengthens.

Protein and amino acids. Most researchers report a small increase in N content which is attributed to a concentration effect. The solubility of all protein fractions is decreased from raw maize to tortillas, with an increase in the insoluble fraction.

Bressani and Scrimshaw (1958) extracted the nitrogen from raw maize and tortillas using water, sodium chloride, 70 percent alcohol and sodium hydroxide. The solubility of the water, salt and alcohol protein fractions was significantly lower in tortillas, with the alcohol-soluble proteins affected most. Only a small decrease of about 13 percent in the solubility of the alkali-soluble fraction was detected. Because of this, the insoluble nitrogen fraction increased from 9.4 percent in maize to 61.7 percent in tortillas.

Ortega, Villegas and Vasal (1986) observed similar changes in both common and QPM maize using the Landry-Moureaux (1970) protein fractionation technique. The solubility of true zeins decreased 58 percent in the tortillas prepared from common maize and 52 percent in QPM tortillas. The authors indicated that hydrophobic interactions may have been involved in the change in protein solubility observed. Sproule et al. (1988) noted a decrease in the albumin

plus globulin-nitrogen, expressed as percentage of total nitrogen, from maize to tortillas.

The changes in amino acid content from maize to tortillas are summarized in Table 20. In vitro enzymatic studies of amino acids indicated that total nitrogen and alpha-amino nitrogen were released faster from maize than from tortillas. Values for alpha-amino nitrogen released, expressed as a percentage of the total nitrogen release, were higher for tortillas than for raw maize after 12 hours of hydrolysis with pepsin. The percentage of alpha-amino N from the total was similar for maize and tortillas at 60 hours of hydrolysis with trypsin and pancreatic. After 60 hours of hydrolysis with pepsin, trypsin and pancreatin, the percentage of enzymatically released amino acids with respect to the acidhydrolysed amino acids suggested a faster release from tortillas than from maize. This information was recorded up to 36 hours for most of the amino acids except leucine, phenylalanine, tryptophan and valine, which were released at about the same rate. At 60 hours of hydrolysis the amino acid concentrations of the maize and tortilla hydrolysates reached comparable levels, except for methionine (Bressani and Scrimshaw, 1958). These authors reported losses of arginine (18.7 percent), histidine (11.7 percent), lysine (5.3 percent), leucine (21 percent), cystine (12.5 percent) and small amounts of glutamic acid, proline and serine.

Sanderson et al. (1978) found small losses of arginine and cystine from alkaline treatment of common and high-lysine maize. These same authors found 0.059 and 0.049 g of lysino-alanine per 100 g protein from common and high-lysine maize respectively, but none was found in raw maize. In commercial masa, they found 0.020 g lysino-alanine per 100 g protein, while in tortillas the level found was 0.081 g per 100 g protein.

TABLE 20 - Amino acid changes during the alkaline cooking of maize (9/16 g N)

Amino acid	**Maize**	**Tortilla**	**Maize**	**Dough**	**Tortilla**	**QPM**	**Dough**
Arginine	5.1	4.2	5.4	4.6	5.5	8.3	7.9
Histidine	2.7	2.4	2.9	2.8	3.5	3.9	3.8
Isoleucine	4.2	4.5	3.7	3.8	3.5	3.4	3.3
Leucine	12.2	9.6	12.6	13.4	12.1	8.3	8.3
Lysine	3.0	2.9	3.0	2.7	2.9	5.1	5.2
Methionine	1.9	1.9	2.8	2.9	2.3	1.9	1.9
Cystine	1.0	0.9	-	-	-	-	-
Cysteine	-	-	2.0	1.7	1.9	2.5	2.2
Phenylalanine	3.7	3.8	5.0	5.2	4.7	4.3	4.2
Tyrosine	3.8	3.8	4.5	4.6	4.4	3.8	3.7
Threonine	3.0	3.0	3.8	3.8	3.4	3.6	3.6
Tryptophan	0.5	0.5	-	-	-	-	-
Valine	4.5	4.8	4.8	5.3	4.9	5.1	5.0
Glutamic acid	20.3	19.0	18.8	19.5	18.9	15.4	15.7

Aspartic acid	6.2	6.2	7.2	6.9	5.8	8.4	8.4
Glycine	4.8	4.8	4.0	4.3	3.5	4.7	4.6
Alanine	8.8	8.8	7.7	8.1	7.6	6.1	6.1
Serine	4.5	4.2	5.0	5.0	4.7	4.4	4.5
Proline	11.0	10.1	9.2	10.7	8.7	7.0	7.6

Sources: Bressani and Scrimshaw, 1458; Sanderson el al., 1978

Lunven (1968), using his own amino acid column chromatography technique, observed significant losses in both lysine and tryptophan during the alkaline treatment of common maize. Ortega, Villegas and Vasal (1986) found small losses in tryptophan in tortillas of both common maize (about 1 1 percent) and QPM (15 percent). On the other hand, they reported minimal losses in lysine from both types of maize, similar to those previously noted. Higher losses for both amino acids have recently been reported by Bressani et al. (1990) from common maize and QPM (Nutricta) maize converted into tortillas by rural processing. Ortega, Villegas and Vasal (1986) also indicated that on the basis of the very small loss of lysine in the alkaline product, minimal amounts of lysino-alanine were probably present in the tortillas of common maize and QPM used in their study.

TABLE 21 - Vitamin content of raw maize and tortillas (mg/100 9)

				Folic	Panthothenic	Vitamin		Total

Product	Thiamine	Riboflavin	Niacin	acid	acid	H.	Carotene	carotenoids
Raw maize								
White	0.38	0.19	2.00	-	-	-	-	-
Yellow	0.48	0.10	1.85	-	-	-	0.30	1.32
White	0.34	0.08	1.64	-	-	-	0.15	-
Tortillas								
White	0.10	0.04	1.01	-	-	-	-	-
Yellow	0.11	0.05	1.01	-	-	-	0.12	0.41
White	0.19	0.08	0.96	-	-	-	0.06	-
Industrial	0.13	0.08	1.11	-	-	-	-	-
Industrial	0.07	0.04	1.61	0.014	0.24	0.12	-	-
Industrial	0.08	0.05	2.11	0.015	0.16	0.27	-	-

Sources: Bressani, Paz y Paz and Scrimshaw, 1958; Cravioto e, al., 1945; Ranhotra, 1984; Saldana and Brown, 1984.

Vitamins. Losses in thiamine, riboflavin, niacin and carotene occurred during processing of maize into tortillas by lime-cooking. A summary of some data is shown in Table 21. The vitamin

that has attracted the attention of a number of researchers has been niacin because of its relationship to pellagra. The biological implications of the lime-cooking process on niacin availability and pellagra is discussed in the next section. This section discusses the changes in concentration of niacin resulting from limecooking. Bressani, Gmez-Brenes and Scrimshaw (1961) reported that the seed-coat of maize contained 4.2 mg niacin per 100 g, while the germ and endosperm contained about 2 mg niacin per 100 g. About 79.5 percent of the kernel niacin was provided by the endosperm, and 10 percent each by the germ and seed-coat. After lime-cooking, the endosperm contributed about 68 percent of the total niacin and the germ about 5.5 percent. After cooking, 26 percent of the total was found in the cooking water. The percentage of niacin extracted in water was 68.5 percent of the total with raw grain and 76 percent with lime-cooked maize. Furthermore, enzymatic hydrolysis with pepsin yielded 69 percent of the niacin of all the samples, and after trypsin and pancreatin hydrolysis niacin yields were 78 and 100 percent respectively. This information was interpreted to mean that niacin is slightly more available from lime-treated maize than from raw maize.

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Lime-treated maize (part II)

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Nutrient availability

Although the lime-cooking process to convert maize into tortillas induces some important losses in nutrients, the process also causes important changes in nutrient availability.

***Calcium*. Because of the use of calcium hydroxide in converting maize into tortillas, the calcium content of the product increases significantly, up to about 400 percent. Bioavailability studies conducted by Braham and Bressani (1966) with animals showed that somewhat less of the calcium was available in lime-treated maize (85.4 percent) than in skim milk (97 percent). Calcium bioavailability increased when lime-treated maize was supplemented with its limiting amino acids, lysine and tryptophan. Recently, Poneros and Erdman (1988) confirmed the high bioavailability of calcium from tortillas with or without the addition of ascorbic acid. As pointed out in a previous section, the use of calcium hydroxide improves the calcium-to-phosphorus ratio in tortillas, which possibly favours the utilization of the calcium ion by the animal. This is an important finding for populations who do not consume diets high in this essential mineral. Furthermore, the finding that better quality in maize protein favours calcium big-utilization is of nutritional significance and provides an additional reason for the commercial production of QPM for people who depend on maize for their nutrition.**

***Amino acids*. Bressani and Scrimshaw (1958) carried out studies using in vitro enzymatic digestions with pepsin, trypsin and pancreatic. At the end of the pepsin digestion, the amount of alpha-amino nitrogen as a percentage of total digested nitrogen was twice as high from tortilla (43.1 percent) as from maize (21.4 percent) and levels of histidine, isoleucine, leucine,**

lysine methionine, phenylalanine, threonine and tryptophan were higher from the tortilla hydrolysate than from maize, suggesting a faster release from the proteins. These authors proposed that the difference in rate of release could derive from the significant decrease in the solubility of the prolamine protein fraction in tortillas, as compared with maize. Serna-Saldivar et al. (1987), however, working with ileum-cannulated pigs, found that at this level in the intestinal tract the digestibility of most of the essential amino acids was somewhat higher from water-cooked maize than from limecooked maize. Digestibility of the protein decreased slightly, possibly because of the heat treatment involved (Bressani et al., 1990). Other researchers have suggested that during maize processing, hydrophobic interactions, protein denaturation and cross-linking of proteins are probably responsible for changes in the solubility of these components, which could affect amino acid release during enzymatic digestion.

***Niacin*. The alkaline treatment of maize has been reported to destroy its pellagragenic factor. Evidence from a large number of researchers has suggested that pellagra results from an imbalance of the essential amino acids, increasing the niacin requirement of the animal. This point has been extensively debated between those who claim that niacin in maize is bound and not available to the animal and those who favour the theory of improved amino acid balance induced by the alkaline-cooking process, as lime treatment results in release of the bound niacin. Pearson et al. (1957) have shown that boiling maize in water has the same effect (that is, it increases niacin availability). Bressani, Gmez-Brenes and Scrimshaw (1961) found that in vitro enzymatic digestion liberated all the niacin from raw maize as from tortillas and reached the conclusion that differences in amino acid balance rather than in bound niacin were**

responsible for the differences between raw and lime-processed maize in biological activity and pellagragenic action. Lime treatment of maize improves amino acid balance, as demonstrated by Cravioto et al. (1952) and Bressani and Scrimshaw (1958). Other workers have shown that experimental animals grow better when fed lime-treated rather than raw maize. Using cats which cannot convert tryptophan into niacin - Braham, Villareal and Bressani (1962) showed that niacin from raw and lime-treated maize was utilized to an equal extent, suggesting its availability is not affected by processing.

***Dietary Fibre*. It has been shown above that when maize was processed into tortillas by lime-cooking, total dietary fibre (TDF) decreased at the dough stage and increased in the tortilla to levels only slightly below those found in raw maize. In these studies the levels of TDF in tortillas averaged 10 percent on a dry weight basis. If a person consumed about 400 g of tortilla (dry-weight), the TDF intake would be 40 g, a value significantly higher than the recommended intake. Even small children can consume relatively large amounts of dietary fibre, which can affect the availability of iron. Hazell and Johnson (1989), however, indicated that maize-based snack foods prepared by extrusion cooking have a higher iron availability than raw maize. These authors indicated that refining of raw maize, product formulation, extrusion cooking and addition of flavourings were responsible to different degrees. Likewise zinc intake could be affected. The other mineral that could be affected would be calcium; however, Braham and Bressani (1966) and Poneros and Erdman (1988) showed that calcium is relatively well available from tortillas and that its availability is increased when the protein quality is improved through addition of the limiting amino acids. An excess of calcium rather than dietary fibre could be responsible for zinc availability, as has been indicated in a number of studies.**

Protein quality of maize and nutrient bioavailability

Growing rats retained calcium from tortillas better when it was supplemented with lysine its limiting amino acid, and with a mixture of amino acids. Protein quality is an important factor in bioavailability of nutrients from maize and its lime-treated products. As already stated, niacin availability also improves when protein quality is improved, and studies with QPM have shown better utilization of niacin. The same observation has been made on the utilization of carotene, which is higher in lysine-supplemented yellow maize than in the unsupplemented product.

***Changes in quality*. Changes in nutritional value, particularly that of protein, during the transition from raw maize to tortillas have been studied mainly in animals. Even though chemical losses in some nutrients take place upon limecooking of maize, protein quality is slightly but consistently better in tortillas than in raw maize. Table 22 summarizes the results of various studies where raw maize and the tortillas made from it have been evaluated. The protein efficiency ratio of the tortillas is in general somewhat higher than that of the raw maize, although some studies have reported otherwise. The difference may be attributed to processing conditions, particularly the concentration of lime added, which is lower in rural home cooking than at the industrial level. The chemically determined amino acid pattern of the tortillas is no better than the pattern in raw maize. The only explanation is that the process increases the availability of key amino acids. This is indicated by the results of feeding studies with young rats (Bressani, Elas and graham, 1968). Both raw maize and the lime-cooked dough were supplemented with increasing levels of lysine alone (from 0 to 0.47 percent of the diet). Maximum PER for maize was obtained with an addition of 0.31 percent and for the lime-**

cooked dough with 0.16 percent. At all levels of supplemental lysine the dough gave higher PER values than the raw maize.

Tryptophan supplementation alone was also tested, and in this case 0.025 percent addition gave the highest PER for maize, with no response for the dough. The addition of the two amino acids at the level of 0.41 percent lysine with tryptophan varying from 0.05 to 0.15 percent improved the quality of both materials, although it was higher for the dough.

TABLE 22 - Protein quality of maize and tortillas

Type of maize	**Protein quality (PER)**		
	Raw maize	**Tortillas**	**Casein**
Common	1.13 0.26	1.27 0.27	
Common	1.49 0.23	1.55 0.23	2.88 0.20
QPM (Opaque-2)	2.79 0.24	2.66 0.14	2.88 0.20
Common	1.38	1.13	2.50
Common Tropical	0.99 0.25	1.41 0.11	2.63 0.17
Common Highland Xetzoc	0.96 0.19	1.41 0.20	2.63 0.17
Common Highland	1.02 0.19	1.41 0.17	2.63 0.17

Azotea			
Common Highland Sta. Apolonia	0.71 0.20	0.98 0.17	2.63 0.17
QPM Nutricta	1.91 0.23	2.12 0.12	2.63 0.17
Biological value of common maize	59.5	59.1	69.4
Net protein utilization of common maize	51.2	49.4	64.5

These results were interpreted to mean that the quality of lime-treated maize is superior to that of raw maize. This explanation is supported by in vitro studies showing a greater release of essential amino acids (EAA) from tortillas than from maize, even though Ortega, Villegas and Vasal (1986) reported in vitro protein digestibility in maize, dough and tortillas to be 88, 91 and 79 percent respectively. For QPM the respective values were 82, 80 and 68 percent. Recently, Serna-Saldivar et al. (1987) reported on dry matter, gross energy and nitrogen digestibilities of maize cooked with and without lime. No differences in dry matter or gross energy digestibility values were found between the different processing treatments. Cooking maize with lime, however, reduced nitrogen digestibility from 76.5 to 72.8 percent. These values were measured near the end of the small intestine in pigs. Values for dry matter, gross energy and nitrogen digestibility increased when measured over the pigs' total digestive tract. From nitrogen balance studies, the same authors reported a retention of intake nitrogen of 45.8 percent for

maize cooked without lime and 41.2 percent for lime-cooked maize. Retention of absorbed nitrogen was 48.2 percent for the lime-cooked maize and 52.9 percent for the maize cooked with water alone. Digestible and metabolizable energy were similar in maize processed with and without lime. The authors concluded that the lime-cooking process decreased the nutritive value of maize.

In another study by Serna-Saldivar et al. (1988b), this time conducted with rats, the authors noted an increase in percentage of dry matter and gross energy digestibilities from maize to nixtamal (dough) and to tortillas; however, protein digestibility decreased. In vitro studies correlated with in vivo values. graham, Bressani and Guzmn (1966) showed better weight gain in DurocJersey pigs fed lime-treated maize than in those fed raw maize, with better feed efficiency. In studies with dogs, lysine and tryptophan added to lime-cooked maize improved nitrogen balance to the value obtained with skim milk (Bressani and de Villareal, 1963; Bressani and Marenco, 1963). It was further shown that after these two amino acids, isoleucine, threonine, methionine and valine increased nitrogen retention above values measured with lysine and tryptophan. Lime-treated maize has also been evaluated in children (see Chapter 6). Nitrogen balance results have shown a high response to lysine and tryptophan addition, which in turn is dependent on the level of protein intake. At low levels, only lysine improved quality, but as nitrogen intake increased, the addition of tryptophan with lysine became important. All studies suggest that in limetreated maize, lysine is slightly more deficient than tryptophan, and the contrary seems to be the case for raw maize. Nevertheless, for a significant improvement in protein nutritional quality of lime-treated maize, both of these amino acids are required.

***Use of QPM*. Nutritionally improved (QPM) maize shows the same changes in protein quality and bioavailability after lime-cooking and conversion to tortillas as observed in normal maize. The difference is that QPM tortillas and products are nutritionally superior to those made from common maize. They are as acceptable to consumers.**

Other effects of lime-cooking

***Lysinoalanine formation*. In 1969, De Groot and Slump demonstrated that alkali treatment of proteins gave rise to peptides such as lysinoalanine (LAL), lanthionine and ornithine which had negative effects on animals. They were not biologically available and had detrimental effects on protein quality. Consequently, the effect of the alkaline-cooking process to convert maize into tortillas has received attention from various researchers. Sternberg, Kim and Schwende (1975) reported that commercial samples of masa flour, tortillas and taco shells contained 480,200 and 170 g LAL per gram. Sanderson et al. (1978) also found that lanthionine and omithine were formed during alkaline cooking of maize. These authors found no LAL in common or in high-lysine raw maize; however, these products contained 0.059 and 0.049 g percent protein respectively after alkali treatment. A commercial masa contained 0.020 percent, and tortillas 0.081 percent protein. These authors also reported lanthionine and ornithine values in the masa prepared from the two types of maize. Chu, Pellet and Nawar (1976) reported values of 133.2 g of LAL per gram protein when maize was processed with 4.1 mol per kg of lime for 30 minutes at 170F (76.6C). The use of sodium hydroxide under equal conditions yielded higher levels of LAL. Since higher levels of LAL were obtained with NaOH and KOH, the authors suggested that calcium ions may in some way interfere with the mechanism of LAL formation. It**

is difficult to evaluate the significance of LAL formation during tortilla-making for people who eat relatively large amounts of this food daily. Since this has been practiced for a long time, the small amounts may not interfere with nutritive value or cause any pathological effects. Studies on the effect of lime level on the protein quality of maize have shown, however, that levels above 0.5 percent of grain weight reduce protein quality. The type of maize used and its size are of importance in this respect. Softer types of grains are more affected than hard grains cooked under similar conditions (Bressani et al., unpublished data).

***Mycotoxins and alkaline-cooking of maize*. The presence of mycotoxins in a variety of cereal grains and other foods and foodstuffs widely recognized, and maize is no exception. In Central America, where maize is such an important food, the grain is harvested twice a year in the tropical areas. One harvest is in August, when rain and temperature conditions are ideal for the growth of fungi. Martnez et al. (1970b) reported the presence of six different fungi in maize samples obtained from different markets throughout Guatemala. The frequency of Aspergillus versicolor was 57.1 percent; of Aspergillus wentii, 32.1 percent; of Aspergillus ruber, 26.8 percent; of Aspergillus echinulatus, 25.0 percent; of Aspergillus flavus, 25.0 percent; and of Chaedosporium spp., 26.8 percent.**

Because of the significance of the presence of mycotoxins in cereal grains, a number of studies have been conducted to assess the degree of retention of mycotoxins during grain processing. The effect of calcium hydroxide cooking of maize has received some attention. Martnez-Herrera (1968) fed infected maize, raw and alkali-processed, to chickens and rats. The maize was infected with Fusarium sp., Penicillium spp., Aspergillus niger and A. flavus. The author found

high mortality among birds fed on the raw infected maize, but none in the group of chickens fed the same maize processed with calcium hydroxide. In young rats, the raw and infected grain reduced weight gain and caused some mortality. Infected grain processed with lime induced no mortality, however, and weight gain as well as feed efficiency were like those in the control. Adult rats were also affected by the infected maize, but not by infected maize processed with lime. The study did not report levels of mycotoxins before and after processing.

Martinez (1979) reported on studies of tortilla samples collected in Mexico City in different seasons. He found that 15 to 20 percent of the samples collected in spring 1978 and in the rainy season of 1977-1978 contained aflatoxins. Furthermore, he found that concentrations of aflatoxins B1 varied from 50 to 200 ppb. He also indicated that lime-cooking of maize reduced aflatoxin concentrations by 50 to 75 percent. Martnez and also de Campos, Crespo-Santos and Olszyna-Marzys (1980) reported that lime concentrations of up to 10 percent were no more effective in reducing aflatoxins than a 2 percent concentration.

Ulloa-Sosa and Schroeder (1969) reported that the tortilla-making process was not effective in removing aflatoxins from contaminated maize. Nevertheless, others have obtained different results. For example, SolorzanoMendizabal (1985) found that maize inoculated with A. flavus and Aspergillus parasiticus produced high levels of aflatoxins which were reduced by lime-cooking, completely in some cases, but most often by up to 80 percent. Lime concentration varied from 0.6 to 8 percent, and analyses were done on maize, masa, tortillas and cooking waters. In another study, de Arriola et al. (1987, 1988), using QPM Nutricta, found that the lime levels at which nixtamal is normally prepared in Guatemala do not reduce aflatoxin in

contaminated grain sufficiently to make it safe for human consumption.

Lime levels of 2 percent and above gave high aflatoxin reduction, but the tortillas were not acceptable. Aflatoxin B1 was reported to be reduced the most. Torreblanca, Bourges and Morales (1987) found relatively high aflatoxin levels in both maize and tortillas in a study conducted in Mexico City. Aflatoxin B1 was found in 72 percent of the maize tortilla samples tested; furthermore, 24 percent of the samples gave positive reactions for zearalenone. Carvajal et al. (1987) found mycotoxins in maize and tortillas in Mexican samples and indicated that aflatoxins, zearalenone and deoxynivalenol (DON) were not destroyed by the lime treatment or by temperatures of 110C.

Price and Jorgensen (1985) found that the alkaline cooking process reduced aflatoxin levels from 127 g per kg in raw maize to 68.6 g per kg in tortillas. The authors concluded that the process was poorly effective, since the lower value obtained was still much above the value established as acceptable (about 20 mg per kg). These authors found that acidification - as it occurs in the intestinal tract - increased aflatoxin levels. Abbas et al. (1988) reported on the effect of 2 percent lime-cooking of maize on the decomposition of zearalenone and DON. They found significant reductions, i.e. 58 to 100 percent for zearalenone and 72 to 82 percent for DON. Furthermore, 15-acetyl-DON was completely destroyed.

Results obtained by various authors are somewhat conflicting, since some of them report partial reduction in some mycotoxins while others note total reduction. In many studies the mycotoxin levels were relatively high, necessitating stronger processing conditions in terms of

lime concentration and cooking time. The problem warrants further study. Grain quality is probably the best means of ensuring the absence of mycotoxins rather than dependence on lime to reduce them partly or eliminate them in the final product.

***Microbiological aspects of tortillas and tortilla flour*. Studies on the microflora in lime-cooked maize tortillas are very limited. Capparelli and Mata (1975) showed that the main contaminants of tortillas as made in the highlands of Guatemala were coliforms, Bacillus cereus, two Staphylococcus species and many types of yeasts. When tortillas are first cooked, bacterial counts are about 103 or fewer organisms per gram, which is a safe level for consumption. After they are cooked for about five minutes on a hotplate they are placed hot in a basket, often covered with a cloth. This captures the vapour from the tortillas, creating an environment appropriate for microbial growth. After some ten hours under these conditions the surfaces of stacked tortillas become slimy and they are not acceptable for consumption.**

Although there are many opportunities in rural areas for contamination during processing from maize to tortillas, the factors that possibly contribute the most are the water used during conversion of cooked maize to dough and the mill used to grind the cooked maize. Molina, Baten and Bressani (1978) reported a greater increase in bacteria counts in tortillas fortified with soybean flour and vitamins than in unfortified tortillas. In this case the mill used to grind the cooked maize to make the dough was chlorinated, which helped in lowering the bacteria count in the soy-supplemented maize. The tortillas made from it also had a lower bacteria count. The rate of increase in bacterial number decreased as well. Higher bacteria counts were reported by Valverde et al. (1983) in the cough and tortillas made from QPM Nutricta than in

those from common maize, showing the effect of nutritional quality on bacterial growth.

The relatively high moisture content which is responsible for a very short shelf-life has limited marketing of tortillas. Nevertheless, there is a demand for them in urban areas, where they are marketed under refrigerated conditions. A number of attempts have been made to lengthen their shelf life. Rubio (1972a, 1972b, 1973, 1974a, 1974b, 1975) patented a number of methods which included various additives: epichlorohydrin and polycarboxylic acid and their anhydrides; hydrophilic inorganic gels; sorbic acid and its salts as well as the methyl, ethyl, butyl and propyl esters of para-hydroxy benzoic acid; and acetic and propionic acids. Pelaez and Karel (1980) developed an intermediatemoisture tortilla with a stable shelf-life. It was free from microbial growth, including Staphylococcus aureus, yeasts, moulds and enterotoxin. This was achieved through the use of glycerol, corn solids DE-42 and salt, as well as the mycostatic agent potassium sorbate. Protection with appropriate packaging was claimed for at least 30 days and the appearance, texture and other characteristics were similar to those of regular tortillas with a water activity of 0.97. Hickey, Stephens and Flowers (1982) reported relatively good protection of tortillas with low levels of sorbates or propionates added to the dough, and with a spray of sorbate on the surface (both sides) after cooking on the hot plate. More recently, Islam, Lirio and Delvalle (1984) claimed that using calcium propionate extended the shelf-life of tortillas at room temperature to 2 to 5 days; with dimethyl fumarate shelf-life was 2 to 11 days under the same storage conditions and using polythene bags. Although advances have been made in extending shelf-life, it still constitutes a problem for people who buy food in supermarkets.

Reports on the microbiology of tortilla flour and the tortillas made from it are not available. Lower total bacteria counts would be expected, however, because of the process employed to prepare the flour and use it at home.

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Ogi and other fermented maize products

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Chemical changes

The process of fermenting maize, sorghum, millet or rice to produce ogi not only removes parts of the maize kernel such as the seed-coat and the germ, but also involves washing, sieving and decanting, all of which induce changes in the chemical composition and nutritive value of the final product. Akinrele (1970) reported on specific nutrients of a number of ogi samples produced in different ways: unfermented and fermented with Aerobacter cloacae, Lactobacillus plantarum and a mixture of the two bacteria. He compared the values found with those from the traditionally fermented product. Judging from the ratio of amino nitrogen to total nitrogen,

the author reported that protein was degraded to a very small amount by any bacterial species. When compared with the unfermented ogi, A. cloacae appeared to synthesize more riboflavin and niacin, which did not take place with L. plantarum. Traditionally produced ogi had more thiamine and slightly lower values of riboflavin and niacin than that made with maize and A. cloacae. In any case the changes were small, and smaller if compared with whole maize, whereas in comparison with degermed maize, the ogi products contained more riboflavin and niacin. Akinrele (1970) and Banigo and Muller (1972) reported on the carboxylic acids in ogi and found lactic acid in greatest concentration (0.55 percent) followed by acetic acid (0.09 percent) and smaller amounts of butyric acid. The latter investigators suggested levels of 0.65 percent for lactic acid and 0.11 percent for acetic acid, responsible for the sour taste, as goals for flavour evaluations. Banigo, de Man and Duitschaever (1974) reported on the proximate composition of ogi made from common whole maize which was uncooked and freeze-dried or cooked and freeze-dried after fermentation. Changes were relatively small in all major nutrients, with a slight increase in fibre and a decrease in ash content when compared with whole maize.

These authors also reported on amino acid content; they found no differences between maize flour and ogi for all amino acids including the essential ones. The ogi samples, however, had about twice the amount of serine and somewhat higher values for glutamic acid. Adeniji and Potter (1978) reported that ogi processing did not decrease the protein content of maize, but total and available lysine were significantly reduced. On the other hand, tryptophan levels were more stable and in two samples increased, probably because of fermentation. These authors also found an increase in neutral detergent fibre and ash but no change in lignin.

Akingbala et al. (1987) found a decrease in protein, ether extract, ash and crude fibre in ogi as compared with maize that was processed as a whole grain or dry milled.

Nutritional changes

Nutritional evaluations of ogi and other maize-fermented products are not readily available. Adeniji and Potter (1978) found a substantial decrease in protein quality of drum-dried common maize ogi, which they ascribed to the drying process. These same authors reported significant losses in lysine Several authors have more recently tested maize and sorghum and reported that fermentation improved the nutritional quality of the product. Akinrele and Bassir (1967) found net protein utilization, protein efficiency ratio and biological value of ogi inferior to those values in whole maize, even though some increase in thiamine and niacin was obtained. It has been indicated that some of the micro-organisms responsible for ogi fermentation, such as Enterobacter cloacae and L. plantarum, use some of the amino acids for growth. This together with the elimination of the germ from kernels explains the very low protein quality of ogi and similarly produced maize products. However, there are some exceptions, such as kenkey and pozol, both products in which the maize is fermented with the germ. Although protein quality values are not available for kenkey, Cravioto et al. (1955) found higher levels of tryptophan and available lysine which suggested higher protein quality than in raw maize or lime-treated maize. More recently, Bressani (unpublished) found the fermented product to be higher in protein quality than raw maize, but not different in quality from lime-cooked dough.

Use of QPM

Adeniji and Potter (1978) used high quality protein maize to make ogi and found similar results to those from common maize, except that the protein quality was higher (although lower than that of the original raw maize). Pozol made from QPM has significantly higher protein quality than raw QPM (Bressani, unpublished data).

Arepas

Chemical changes

Arepa flour is made in a dry milling process which removes the pericarp and the germ from maize. Therefore, arepa flour may be expected to differ from whole maize flour, and this was in fact reported by Cuevas et al. (1985). The protein, ether extract, fibre and ash content of arepa flour from both white and yellow maize were lower than in whole maize. The same is true for thiamine, riboflavin and niacin as well as for calcium, phosphorus and iron. These changes evidently result from the removal of the germ and seed-coat.

Nutritive value

Arepa flour has been subjected to biological assay for protein quality by Chavez (1972a). He reported a decrease of about 50 percent in protein quality from maize (0.74) to arepa (0.33), although there was some increase in protein digestibility.

Use of QPM

High protein quality maize has been used to make arepas. Chavez (1972b) found the process to reduce nitrogen, lysine and tryptophan, thiamine and niacin and attributed this to germ removal. Protein quality was also significantly less than in whole maize, but was nonetheless superior to that of maize and arepas from normal maize. All products - tortillas, ogi, pozol, kenkey and arepas made from QPM are of better protein quality and energy value than the products made from common maize.

Other dry milling products

Chemical changes

The main maize products for food use derived from dry milling include flaking grits, coarse or fine grits, maize cones and maize flour. They are products from which the pericarp and germ have been eliminated and they differ from each other in granulation, with flaking grits having the largest particle size and flour the smallest. Basically, their chemical compositions based on food composition data are very similar.

Nutritive value

The protein quality of these products, as with most dry-milled maize products, is inferior to that of the original whole grain. If there are any changes, these come about from the processes

used to turn such products into the different forms in which they are consumed. For example, the protein digestibility of maize meal was reported by Wolzak, Bressani and Gmez-Brenes (1981) to be 86.5 percent and that of corn flakes 72.0 percent. A significant diminution of protein quality also takes place since available lysine decreases.

QPM products

Studies on dry milling of QPM, particularly the hard-endosperm types, are not readily available. Wichser (1966) found yields of 8.8 percent grits from milled QPM, while the yield of grits from maize hybrids was about 17 percent. The yields of meal and flour were essentially the same from QPM and hybrid maize. However, the fat, protein, fibre and ash contents in QPM grits, breakfast cereal and flour were higher than those in similar products from hybrid maize.

Not much information on the nutritional value of QPM dry-milled products is available; however, Wichser (1966) showed the endosperm of QPM to have a net protein ratio (NPR) of 76 percent of the value of casein (100 percent), while the endosperm from hybrid maize had an NPR of 47 percent of the value of casein. These results are very similar to those for maize flour made for arepa production from QPM and common maize as shown by Chavez (1972a).

Chapter 6 - Comparison of nutritive value of common maize and quality protein maize

Consumption of maize

Maize in its different processed forms is an important food for large numbers of people in the developing world, providing significant amounts of nutrients, in particular calories and protein. Its nutritional quality is particularly important for small children. Table 23 shows the consumption of maize as tortillas or lime-treated maize by children in Guatemala. Amounts varied from 64 to 120 g per day, providing about 30 percent of the daily protein intake and close to 40 percent of the daily energy intake. Garcia and Urrutia (1978) reported an intake of 226 g of tortillas by weaned three-year-old children, providing about 47 percent of their calories.

Although these findings are not basically bad, adequate supplementary foods are often not provided or are given only in insignificant amounts. Food legumes are the most readily available supplementary food in developing countries; however, the amounts are generally very small (Flores, Bressani and Elas, 1973). The average intake of beans per age group for the six countries in Central America was 7, 12, 21 and 27 g per child per day at 1, 2, 3 and 4/5 years, respectively. On the basis of 22 percent crude protein in beans, the amounts of protein provided by this food were 1.5, 2.6, 4.6 and 5.9 g, respectively; however, amounts of digestible protein on the basis of a true digestibility of 70 percent were only 1.0,1.8,3.2 and 4.1 g. Thus beans provided about 14, 18, 22 and 30 percent of the dietary protein in the total intake from maize and beans. These amounts and their supplementary effects were very small, particularly for the one- and two-year-old children.

TABLE 23 - Maize consumption and its contribution to daily calorie and protein intake of children in a rural area of Guatemala

Age (years)	Maize intake (g/day)	Protein intake			Calorie intake		
		Maize (g/day)	Total (g/day)	Percent of total from maize	Maize (cal/day)	Total (cal/day)	Percent of total from maize
1-2	64	5.4	20.0	27	231	699	33
2-3	86	7.3	21.7	34	310	787	39
34	120	10.2	27.9	36	433	981	44
4-5	89	7.6	23.3	33	321	819	39

Source: M. Flores (cited in Bressani. 1972)

Data for 1979-1981 from FAO (1984) showed that 22 of 145 countries had a maize consumption of more than 100 g per person per day as indicated in Table 24, which also gives the calories and protein that maize provides. It should be pointed out, however, that 1960-1962 figures from FAO food balance sheets (FAO, 1966) were higher for some countries than the 19791981 figures. The figures confirm the importance of maize as a staple food in some Latin American

countries, particularly Mexico and Central America, as well as in some African countries. It follows that if the maize intake is high, maize contributes significant amounts of calories and protein to the daily intake of people in these countries.

Table 25 summarizes maize intake, calories per day and protein per day among the rural and urban populations of the six countries of Central America. Two general trends are evident. The first is that maize intake decreases from north to south. The cereal grain that replaces it is rice. The second trend is that intake of maize is higher in rural than in urban areas. In at least three countries maize makes up the greatest proportion of all the ingested food in the rural sector and is therefore an important source of nutrients in the diet. The table shows that maize provides up to 45 and 59 percent of the daily intake of calories and protein respectively.

TABLE 24 - Maize intake and its calorie and protein contribution to the daily diet

Country	**Intake (g/person/day)**	**Calories (per person/day)**	**Protein (g/person/day)**
Benin	160.5	481	12.7
Botswana	209.3	665	17.5
Cape Verde	334.1	1 052	28.0
Egypt	149.7	508	13.4

El Salvador*	245.0	871	23.3
Guatemala	276.2	977	15.4
Honduras	255.9	878	22.8
Kenya	286.1	808	21.3
Lesotho	315.4	1002	26.4
Malawi	468.8	1422	37.6
Mexico	328.9	1061	27.1
Nepal	116.4	379	9.4
Nicaragua'	131.0	472	11.1
Paraguay	131.2	445	11.6
Philippines	152.1	399	8.7
Romania	128.6	373	8.6
Singapore	122.2	345	8.6
South Atrica, Rep.	314.7	961	24.6
Swaziland	381.4	1279	33.7
Tanzania, United Rep.	129.1	421	10.0
Togo	136.9	411	10.8

Venezuela	118.3	339	7.4
Zambia	418.6	1226	31.3
Zimbabwe	330.9	958	25.2

Sources: FAO, 1984; *FAO, 1966

TABLE 25 - Importance of maize consumption in rural areas

Country	**Urban maize intake (g/day)**	**Rural maize intake (g/day)**	**Rural calorie intake (per day)**		**Rural protein intake (g/day)**	
			From maize	**Total**	**From maize**	**Total**
Guatemala	102	318	1 148	1 994	27.0	60
Et Salvador	166	352	1 271	2 146	29.9	68
Honduras	135	225	812	1 832	19.1	58
Nicaragua	56	131	472	1 986	11.1	64
Costa Rica	14	41	148	1 894	3.5	54
Panama	4	4	14	2 089	0.3	60

Source: INCAP, Guatemala, 1969

Although this information was compiled from dietary surveys conducted in 1969, figures have not changed significantly in recent years. For example, in 1976 average consumption in El Salvador varied from 146 to 321 g per person per day; in Honduras in 1983 consumption in different regions varied from 1 1 1 to 246 g per person per day; and in Costa Rica in 1986, intake varied from 14 to 31 g per person per day. Chavez (1973) indicated that about 45 percent of the national calorie intake is provided by maize in Mexico. In poor rural areas men may consume about 600 g of maize and women about 400 g. On this basis the importance of the nutritional quality of maize is obviously great. Although all nutrients are of interest, the quality of protein has received more attention from researchers.

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Common maize

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Protein quality for children

The protein quality of maize evaluated for children recovering from protein energy malnutrition has been reported by various researchers. Table 26 shows the results when lime-cooked maize was supplemented with maize gluten to obtain a product with higher protein content and to facilitate higher protein intakes with lower intakes of solids. The amino acid deficiencies in maize protein were thus magnified and this facilitated their detection using the nitrogen balance technique (Scrimshaw et al., 1958; Bressani et al., 1958, 1963). The results showed decreasing nitrogen retention as nitrogen intake decreased, which was to be expected; however, even at a high nitrogen intake of 469 mg per kg body weight per day, retention was significantly lower than nitrogen retention from milk given in amounts providing the same level of protein. Apparent protein digestibility indicated as nitrogen availability was fairly similar for different nitrogen intakes, varying from 72 to 78 percent. Table 27 refers to nitrogen balance studies in children fed water-cooked maize. Nitrogen retention from maize was significantly lower than from milk at the same level of protein intake. Protein digestibility was 80 percent for milk and 75 percent for maize (Viteri, Martnez and Bressani, 1972). Similar data were obtained with cooked maize endosperm and whole normal maize (Graham, Placko and MacLean, 1980), as shown in Table 28. In this case nitrogen balance was lower for common maize endosperm than for the whole kernel and lower than the results from the reference protein, casein. Graham et al. (1980) calculated that in order to match nitrogen retention from casein, the children would have to obtain 203.9 percent of their energy requirements from maize, which is obviously impossible.

TABLE 26 - Nitrogen balance in children ted lime-treated maize as the sole protein source

Protein intake (g/kg/day)	Nitrogen (mg/kg/day)			% of intake	
	Intake	Absorbed	Retained	Absorbed	Retained
3	470	339	9	72	2
	(435 to 479)	(327 to 369)	(-8 to 174)	(61 to 77)	(-2 to 36)
2	331	260	22	78	7
	(308 to 367)	(207 to 284)	(-41 to 59)	(65 to 82)	(-13 to 17)
1.5	238	180	-11	76	-4
	(235 to 241)	(168 to 193)	(-22 to -2)	(70 to 82)	(-9 to -1)

Note: Diet consisted of 95% lime-treated maize and 5% maize gluten
Source: Viteri, Martnez and Bressani, 1972

TABLE 27 - Nitrogen balance In children fed common maize and milk

Food	Intake (g/kg/day)	Protein intake (g/kg/day)	Nitrogen absorbed (mg/kg/day)	Nitrogen retained (mg/kg/day)	% N intake absorbed	% N intake retained
Milk	195	1.25	157	75	80	38
	(175-210)		(114-181)	(40-106)	(61-47)	(22-50)

Common maize	192	1.25	144	30	75	16
	(183-198)		(129-157)	(10-59)	(66-20)	(5-30)

Note: Average values. with dispersion in parentheses
Source: Viteri, Martinez and Bressani, 1972

TABLE 28 - Nitrogen balance in children fed whole common maize kernels and maize endosperm flour

Food fed	**Nitrogen absorbed (% of intake)**	**Nitrogen retained (% of intake)**
Endosperm	64.1 11.4	15.1 8.9
Casein	81.8 5.2	37.0 14.2
Whole kernel	73.1 1.9	26.8 4.6
Casein	83.5 2.5	39.6 9.1

Source: Graham. Placko and MacLean, 1980

As was discussed earlier, germ proteins do contribute significantly to essential amino acids

(EAA), so maize food products without the germ, including QPM endosperm, are always lower in protein quality than the whole kernel. Similarly, maize with a high zein content is of a lower quality than maize with lower prolamine content, because of a higher relative lysine deficiency and a higher imbalance of essential amino acids such as leucine relative to isoleucine.

TABLE 29 - Effects on nitrogen retention of additions of lysine tryptophan and methionine to lime-treated maize (nitrogen values in mg/kg/day)

Diet	**Nitrogen intake**	**Faecal nitrogen**	**Urinary nitrogen**	**Nitrogen absorbed**	**Nitrogen retained**
Basal (B)	461	117	334	344	10
B + tryptophan	457	115	289	342	53
B + tryptophan + lysine	464	135	243	329	86
B + tryptophan + lysine + methionine	459	135	272	324	52

Note: Amino acids used: DL-tryptophan: 0.34%, L-lysine/HCl: 0.56%, DL-methionine: 0.34%
Source: Scrimshaw et al., 1958

Amino acid supplementation

It is widely accepted that maize proteins are deficient in both lysine and tryptophan, as documented from studies with animals. In tests with children, however, the EAA contents of lime-treated maize supplemented with 5 percent maize gluten to raise the protein content (Scrimshaw et al., 1958; Bressani et al., 1958, 1963) were compared with the amino acid contents of the 1957 FAO reference protein. This comparison suggested the following order of amino acid deficiency: tryptophan, lysine methionine, valine, isoleucine and threonine. It also suggested the amounts of amino acids needed to reach the reference level. Representative results from two children fed 3 g of protein per kg body weight per day are shown in Table 29. There was an apparent response to the addition of 148 mg DL-tryptophan per g N which was much improved by the simultaneous addition of tryptophan and lysine the latter in the amount of 243 mg per g N. Addition of methionine decreased nitrogen retention.

TABLE 30 - Response to lysine and tryptophan added alone (nitrogen values in mg/kg/day)

Diet	**Nitrogen intake**	**Faecal nitrogen**	**Urinary nitrogen**	**Nitrogen absorbed**	**Nitrogen retained**
Subject No.1					
Milk	586	93	320	393	73
Basal (B)	474	185	349	289	-60
B + tryptophan	474	108	352	366	14
B	479	111	346	368	22

B + lysine	482	120	324	362	38
Subject No. 2					
Milk	392	45	295	347	52
Basal (B)	320	56	273	264	-9
B + lysine	335	54	257	285	24
8	346	63	287	283	-4
B + tryptophan	337	52	308	285	-23

Note: Levels added to give 75-90 mg tryptophan/g N and 180-270 mg L-lysine HCl/g N
Source: Bressani et al., 1958

In other studies, nitrogen balance tests were carried out to learn about the response previously obtained by tryptophan addition alone. The results from two subjects (Table 30) clearly show that tryptophan had no effect on improving protein quality. The addition of lysine on the contrary, appeared to give a response, suggesting lysine to be more limiting than tryptophan.

Similar studies were carried out by feeding children 2 g of protein per kg body weight per day. The results in two children are summarized in Table 31. Tryptophan addition did not induce a positive nitrogen retention, but the addition of tryptophan and lysine with and without isoleucine improved nitrogen balance. Methionine addition decreased retention of nitrogen, as

previously demonstrated.

TABLE 31 - Effects on nitrogen retention of additions of lysine tryptophan, isoleucine and methionine to lime-treated maize (nitrogen values in mg/kg/day)

Diet	Nitrogen intake	Faecal nitrogen	Urinary nitrogen	Nitrogen absorbed	Nitrogen retained
Basal (B)	320	68	270	252	-18
B + tryptophan	320	91	241	229	12
B + tryptophan + lysine	321	105	201	216	15
B + tryptophan + lysine + isoleucine	321	90	207	231	24
B + tryptophan + lysine + isoleucine + methionine	314	84	217	230	13
B	319	98	242	221	-21

Note: Amino acid levels added: DL-isoleucine 0.45%; other amino acids added in amounts shown in Table 29
Source: Bressani et al., 1958

Nitrogen balance tests were performed with protein intake of 1.5 g per kg body weight per day. The results for one child are shown in Table 32. Although lysine addition did not induce a positive balance, it did tend to cause a decrease in nitrogen losses. The improvement from lysine and tryptophan, with and without isoleucine, is evident. The addition of methionine, even at this level of protein intake, decreased the nitrogen balance as previously indicated for higher intakes of protein.

Because of the consistency of the results, the data obtained for different protein levels under the various dietary treatments were pooled. The results are shown in Table 33. There was a response to tryptophan addition only at the highest level of dietary protein, but the response to lysine was consistent at all protein intake levels, suggesting that this amino acid is more deficient than tryptophan. The response to addition of lysine alone, however, was small and without much nutritional significance, which implies the need to add both amino acids at the same time, as can be done with supplementary foods.

TABLE 32 - Effects of amino acid supplementation of maize at intakes of 1.5 9 protein per kg body weight per day (nitrogen values in mg/kg/day)

Treatment	Nitrogen intake	Faecal nitrogen	Urinary nitrogen	Nitrogen absorbed	Nitrogen retained
Basal (B)	241	71	187	170	-17
B + lysinea	239	59	184	180	-4

B + lysineb	239	48	193	191	-2
B + lysine + tryptophan	239	47	162	192	-30
B + lysine + tryptophan + isoleucine	240	44	150	196	46
N + lysine + tryptophan + isoleucine + methionine	240	55	162	185	23
B	235	45	193	190	-3

[a]0.56% L-lysine HCl
[b]0.30% L-lysine HCl
Other amino acids added in the amounts shown in Table 29
Source: Bressani et al., 1958

A nitrogen intake level of 239 mg per kg body weight per day is equivalent to 20 g of maize per kg per day, or about the 200 g of maize normally ingested by children. Supplementation with lysine alone would have little effect. When tryptophan is also added, however, the nitrogen retention is significantly higher and even surpasses that of milk at the highest level of dietary protein. The overall conclusion that can be reached from the results obtained by amino acid supplementation of maize is that both lysine and tryptophan must be added to obtain a significant response in protein quality as measured by nitrogen retention. It also appears that

the two amino acids are equally limiting in spite of the fact that the addition of lysine alone tended to improve protein quality slightly, while the results from the addition of tryptophan were inconsistent.

The effect of methionine deserves further comment. It was attributed to an amino acid imbalance, because maize already contains enough of this amino acid to meet nutritional requirements.

TABLE 33 - Nitrogen balance in children fed lime-treated maize at various levels of protein intake with and without amino acid supplementation

The results shown in Table 34 indicate that valine also decreases nitrogen retention and that its effect can be reversed by the addition of isoleucine and threonine. A more detailed study in dogs led to the conclusion that there is also a close interrelationship among all four of these amino acids methionine, valine, isoleucine and threonine - as supplements to maize proteins (Bressani, 1962,1963).

It is a point of major importance that children are so sensitive to small changes in amino acid proportions that they are readily detectable in a short period by testing the nitrogen balance. The data presented here emphasize the importance of establishing a proper balance among the essential amino acids if a maximum retention of nitrogen is to be obtained. This is the principle of amino acid supplementation. The results obtained on the amino acid supplementation of maize confirm data derived from studies with rats, pigs and other animals. Results of studies on

adult human subjects are shown in the next section.

TABLE 34 - Effect of multiple amino acid supplementation of maize (nitrogen values in mg/kg/day)

Diet	**Nitrogen intake**	**Faecal nitrogen**	**Urinary nitrogen**	**Nitrogen absorbed**	**Nitrogen retained**
Basal (B)	471	117	315	354	39
B + lysine + tryptophan + methionine	451	223	244	228	-16
B + lysine + tryptophan + methionine + valine	454	241	242	213	-29
B + lysine + tryptophan + methionine + valine + isoleucine	460	128	265	332	67
B + lysine + tryptophan + methionine + valine + isoleucine + threonine	447	190	218	257	39
B + lysine + tryptophan + methioninea + valine +	450	129	238	321	83

isoleucine + threonine					

[a]0.14% DL-methionine in this diet only, all others 0.34% DL-methionine. DL-valine: 0.90%, DL-threonine: 0.22%.
Other amino acids added in amounts shown in Table 29
Source: Scrimshaw e, al., 1958

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Quality protein maize

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Children

The high consumption of maize by the human population in a number of countries in Latin America and Africa and the well-established lysine and tryptophan deficiencies in maize protein motivated the search for a maize kernel with higher concentrations of these essential amino acids in its protein. The possibility of finding better varieties of maize appeared feasible on the

basis of three facts. One was that by selection, oil content in the maize kernel could be increased from about 4 to 15 percent (Dudley and Lambert, 1969). This increase was obtained by increasing the size of the germ, the part of the kernel where the oil is concentrated. The same researchers showed that it was possible to increase total protein content from about 6 to 18 percent by increasing the prolamine (zein) fraction in maize endosperm. The third finding was the wide variability in lysine content reported among varieties and selections of maize.

TABLE 35 - Summary of the nitrogen balances of children fed whole milk and opaque-2 maize (nitrogen values in mg/kg/day)

Treatment	**Nitrogen intake**	**Faecal nitrogen**	**Urinary nitrogen**	**Nitrogen absorbed**	**Nitrogen retained**	**% N intake absorbed**	**% N intake retained**
1.8 g protein/kg/day							
Milk	277	52	157	225	68	81.2	24.5
Opaque-2	295	72	140	223	83	75.6	28.1
Milk	271	42	152	229	77	84.5	28.4
1.5 g protein/kg/day							

Milk	187	31	88	156	68	83.4	36.4
Opaque-2	238	68	108	170	62	71.4	26.0
Milk	190	34	108	156	48	82.1	25.3

Source: Bressani, Alvarado and Viteri, 1969

The search for a high quality protein maize succeeded when Mertz, Bates and Nelson (1964) announced their discovery that the opaque-2 gene used as a marker in maize breeding significantly increased lysine and tryptophan in the cereal protein.

Results from initial alkaline processing studies of opaque-2 maize (cultivated in Indiana, United States, in 1965) showed that the process did not induce significant nutritional changes in the dough or in the tortillas, as concluded from chemical data and biological trials with rats.

The protein quality of alkali-processed opaque-2 maize was evaluated in children using the nitrogen balance index (the relationship between nitrogen absorption and retention). Six healthy children were used in two studies. The average nitrogen balances, at protein intake levels of 1.8 and 1.5 g per kg body weight per day, are presented in Table 35 (Bressani, Alvarado and Viteri, 1969). As can be observed, there were no significant differences in nitrogen retention among the children fed the diets based on milk and on alkali-processed opaque-2 maize when the level of protein intake was 1.8 g per kg per day. The data demonstrate differences in nitrogen absorption.

The apparent protein digestibility for processed opaque-2 maize averaged 73.5 percent in these studies. Based on faecal metabolic nitrogen determined in the children, true protein digestibility was 83.8 percent. From these results, it was concluded that the quantities of opaque-2 maize ingested by the children were 16.3 to 16.7 g and 12.9 to 14.5 g per kg body weight to take in 1.8 and 1.5 g protein per kg per day, respectively. These figures are equivalent to a total maize intake of 140 to 227 g per day, amounts similar to those commonly ingested by children in Guatemala.

With the data obtained in this study and data on urinary endogenous nitrogen, the relationship between nitrogen absorption and retention from milk and from opaque-2 maize was calculated. This nitrogen balance index constitutes a good measure for the biological value of proteins. The index was 0.80 for milk and 0.72 for opaque-2 maize, establishing then that the protein value of opaque-2 maize is equivalent to 90 percent of the biological value of milk. When the figure for true digestibility was used, the biological value of opaque-2 maize protein was calculated to be 87.1 percent. The figures also indicated that 90 mg of nitrogen must be absorbed from opaque-2 maize to obtain a nitrogen equilibrium.

For comparative purposes the same type of analysis was carried out for common maize in children (Scrimshaw et al., 1958; Bressani et al., 1958, 1963). Data on the nitrogen balance index were obtained from various studies in which children were fed with maize proteins as the only protein source in their diet. The biological value calculated was 32 percent. These data demonstrated again the low quality of common maize protein.

The difference between the nutritive value of opaque-2 maize protein and that of common maize is clearly shown in Figure 2, obtained from data in the studies described above. This figure shows the nitrogen retention in groups of children fed exclusively with opaque-2 and in others fed with common maize, in both cases at different protein intake levels. The supplementation effect of lysine and tryptophan on common maize is also shown. Even at intakes of 400 or 500 g of common maize, nitrogen retention is quite low, and this decreases to lower levels when the intake is reduced to200 or 300 g per day. With opaque-2, on the contrary, intakes of 140 or 230 g per child per day induced positive retentions that exceeded even those obtained with common maize supplemented with lysine and tryptophan. This suggests that it may be necessary to supplement common maize with other amino acids to make it comparable in protein value to opaque-2 maize.

FIGURE 2 - Nitrogen retention of children fed milk, common maize (alone and supplemented) and opaque-2 maize

The difference between opaque-2, common maize and the latter supplemented with lysine and tryptophan can be attributed to the better essential amino acid pattern found in opaque-2 maize, since the digestibility of the three is essentially the same. QPM maize also has a lower leucine content, implicated in the low nutritional value of maize.

The information presented clearly indicates the superiority of opaque-2 maize protein to that of common maize, a fact that is of great importance for populations consuming large quantities of maize as part of their habitual diet.

In a study by Luna-Jaspe, Parra and Serrano (1971) the nitrogen retention of common maize, Colombian opaque-2 maize (ICA H-208) and milk was compared in three children aged 24 to 29 months and weighing 5.9 to 10.1 kg. The protein and calorie intakes were approximately 1 g and 100 calories per kg body weight daily. Nitrogen retention was negative when the children received the opaque-2 maize. Common maize, however, gave an even lower or more negative figure. When milk was given, one child showed a negative balance and the other two a positive one, with the average balance on the positive side.

The authors indicated that the apparent protein digestibility of common maize was 61.5 percent, opaque-2 maize 57.9 percent and milk 66.4 percent. They also concluded that opaque-2 maize is of a higher nutritional value than common maize. They pointed out, however, that its use for young children with a rapid growth rate should be carefully controlled, and they could not recommend it as the main source of daily protein intake.

The results of these investigators are in agreement with those reported by other workers (Bressani, Alvarado and Viteri, 1969). The latter found that with 90 mg N absorbed per kg body weight per day, nitrogen equilibrium was obtained. The investigators in Colombia found that 90 mg absorbed nitrogen yielded a relatively low negative retention, while 100 mg absorbed nitrogen yielded nitrogen equilibrium. The differences between the results were not significant, and they could be explained by the age of the children, who were younger in the Colombian study and had lower body weight than the subjects used in the 1969 study. A more important factor was the lower protein intake. In any case, the data suggest that a minimum daily intake of approximately 125 g of opaque-2 maize might guarantee nitrogen equilibrium. This could not

be obtained by using even twice the amount of common maize.

Similar studies were conducted by Pradilla et al. (1973) using the same variety of maize but with the opaque-2 gene (H-208 opaque). A crystalline endosperm containing the opaque-2 gene was also tested. The results are shown in Table 36, in which similar values may be observed for digestibility, biological value and nitrogen retention for the two maize selections containing the opaque-2 gene. These values were slightly lower than those for casein but significantly higher than values for common maize. In more recent studies Graham et al. (1989) evaluated QPM Nutricta, a maize variety containing the opaque-2 gene. This maize is high yielding, has a hard endosperm and contains high levels of lysine and tryptophan, although not as high as those in the original opaque-2 maize first studied. These authors used six male children aged 7.9 to 18.5 months who were recovering from malnutrition. Common maize and QPM as well as a casein diet were fed to provide 6.4 percent of the calories as protein. Total energy intake was approximately 125 kcal per kg per day, which was calculated to support weight and growth at previously established rates. The nitrogen balance results are shown in Table 37. Nitrogen absorption from QPM and common maize was 70 and 69 percent respectively, and 82 percent from casein. Nitrogen retention as a percentage of intake was 32 percent for QPM as compared with 41 percent for casein and 22 percent for common maize. These results, like others previously reported, confirm the great superiority of opaque2 maize to common maize as food for children.

TABLE 36 - Comparative nitrogen balances in children fed QPM and common maize

Protein	**Protein digestibility (%)**	**Net protein utilization (%)**	**Biological value (%)**	**Nitrogen source retention (g/day)**
Casein	98	75	77	1.81
H-208 opaque	91	89	76	1.52
H-208 crystallinea	87	65	75	1.50
H-208 common	78	36	47	0.93

[a]High lysine and tryptophan
Source: Pradilla et al., 1973

TABLE 37 - Digestibility and energy and protein use from common maize, quality protein maize and casein, measured in six infants

Graham et al. (1980) and Graham, Placko and MacLean (1980) also reported on studies of eight convalescent malnourished children, 10 to 25 months of age, who were fed opaque-2 and sugary-2 opaque-2 endosperm and the whole kernel. Protein was fed so as to provide 6.4 percent of total calories, and the diets provided 100 to 125 kcal per kg body weight per day. The results showed an apparent N retention from the endosperm meal lower than that from the whole kernel meals, and both were lower than from casein. The difference between whole

kernel and endosperm nitrogen retentions can probably be attributed to the amino acids contributed by the germ. The same researchers reported on plasma-free amino acids in the studies described above and concluded that the types of maize tested were possibly limiting in lysine tryptophan and isoleucine.

These authors also reported that for the children to match N retention from casein, presumably equal to the requirement, they would have to consume 203.9, 148 or 122.5 percent of their energy requirements as common, opaque2 or sugary-2 opaque-2 endosperm meals, which is impossible. For whole meals, they would have to consume 108.2, 90.3 or 84.2 percent of their energy as common, opaque-2 or sugary-2 opaque-2 maize.

Growth studies of children fed QPM have been conducted by various workers, among them Amorin (1972) and Valverde et al. (1981). In all reports, QPM was significantly superior to common maize and only slightly below the growth response observed when milk was fed.

Graham et al. (1989) stated: "To anyone familiar with the nutritional problems of weaned infants and small children in the developing countries of the world, and with the fact that millions of them depend on maize for most of their dietary energy, nitrogen and essential amino acids, the potential advantages of quality protein maize are enormous. To assume that these children will always be given a complementary source of nitrogen and amino acids is a cruel delusion."

Human adults

Two studies evaluating the protein quality of opaque-2 maize for human adults have been published. In the first, Clark et al. (1967) used ten university students as subjects in two experiments. The maize utilized was finely ground and included the whole grain. It contained 11 to 12 percent protein, 4.65 g lysine per 16 g N and 1.38 g tryptophan per 16 g N. values similar to those of the opaque-2 maize used in the study of children by Bressani, Alvarado and Viteri (1969). The maize was given in quantities of 300, 250, 200 and 150 g per day, which provided 5.58, 4.65, 3.72 and 2.79 g nitrogen per individual per day. The results of one experiment are shown in Table 38. All the individuals were in positive balance with an intake of 300 g of the maize and all of them were in equilibrium when they were administered 250 g. The 200 and 150 g levels resulted in a negative balance. With these data the regression equation between nitrogen balance and maize consumed was calculated. On the average, nitrogen equilibrium was obtained with an intake of 230 g.

TABLE 38 - Average daily nitrogen balance in adult human subjects fed at different intake levels of opaque-2 maize

Maize kernels	Human weight (kg)	Nitrogen[a] (g)		
		Faeces	Urine	Balance
300	64.4	1.38	4.33	0.29
250	64.6	1.23	4.63	0.07

200	64.9	1.1 7	4.93	-0.09
1 50	65.0	0.97	5.37	-0.34

[a]Total nitrogen intake: 6.00 g
Source: Clark et al.. 1967

The same authors studied the effect of lysine or tryptophan supplementation alone. Only one subject showed improved nitrogen retention. The addition of methionine did not induce any change. This indicated that the protein of opaque2 maize was not deficient in these three amino acids for adult human subjects. Similar results were reported by Clark et al. (1977) for adult human subjects fed QPM and sugary-2 opaque-2 maize.

Unfortunately no studies have been done on adult human subjects comparing opaque-2 and common maize in the same study. The protein quality of common maize has, however, been evaluated in human adults by Kies, Williams and Fox (1965). In one study ten subjects were fed degermed maize to provide nitrogen intakes of 4, 6 and 8 g per day. The results clearly indicated that when the degermed maize provided 4 and 6 g of nitrogen, the average nitrogen balance was negative. When the intake increased to 8 g of nitrogen per day, the balance became positive. The regression between nitrogen intake and nitrogen retained was calculated. From the equation it was calculated that 6.9 g of degermed maize nitrogen was necessary to give nitrogen equilibrium. The regression coefficient, multiplied by 100 and divided by the protein digestibility, gives the biological value of the protein. In the present case this value was 46.5 percent.

Based on 8.0 g protein per 100 g degermed maize, an intake of 6.9 g nitrogen is equivalent to 539 g maize. This figure is close to levels of maize consumed by adults in Mexico, Guatemala and El Salvador.

In the study described above lysine and tryptophan added alone did not produce changes in average nitrogen retention. When both amino acids were added, however, nitrogen retention increased - not necessarily because of the higher amount of nitrogen being administered with the addition of these two amino acids. This possibility may be discarded in view of the response obtained when non-specific nitrogen was added. These data demonstrate that the common maize protein is deficient in lysine and tryptophan for adult humans, as it is for children (see above in this chapter).

The results of these studies of amino acid intake from QPM and common maize (Clark et al., 1967; Kies, Williams and Fox, 1965) are compared in Table 39. As shown earlier in this chapter, twice as much common maize is necessary to obtain nitrogen equilibrium in adults. This is equivalent to a protein intake of approximately 1.6 times more from common maize than from opaque-2. EAA intake follows the same trend as total nitrogen intake.

Using a biological value of 82 percent for opaque-2, of the 28 g ingested about 23 g are retained, which is the approximate amount (21 g) retained from common maize, which has a biological value of 46.5 percent. These data indicate the great losses of nitrogen occurring with common maize. With the exception of lysine and tryptophan, common maize provides a greater quantify of essential amino acids. They are, however, a load the body has to discard, a load

that is greater in the cases of leucine, tyrosine and valine. The physiological cost of metabolizing these unnecessary amino acids is unknown, but it should be estimated.

TABLE 39 - Protein and amino acid Intake of opaque-2 and common maize needed to obtain nitrogen balance (g/day)

	Opaque-2	**Common**
Maize	250	547
Proteina	27.9	43.8
Isoleucine	1.01	2.00
Leucine	2.70	5.60
Lysine	1.34	1.25
Methionine	0.60	0.80
Cystine	0.55	0.56
Phenylalanine	1.33	1.96
Tyrosine	1.14	1.64
Threonine	1.10	1.72
Tryptophan	0.39	0.26

Valine	1.54	2.20
Total amino acids	11.70	18.99

[a] Protein digestibility of opaque-2 maize, 76.5%; biological value of common maize protein, 46.5%
Sources: Clark et al.. 1967: Kies, Williams and Fox, 1965

Furthermore, the amino acid intake pattern is unbalanced, which may be an additional reason for the poor biological value of the common maize protein. Another method of analysing intake of individual amino acids is to express it as a percentage of the total amino acid intake, a calculation which magnifies the deficiency in lysine and tryptophan in common maize and also indicates the excess of other amino acids. This information, in reference to adults as well as children, demonstrates once more the excellent quality of opaque-2 maize protein and the poor quality of common maize protein.

Biological value of protein of common maize and QPM

No direct comparative studies are available on the digestibility and biological value of common and opaque-2 maize proteins, so to make a comparison between them the studies of common maize by Truswell and Brock (1961, 1962) and of opaque-2 maize by Young et al. (1971) will be used. In one of the studies conducted by Truswell and Brock (1962), the experimental subjects received 90 percent of their nitrogen intake from maize and 10 percent from other foods. A

positive nitrogen balance was obtained when the nitrogen intake was more than 7 g per day, although great variability was found as in other studies. The authors calculated the biological value, which averaged 45 percent at a high intake level and 57 percent at a lower level of nitrogen intake. The difference was to be expected, since the biological value of a protein depends on the level of protein intake. Since all the experimental subjects showed a positive nitrogen balance when the intake was high, the authors concluded that the biological value of maize is close to the 57 percent figure. Similar results were found by Young et al. (1971). Truswell and Brock (1961) also found that in adult human subjects fed maize, the addition of lysine tryptophan and isoleucine increased nitrogen balance from 0.475 to 0.953 g N per day in one study and from 0.538 to 1.035 g N per day in a second study. The flour fed was degermed maize flour, in which deficiencies are more apparent.

The biological value of opaque-2 maize protein was studied by Young et al. (1971). Egg protein was used as reference, fed at intakes of 2.64 to 3.95 g nitrogen per day. The authors calculated true protein digestibility and biological value from the faecal metabolic nitrogen and urinary endogenous nitrogen. The protein digestibility of opaque-2 maize protein varied from 67 to 106 percent, with an average for the eight individuals in the study of 92 percent, while the variability for egg protein was from 78 to 103 percept with an average of 96 percent. The average biological value for opaque-2 maize was 80 percent, and for egg the average was 96 percent.

Practical significance of protein evaluation of opaque-2 maize

The evidence presented from studies in both children and adults clearly indicates the superiority of opaque-2 maize over common maize. In spite of this, of the maize-consuming countries only Colombia and Guatemala have made efforts during the last few years to introduce this superior maize into agricultural production systems. The reasons are not clear, since agronomic studies conducted in a number of locations have shown that there are no differences between QPM and common maize in cultural practices, yield per unit of land and physical quality of grain. Furthermore, the plants look alike; QPM kernels are crystalline and grain yields are comparable to those of common maize. These factors are perhaps more important to growers than the nutritional advantages offered by QPM.

Energy content is alike in both types of maize, but the protein content of QPM is higher and is better utilized because of its better essential amino acid balance. The protein value of opaque-2 maize, however, can be analysed from other points as well. The information in Table 39 could be used to decide whether to introduce the opaque-2 maize varieties in grain-consuming countries.

It has been established that the intake of both types of maize as well as their nitrogen content (protein) are alike, but their digestibility percentages are very different: of 48 g of nitrogen intake from common maize, only 39.4 g are absorbed and 8.6 g are lost in the faeces. In the opaque-2 maize, of the 48 g of nitrogen intake, 44.2 g are absorbed and 3.8 g are lost in faeces.

The factor that should be considered, then, is the biological value, which is defined as the amount of absorbed nitrogen needed to provide the necessary amino acids for the different

metabolic functions. The biological value of common maize is 45 percent; from the 39.4 g absorbed, 17.7 g are retained and 21.7 g are excreted. In opaque-2 maize the biological value of the protein is 80 percent; of the 44.2 g of absorbed nitrogen, 35.4 g are retained and 8.8 g are excreted. The total amount of nitrogen lost when common maize is consumed equals 30.3 g, while only 12.6 g are lost when the same amount of opaque-2 maize protein is consumed. In other words, only 37 percent of the common maize intake is utilized, compared to 74 percent from opaque-2 maize. The production and consumption of QPM in maize-eating countries would therefore have a significant beneficial effect on the nutritional state of populations, with important economic implications from the better use of what is produced and consumed.

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Chapter 7 - Approaches to improving the nutritive value of maize

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Because of the great importance of maize as a basic staple food for large population groups, particularly in developing countries, and its low nutritional value, mainly with respect to

protein, many efforts have been made to improve the biological utilization of the nutrients it contains. Three approaches have been tried: genetic manipulation, processing and fortification. Abundant data show great variability in the chemical composition of maize. Although environment and cultural practices may be partly responsible, the variability of various chemical compounds is of genetic origin; thus composition can be changed through appropriate manipulation. Efforts in this direction have concentrated on carbohydrate composition and on quantity and quality of oil and protein. Some efforts have also been made to manipulate other chemical compounds such as nicotinic acid and carotenoids. Processing is not widely recognized as a means of improving nutritive value; however, examples are presented to show its effects and potential. Finally, there have been many efforts to fortify maize, with outstanding results, but unfortunately fortification has not been implemented to a large extent. This approach, however, may become important in the future as more people consume industrially processed foods, which can be more easily and efficiently fortified.

Genetic approaches

Carbohydrates

The component with the greatest concentration in the maize kernel is starch. Since the plant accumulates starch in the endosperm, which is subject to genetic influence, starch can become a good source of energy. The quantity and quality of the carbohydrate fraction can be modified by breeding as described in recent reviews by Boyer and Shannon (1983) and Shannon and

Garwood (1984). The waxy gene (Wx) in waxy maize has been shown to control amylopectin starch in the endosperm up to 100 percent with very low amounts of amylose (Creech, 1965). Other genes and gene combinations have been shown to be responsible for the composition of the starch in the endosperm. The amylose-extender gene (Ae) increases the amylose fraction of the starch from 27 to 50 percent (Vineyard et al., 1958). Other genes cause an increase in reducing sugars and sucrose. Sugary (Su) genes produce relatively high amounts of water-soluble polysaccharides and amylose. Maize kernels containing this gene are sweet and are important for canning. Their starch content and quality also have nutritional implications, since some starch granules have low digestibility while others have high digestibility, as demonstrated by Sandstead, Hites and Schroeder (1968). These researchers suggested that maize varieties with waxy or sugary genes could be of better nutritional value for monogastric animals because of the greater digestibility of the type of starch they produce.

Protein quantity

Classical studies at the University of Illinois demonstrated the feasibility of changing the protein content of the maize kernel by selection. In these studies it was shown that protein content could be increased from 10.9 to 26.6 percent in the high-protein (HP) strain after 65 generations of selection. The low-protein strain contained about 5.2 percent. Dudley, Lambert end Alexander (1974) and Dudley, Lambert and de la Roche (1977) demonstrated that the protein content of standard inbred lines could be increased by crossing with the HP strain from Illinois and then backcrossing to the inbred line. Woodworth and Jugenheimer (1948) concluded that total protein content could be increased by selection in an open pollinated

variety or by crossing standard inbred lines with an HP strain followed by backcrossing and selection in segregating populations.

The full expression of the protein genes in maize can be attained with appropriate levels of nitrogen fertilizers. Tsai, Huber and Warren (1978, 1980) and Tsai et al. (1983) showed that nitrogen fertilization of maize increased total protein because of an increase in prolamine content. Studies conducted by others showed, however, that the protein quality of the HP strains was lower than that of common maize since the increase in protein was due to an increase in the prolamine fraction. Eggert, Brinegar and Anderson (1953), from studies of pigs, showed that HP maize had lower biological value than common maize, which they attributed to the higher prolamine content in HP than in normal protein maize. The value of an HP maize kernel will depend on how it behaves agronomically and economically compared with maize with about 10 percent protein. The data available show that these types of maize not only require more soil nitrogen but also yield less than normal protein maize.

Protein quality

The low protein quality of maize stems mainly from the deficiency in the protein of the essential amino acids lysine and tryptophan. Still, variability in both amino acids has been shown (Bressani, Arroyave and Scrimshaw, 1953; Bressani et al., 1960). As early as 1949, Frey, Brimhall and Sprague were able to show the genetic variability in tryptophan content in a cross between the Illinois HP and LP strains as well as in hybrids. Biological testing in which maize strains furnished the same level of protein in the diet also showed variability. All of these data

suggest the feasibility of improving the quality of maize varieties. Mertz, Bates and Nelson (1964) found that the opaque-2 gene significantly increased the lysine and tryptophan content in maize endosperm. This gene also reduced the leucine level, giving a better leucine-to-isoleucine ratio. In 1965, Nelson, Mertz and Bates showed that the floury-2 gene when homozygous could also increase the lysine and tryptophan levels in maize. Research conducted at the Centro Internacional de Mejoramiento de Maz y Trigo (CIMMYT) eventually yielded maize lines of QPM, which agronomically behave like common maize. As shown elsewhere in this book, the protein quality of these materials is significantly higher than that of common maize as shown by tests in humans.

Although such types of maize are available, it has been difficult to grow them commercially, even though the benefits to be derived from them by large maizeconsuming populations would be high.

Oil

Genetic studies have also revealed that oil content in maize is subject to genetic influence, with diversity often found, although environment and agronomic practices can influence fatty acid composition (Jellum and Marion, 1966; Leibovits and Ruckenstein, 1983). As with protein content, mass selection over 65 years increased oil content from 4.7 to 16.5 percent. This increase was obtained through increases in the size of the germ. The problem with high-oil varieties is a low yield, although it has been reported that varieties with 7 to 8 percent oil yield as well as varieties with lower oil content. Besides total oil content, some studies have shown

that the fatty acid content may also be subject to genetic control, as seen by changes in linoleic acid content in maize oil. Poneleit and Alexander (1965) suggested a single-gene or single-gene-plusmodifier effect. A multi-gene system of inheritance has been proposed by other investigators. QPM oil fatty acid composition was found to be similar to that reported for normal maize.

Other nutrients

Because of the association of maize consumption and pellagra and the low availability of nicotinic acid in maize, efforts have been made to increase niacin in maize by genetic means. Variability in 22 varieties planted in one location ranged from 1.25 to 2.6 mg per 100 g (Aguirre, Bressani and Scrimshaw, 1953). The problem with niacin in maize and in other cereal grains is that it is unavailable to the animal organism.

The other nutrient that has received some attention is carotene, a precursor of vitamin A. Results from some investigators have shown yellow maize to vary in vitamin A activity from 1.52 to 2.58 g per gram. Cryptoxanthein contributed 3X.3 to 57.3 percent of the total activity and beta-carotene the difference (Squibb, Bressani and Scrimshaw, 1957). Other researchers have indicated that provitamin A activity is under genetic control in the maize kernel.

Processing

Often the processing of foodstuffs stabilizes nutrients in the food, but losses may take place

when optimum conditions are exceeded. There are cases, however, in which processing induces beneficial changes in the food; a classic case is the elimination of antiphysiological factors in beans.

Lime-cooking

Lime-cooking of maize as described in Chapter 4 causes some losses in nutrient content, but it also induces some important nutritional changes. Its effects on calcium, amino acids and niacin content have already been described in Chapter 4.

Other processes

Besides the lime cooking process, other processes have been reported to improve the quality of maize. One such process is natural fermentation of cooked maize, which results in higher B-vitamin concentration and protein quality (Wang and Fields, 1978). Pozol, a food made from lime-treated maize allowed to ferment naturally, has been shown to be of higher quality than raw maize or tortillas. Germination of the grain has also been reported to improve the nutritional value of maize by increasing lysine and to some extent tryptophan (Tsai, Dalby and Jones, 1975; Martinez, Gmez-Brenes and Bressani, 1980) and decreasing zein content. A similar result was found with QPM.

Fortification

A third approach often used to improve the nutritive value of foods, mainly cereal grains, is fortification. Because of the great nutritional limitations in maize, many efforts have been made to improve its quality, and particularly that of its protein, through addition of amino acids or protein sources rich in the limiting amino acids.

Supplementation with amino acids

Raw maize proteins have been shown to be of a low nutritive value because of deficiencies in the essential amino acids lysine and tryptophan. Many studies conducted with animals have demonstrated that the addition of both amino acids improves the quality of the protein. Some workers have even found that besides lysine and tryptophan, isoleucine is also deficient, possibly because of an excess of leucine in maize proteins (Rosenberg, Rohdenburg and Eckert, 1960). Similar data have been obtained from studies with animals when lime-treated maize was supplemented with lysine and tryptophan (Bressani, Elas and graham, 1968). These results have been confirmed in nitrogen balance studies conducted with children as shown in Chapter 6. (Selected results are shown in Table 32.) The finding that the addition of lysine and tryptophan at the lower levels of protein intake gave a nitrogen retention significantly higher than at the higher level of protein intake has often been overlooked, and the importance of protein quality has been overshadowed by that of energy intake.

Supplementation with protein sources

The results from animal and human studies in which limiting amino acids have been added to

lime-treated maize have served as the basis for evaluating the ability of different types of protein supplements to improve its protein quality. Studies on protein supplementation of lime-treated maize flour have been published by many researchers using different food sources including milk, sorghum, cottonseed flour, fish flour, torula yeast and casein. Table 40 summarizes the results of adding small recommended amounts of various protein sources. The quality increase is at least 200 percent of the protein quality value of maize. In tests with young dogs, the nitrogen balances when maize was supplemented with 5 percent skim milk, 3 percent torula yeast and 4 percent fish flour were significantly higher than those measured when maize was given alone. Most of the supplements that have been tested have several characteristics in common. They all have a relatively high protein content and are good sources of lysine, with the exception of cottonseed protein and sesame oil meal. The latter is a good source of methionine. With the exception of casein and/or milk and fish protein concentrate, they are of vegetable origin.

The improvement in quality of protein in tortilla flour is in most cases a synergistic response to lysine and tryptophan enhancement and to a higher level of protein, both provided by the supplement. Since soybean protein in different forms is the supplement to tortilla flour most often tested by different investigators and because it is almost the only one also tested in children, with results comparable to those in studies with animals, its importance and effects are reviewed in this section. Figure 3 depicts the PER for combinations of common maize and opaque-2 maize with soybean flour in different ratios.

TABLE 40 - Recommended levels of protein concentrates to improve the protein quality of lime-

treated maize

Protein source	**Recommended level (%)**	**PER**
None	-	1.00
Casein	4.0	2.24
Fish protein concentrate	2.5	2.44
Soy protein isolate	5.0	2.30
Soybean flour	8.0	2.25
Torula yeast	2.5	1.97
Egg protein	3.0	2.24
Meat flour	4.0	2.34
Cottonseed flour	8.0	1.83

Source: Bressani and Marenco, 1963

Studies show that maximum PER is achieved upon addition of 4 to 6 g percent soybean protein, whether from whole soy, soy flour (50 percent), soy protein concentrate or soy protein isolate (Bressani, Elas and graham, 1978; Bressani et al., 1981). For reasons of availability, cost and

practical applications in developing countries, the results with whole soybean are discussed here. The 4 to 6 g percent level of supplementary protein can be provided by either 15 percent whole soybean or 8 percent soybean flour, which have resulted in comparable protein quality improvement. The advantage of using 15 percent whole soybeans is that supplementation can be carried out in the home with soybeans produced by the family; soybeans are very economical, and besides providing higher protein quantity and quality, they give some additional energy from the oil they contain.

FIGURE 3 - Protein efficiency ratio of combinations of common or opaque-2 maize and soybean flour

Whether the supplementation process is at home or at the industrial level, it has been demonstrated that nutritional quality improves, with the process being capable of destroying all trypsin inhibitor and urease activity in the soybean (Del Valle and Prez-Villasenor, 1974; Del Valle, Montemayor and Bourges, 1976; Bressani, Murillo and Elas, 1974; Bressani et al., 1979). Tortillas made with 15 percent soybeans have been shown to be acceptable to rural consumers and have many of the properties of tortillas without soybeans, except that they are more flexible and softer. Many attempts have been made to transfer this technology at both the industrial and the home level, but this has not been a sustainable approach for various reasons such as the cost of soybeans and (possibly) changes in organoleptic characteristics.

With the relative increase in industrially produced lime-treated maize flour, fortification with protein sources and other nutrients is efficiently accomplished in a dry-mixing operation, as is

done with other cereal flours. The problem is not so much the technology, but the lack of legislation, which if implemented could improve the quality of maize tortillas as is done with wheat flour in many countries throughout the world. The studies described above led to the development of a dry supplement to tortilla flour which contained 97.5 g percent of soybean flour (50 percent protein), 1.5 percent L-lysine HCl, 26.8 mg percent thiamine, l 6.2 mg percent riboflavin, l 9.3 mg percent niacin, 0.60 percent ferric orthophosphate, 0.031 percent vitamin A 250 and 0.133 percent corn starch. The quantity recommended for addition to tortilla flour was 8 percent by weight. Nitrogen balance studies in children fed this food are shown in Table 41 (Viteri, Martnez and Bressani, 1972). Maize nitrogen balance was only 42 percent of the nitrogen balance from milk. When maize with the supplement was fed, nitrogen balance was 84 percent of that from milk. All studies, in animals and children, show the same response, i.e. a significant improvement in the protein quality of maize. The effectiveness of this supplement was partially tested by Urrutia et al. (1976) and preliminary data suggested some improvement in the nutritional status of young children. Other maize-based foods such as arepas and fermented maize foods have also been shown to be improved by supplementation with soybean flour.

Supplementation with green vegetables

One form in which masa is eaten in some countries is the tamalifo. This is made by wrapping the dough in maize husks and placing it over steam.

TABLE 41 - Nitrogen balance in preschool children ted milk, normal maize and soybean/lysine

supplemented maize

Tomalitos are often eaten instead of tortillas and have the advantage of remaining soft for a longer period. There are various ways to prepare them, some of which include the young leaves of native vegetables such as crotalaria and amaranthus. Chemical and nutritional studies have demonstrated that about a 5 percent contribution of these leaves improves the protein quality of the dough (Bressani, 1983). The reason is that they have relatively high levels of protein rich in lysine and tryptophan. They also provide minerals and vitamins, particularly provitamin A. Leaf protein concentrates have also been shown to improve the protein quality of cereal grains (Maciejewicz-Rys and Hanczakowski, 1989).

Supplementation with other grains

Sorghum is another grain that has been processed by lime-cooking in Mexico and Central America, particularly in areas where maize does not grow well. Sorghum tortillas, however, are not of the same organoleptic or nutritional quality as maize tortillas. Many successful efforts have been made to use blends of both cereal grains, among others by Vivas, Waniska and Rooney (1987) and Serna-Saldivar et al. (1987, 1988a, 1988b). Other approaches include the use of blends of common maize, since germination has been reported to increase lysine Mixtures of tortilla flour and rice and of tortilla flour and wheat flour have also been studied. The rice/maize products have higher nutritive value than the wheat/maize tortillas, as shown in Figure 4. These results show the superiority of rice over whole maize flour and of the latter over wheat flour. More recently, blends of amaranth grain with lime-cooked maize flour have

been shown to have an improved protein quality because of the much higher lysine and tryptophan content of amaranth as compared with maize. The product has been reported to be of an acceptable organoleptic quality. Other products added include potato, rice and pinto beans, providing foods with acceptable sensory attributes.

High-quality protein foods

The nutritional value of maize, particularly maize protein, can also be improved by protein complementation. In this approach, the objective is to combine two or more protein sources with maize to maximize the quality of the product by achieving a good balance of the essential amino acids. Using this approach a number of high-quality foods have been developed. (Similar results can be obtained with other cereal grains.)

FIGURE 4 - Protein value of mixtures of two cereals

An example, complementation of both common and QPM maize with common black beans, is shown in Figure 5. Here the isonitrogenous replacement of the bean nitrogen by QPM nitrogen resulted in a constant PER increase up to a level corresponding to 50 percent of the protein from each component, with no further change as the nitrogen of the mixture was provided increasingly from the QPM. A similar result is observed with mixtures of the beans and common maize, except that as more of the dietary nitrogen is provided by maize, the protein quality drops. Further studies indicated that on the left side of the peak response the limiting amino acid was methionine, while on the right side it was lisyne. The peak was obtained

through the contribution of lysine from beans to maize and the contribution of methionine from maize to beans. This response has served as the basis for formulating high-quality protein food mixtures containing 70 percent maize and 30 percent common beans.

A similar type of response is observed with mixtures of normal and QPM maize and soybean flour. The peak mixture is equivalent to 77 percent maize and 23 percent soybean flour on a weight basis. When whole soybean flour is used, however, the mixture by weight is 70 percent maize and 30 percent whole soyflour. This product is called maisoy and is commercially produced in Bolivia. It is used to improve lime-treated maize for tortillas or as a wheat flour extender for bakery products. Other oil seed flours have been used in a similar fashion, for example cottonseed flour (CSF) and maize. In this case there is no synergistic effect of complementation. Optimum quality mixtures can be obtained when CSF provides about 78 percent of the protein and maize 22 percent. This distribution by weight is equal to 40 percent CSF and 60 percent maize flour, which is the ratio for incaparina produced in Guatemala since 1960.

Many other mixtures of maize and other foods have been developed. The United States Department of Agriculture has been involved since 1957 in product and process development, and products such as instant and sweetened corn-soya milk and corn-soya bread are well known throughout the developing world. Many other mixtures have been developed with common maize or QPM and other protein sources, giving products of high nutritional value and acceptability.

FIGURE 5 - Protein efficiency ratio of combinations of common or opaque-2 maize and black beans

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Chapter 8 - Improvement of maize diets

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In nutritive value maize is quite similar to other cereal grains. In fact, it is somewhat superior to wheat flour and only to a small extent below rice. These are the three cereal grains most consumed by people throughout the world. The problem with maize lies in the diet of which it is a component, a diet mostly deficient in the kind of supplementary foods necessary to upgrade the nutrients ingested in relatively large amounts of maize. Maize-consuming populations would be nutritionally better off if the maize consumed had the lysine and tryptophan genes of QPM or if it were consumed with a sufficient amount of protein foods such as legumes, milk, soybeans and amaranth seeds and leaves. This, however, will not occur in the near future, and therefore other measures should be taken. In this section, a number of possibilities, the results of studies to improve the nutritional quality of maize-based diets, are

presented.

Maize/legume consumption

Throughout the world, particularly in developing countries, the diet of populations is based on the consumption of a cereal grain, usually maize, sorghum or rice, and a food legume, either common beans or any of the others known. Results of many studies have shown that these two types of basic food nutritionally complement each other. A complementary effect was observed, for example, when animals were fed diets in which the protein was derived from maize and common beans in various proportions from 100:0 to 0:100. When each component provided close to 50 percent of the protein in the diet a high quality was obtained, higher than the individual qualities of the components alone. The reason for this is the essential amino acid make-up of each component. Maize protein is deficient in lysine and tryptophan but has fair amounts of sulphur-containing amino acids (methionine and cystine). On the other hand, the protein of food legumes is a relatively rich source of lysine and tryptophan but is low in sulphur amino acids (Bressani and Elas, 1974). From these studies it was concluded that the protein of beans or food legumes complements the protein of maize best in the proportion of 30 parts beans to 70 parts maize.

This complementarily is also found in maize with cowpeas, with mung beans, with soybeans and with other food legumes. The response is the same even if the protein level in the diet is not fixed as in the example above but varies depending on the protein content of each

component. Beneficial results have been obtained with oil added to the diet in amounts from zero to 10 percent. It is also of significance that food intake was highest at the maximum level of complementation. That is, a higher energy intake was also observed.

The great importance of protein quality has been missed by those who claim that energy is more limiting in diets than protein. The complementary effect described above has also been shown to occur in humans. Nitrogen balance was tested in studies of children fed lime-treated maize and beans in two fixed ratios and ad libitum, as selected by the children (Figure 6). The nitrogen balance at the fixed ratio in Phase 1 (76:24) was lower than when they were fed a ratio of 60:40 maize to beans (Phase 2). Nitrogen balance improved when the children were allowed to select, and the selection was close to seven parts maize and three parts beans by weight. Equally important is the fact that total food intake also increased. The usual intake of maize and beans established by dietary surveys in the 1960s varied between 11:1 and 18:1; therefore the supplementation of beans was relatively small. More recent data (Garcia and Urrutia, 1978) for three-year-old children gave an 8:4 maize-to-bean ratio, and the ratio was even poorer for children 6 to 11 months of age.

Combinations of maize and bean protein, although of relatively high protein value in tests in animals, are not adequate for the treatment of children with protein malnutrition. Furthermore, the increase found by Arroyave et al. (1961) in plasma amino acid levels following a test meal of milk was much higher after a period of treatment with a 1: I maize-bean combination than the response observed when milk protein was given after treatment with either milk or a vegetable mixture made of maize, cottonseed flour, torula yeast and minerals

(Bressani and Scrimshaw, 1961). These results confirmed the inadequacy of the maize and bean diet. Likewise, nitrogen balance results in children fed maize and bean mixtures as compared with milk and other vegetable proteins have been relatively low. Gmez et al. (1957) reported on nitrogen balance experiments made on eight children, one to five years old, with chronic severe malnutrition, who were kept on a diet of maize meal and beans during the experiments. Both nitrogen absorption and retention were extremely variable from child to child; four children had a positive nitrogen balance, and four negative. The addition of tryptophan and lysine to the maize-bean diet greatly improved nitrogen absorption and nitrogen retention in four cases. In these studies, no indication was given on the amounts of maize and beans mixed, and protein intake varied from 1.53 to 8.50 g per day. Frenk (1961) also found poor performance in children fed maize and beans. A significant improvement was obtained upon supplementation with fish meal.

FIGURE 5 - Nitrogen retention of children receiving maize/bean diets

In common with other investigators, Hansen (1961) found that milk initiated the cure of kwashiorkor without difficulty; a two-component mixture of 66 percent maize meal and 3 3 percent cowpea meal, however, did not initiate a cure in the three cases treated with it. A three-component mixture made up of equal parts of maize meal, maize germ and cowpea (Vigna sinensis) brought about satisfactory recovery in the one case in which it was employed.

It would require 238 g of the dry three-component mixture and 267 g of the two-component mixture to supply the essential amino acids contained in 100 g of skim milk. Since the vegetable

formulas also require greater dilution, it is difficult to supply enough of them to meet protein needs.

Scrimshaw et al. (1961) considered that excessive bulk relative to protein content was a major reason for the lack of success in initiating cure of kwashiorkor with mixtures of maize and beans. Hansen et al. (1960) stated that the differences in biological value of the proteins tested were clearly reflected in nitrogen retention, which averaged 13 to 14 percent for milk, 8.8 percent for the two-component mixture and only 5.7 percent for the three component mixture. It was concluded that the two- and three-component mixtures were each adequate to prevent kwashiorkor after initial recovery from the disease but that only the three-component mixture had proteins sufficient in concentration and quality to be satisfactory for use in treatment.

It should be noted that the two-component mixture of 66 percent maize meal and 33 percent cowpea meal is not the best combination of these two sources of protein. Bressani and Scrimshaw (1961) reported that in the best mixtures of these two foods, cowpea provided 50 to 75 percent of the protein, and maize 50 to 25 percent.

In other studies by Hansen et al. (1960) and Brock (1961), the nutritive value of maize alone and of maize supplemented with lysine and tryptophan, with pea flour and fish flour and with pea flour and milk was measured by means of nitrogen balance. Nitrogen retention was increased significantly by each form of supplementation, but at protein intakes of less than 2.5 g per kg body weight per day N retention was significantly less with the lysine and tryptophan supplement or the pea-flour supplement than with a milk diet. These differences disappeared

at higher intakes of protein. The maize-pea mixture supplemented with 12 percent milk or with 10 percent fish flour resulted in nitrogen retentions comparable to those of a milk diet at all levels of protein intake. These variable results for bean and other legume seed proteins may be due to the type of legume seed used, to amino acid deficiencies or to some unknown factor. They deserve further investigation, because legume seeds have good potential for helping to solve the nutritional problems of the world.

Baptist and de Mel (1955) obtained a highly satisfactory response in 23 Ceylonese children one to six years old fed a mixed diet of three cereals and four legumes supplemented with skim milk. On the other hand, Navarrete and Bressani (1981) reported from nitrogen balance studies in adults that a bean diet produced nitrogen equilibrium at an intake of 114 mg N per kg per day; however, an 87:13 maize/bean mixture induced nitrogen equilibrium with an intake of 98 mg N per kg per day.

All these studies suggest that even though maize protein is improved in nutritive value upon addition of beans, its quality is still not fully adequate to feed infants and preschool children. This was evident when high-quality protein supplements were also tested with the maize/bean diet. Bulkiness limiting intake and nutritional quality are two factors of importance in maize/bean mixtures or diets.

Limiting nutrients in a maize/bean diet

Amino acids

It has been shown that adding 0.3 percent L-lysine HCl and 0.10 percent DLtryptophan to a diet of 90 percent maize and 10 percent beans resulted in significant increases in weight gain and protein quality. These did not increase further when methionine was also added (see Table 42). The significance of protein quality in a system based on maize and beans was observed when diets of mixtures of maize and beans plus methionine were offered. The results confirmed the limitation of this amino acid in beans, since a response was observed when more beans were included in the diet. Likewise, those diets with maize and beans and methionine also induced the subjects to consume greater amounts of food or of energy, demonstrating thus the value of protein quality in stimulating food intake (Contreras, Elas and Bressani, 1980, 1981). The results also served to demonstrate that even with the best combination-that is, a 7:3 maize-to-beans ratio-the diet is still short of an adequate quality for small children, and it is even more so when the proportion of beans is lower.

TABLE 42 - Effect on the nutritive value of a 90/10 maize/bean diet of the addition of lysine and tryptophan to maize or methionine to beans

Dietary treatment	**Ave. weight gain (g/28 days)**	**PER**
Maize Beans	69	2.11

Maize + lysine + tryptophan Beans	103	2.64
Maize Beans + methionine	66	1.93
Maize + lysine + tryptophan Beans + methionine	108	2.64

Note: Lysine 0.3% (L-lysine MCI); tryptophan 0.1%; methionine 0.3%
Source: Gmez-Brenes, Elas and Bressani, 1972

Vitamins and minerals

A diet of maize and beans in the ratio of 7:3 responds to the single addition of a complete B-vitamin and fat-soluble mixture and more so to a complete mineral supplement, but not to calories or to lysine and tryptophan. The best results from double combinations have been obtained from minerals plus amino acids, minerals plus vitamins, minerals plus calories, vitamins plus amino acids and vitamins plus calories. The addition of calories plus amino acids did not significantly improve either the weight gain of the subjects or the PER of the diet. For triple combinations an adequate intake of vitamins and minerals is needed before an effect from the amino acids can be obtained, since animals fed with amino acid enriched diets

probably develop a vitamin and mineral deficiency. Although this may be obvious, it is usually not acted on in practice.

It was observed that animals on a diet enriched with amino acids developed vitamin and mineral deficiencies, and many died. This was attributed to a depletion of these nutrients caused by the catalytic effect of the improved protein quality on the potential of the animal to respond to this stimulus.

Provision of additional calories in the diet resulted in a slight decrease in the quality of the diet. This suggests that the addition of calories lowered the protein intake of the diet, which in turn reduced its quality by enhancing essential amino acid deficiencies in the mixture of maize and beans. Similar results were found by Contreras, Elas and Bressani (1980, 1981) using young growing rats and pigs fed maize/bean mixtures in either an 87:13 or a 70:30 weight ratio. These authors confirmed the results previously reported and indicated that one of the main constraints in maize/bean diets is their bulkiness, which does not permit greater intakes. Results of some of these supplementations in rats are summarized in Table 43.

A number of studies have been carried out to learn whether an increase in the protein content of the diet from an increase in maize and bean proteins would improve animal performance. These showed that the use in the maize/ bean diet of a maize with 13 percent protein to replace one with 8.3 percent protein resulted in some increase in weight gain and in utilizable protein in spite of the fact that protein quality decreased as shown by PER and relative nitrogen value (RNV) figures. This was expected, since utilizable protein is the result of protein

quantity and quality. When the two maize samples (low and high protein content) were supplemented in this maize/bean diet with lysine and tryptophan, a greater improvement in weight gain and utilizable protein was obtained than from the diet with the high-protein maize.

TABLE 43 - Nutritive value of a 90/10 maize/bean diet supplemented with vitamins, minerals, calories and amino acids

Supplement	**Ave. weighs gain (g/28 days)**	**PER**
None (basal diet)	26 2.3	1.11 0.07
+ Vitamin mixture	49 4.0	1.55 0.06
+ Mineral mixture	65 4.3	1.94 0.06
+ Calories (5% oil)	23 1.2	0.95 0.05
+ Amino acidsa	26 2.5	1.13 0.08

[a]Lysine (0.3%): DL-tryptophan (0.10%)
Source: Bressani, 1990

Increases in weight gain and utilizable protein compared with the basal diet also resulted when

the proportion of beans in the diet was increased from 10 to 20 percent, but these were lower when compared with the respective amino acid supplemented diets. These data were interpreted to mean that diets of maize and beans in a 90:10 ratio are limiting first in protein quality and to a lower extent in protein quantity (Gmez-Brenes, Elas and Bressani, 1972; Elas and Bressani, 1971; Bressani, Elas and de Espaa, 1981). This is in agreement with the conclusions of Arroyave (1974), who indicated that for one- to two-yearold children to obtain an adequate nitrogen retention from maize and beans, similar to that from 1.27 g milk protein per kg body weight per day, 1.7 g protein per kg per day were required. These results show that the protein of common maize in the diet is improved by the addition of lysine and tryptophan.

Improvement of the maize/legume diet

Animal supplements

Various studies conducted with animals demonstrated that methionine is the limiting amino acid in diets containing more than 30 parts of beans, while those diets containing more than 70 parts of maize are limiting in lysine The diet giving the highest quality is deficient in both amino acids (Bressani, Valiente and Tejada, 1962). At the same time such diets are low in total protein content. Therefore, in order to improve the quality of maize/bean mixtures, it is necessary to add protein sources rich in both amino acids. Studies with animals fed diets based on maize, beans and various animal protein sources such as chicken or beef indicated that a 20 to 30 percent addition of animal protein would result in significant increases in nutritive value

(Bressani, 1987). In experiments by other researchers, animals were fed ad libitum with 1, 2,3 and 4 g of milk as a daily supplement to a diet of maize and beans. The results demonstrated that approximately I to 2 g milk per day added to a basal diet intake of 15 g per day was enough to increase the nutritional quality of the diet, evaluated from the protein quality point of view. In these studies 12 percent milk was found to be the minimum necessary to induce a relatively high improvement in the quality of the maize/bean diet. Furthermore, the effect of the supplement was more consistent when it was given on a daily basis. With growing dogs as experimental animals, Murillo, Cabezas and Bressani (1974) found 20 percent milk as the minimum complement to give the highest nitrogen balance to a maize/bean diet. This was not obtained when the basal maize/ bean diet was supplemented with lysine methionine and tryptophan as found in milk proteins. Torn and Viteri (1981) and Torn et al. (1984) showed in metabolic studies with children that a diet of maize and beans in a weight ratio of 85: 15 with 18 percent animal protein (milk) would induce good and consistent biological responses. These authors concluded from the diet used in the study that protein intakes were adequate when energy intakes corresponded to the estimates of energy requirements.

QPM

Replacement of common maize by QPM is another alternative that could improve the quality of maize/bean diets. The results obtained by feeding animals with mixtures of QPM and beans showed that, as with common maize, optimum complementation takes place at approximately a 50:50 diet protein ratio, equivalent to 70:30 maize/beans by weight (Bressani and Elas, 1969).

However, there are two differences that should be noted. One is that both weight gain of the animals and protein quality were higher with the QPM/bean blends than with the common maize/bean mixtures. The second point, possibly even more important, is that the weight gain and protein quality of mixtures with more than 70 parts of maize were no different from the values found for the best mixture, a 70:30 diet. Likewise, diet intake in a 28-day experimental period increased from 224 g per animal to 388 g at the maximum point and remained constant in all other diets with higher levels of QPM in the mixture.

In other series of studies the protein quality of QPM as a component of a maize/bean diet of 82.8 percent maize and 10.5 percent cooked beans was evaluated in young and adult dogs fed at two levels of protein (Bressani & Elas, 1972; Murillo, Cabezas and Bressani, 1974). The QPM/bean diet was compared with similar diets of common maize and beans and common maize supplemented with lysine and tryptophan and beans. Nitrogen balance data showed that nitrogen retention levels for young or adult dogs fed QPM/bean diets were as high as or higher than those in which common maize in the diet was supplemented with lysine and tryptophan, and the levels were significantly higher with both diets than with maize and beans alone.

These studies, as well as studies conducted with growing pigs, indicated also that maize/bean diets are bulky, which limits the amount that can be ingested to meet nutritional needs fully (Contreras, Elas, and Bressani, 1980, 1981).

High-quality food mixtures

In many developing countries and for quite a long time, many efforts have been made to develop high-quality food mixtures that would supply the nutrients, particularly protein, provided by animal food products. Most of these foods have a relatively high protein content with a good essential amino acid pattern which can to some extent correct deficiencies of amino acids and of other nutrients in maize/bean diets, if consumed in the appropriate amounts. Studies have shown this supplementary effect to be present. Young growing animals were fed a basal diet of about 85 percent lime-treated maize and 15 percent cooked black beans. This diet was properly supplemented with minerals, vitamins and energy. Groups of animals were fed daily I, 2, 3 and 4 g of a high protein food based on maize, soybeans and skim milk. The results demonstrated that these levels, particularly the highest, effectively supplemented the basal diet, as judged by weight gain, protein utilization and biochemical parameters (de Souza, Elas and Bressani, 1970).

These diets with animal foods and with high-quality foods are effective because they are able to provide nutrients still deficient in diets based on maize and beans. Therefore, any food of animal origin and some foods of vegetable origin, such as soybeans and green leafy vegetables, would improve the quality of such diets.

Green vegetables

An examination of a maize/bean diet shows that besides protein quality, other nutrients are deficient. The effect of adding vitamins and/or minerals to such a diet has already been described. Other studies were conducted in which the basal maize/bean diet was

supplemented with small amounts of leafy vegetables such as amaranth, spinach and chipiln (crotalaria). These leafy vegetables provide not only essential amino acids and protein, but vitamins and carotenes which supply to some extent the vitamin A needs of the animal.

Various vegetables as supplements to maize/bean diets have been reported on and results are shown in Table 44. Two sets of diets were tested, one with vitamins added and the other without. The level of addition was 5 percent dry weight. All vegetables in both sets of diets improved weight gain and increased diet intake. Utilizable protein was also higher in the maize/bean diets with vegetables than in the control, and it was highest with the leafy vegetables. Nutritional values were higher with added vitamins than without. These studies clearly indicate that nutritional improvement of 87:13 maize/bean diets is possible by providing vitamins, some additional protein and essential amino acids.

TABLE 44 - Effect of various vegetables added to improve the nutritive value of a common (87/13) maize/bean diet

Vegetable	**Without vitamins**					**With vitamins**				
	Ave. wt. gain (8/28 days)	**Food intake (g)**	**PER**	**RNV**	**Utilizable protein (%)**	**Ave wt. gain (g/28 days)**	**Food intake (g)**	**PER**	**RNV**	**Utilizable protein (%)**

Potatoes	42	274	1.49	59.6	5.6	68	357	2.08	83.2	7.6
Carrots	50	287	1.83	73.2	6.9	65	349	2.04	81.6	7.4
Green peas	52	311	1.66	66.4	6.7	80	370	2.28	91.2	8.7
String beans	55	313	1.75	70.0	7.1	79	378	2.15	86.0	8.3
Spinach	56	282	1.82	72.8	7.9	103	417	2.36	94.4	9.9
Amaranth	67	327	1.96	78.4	8.2	100	420	2.32	92.8	9.5
Crotalaria	63	313	1.92	76.8	8.1	92	329	2.28	91.2	9.7
None	37	268	1.48	50.2	5.4	58	337	1.84	73.6	6.8

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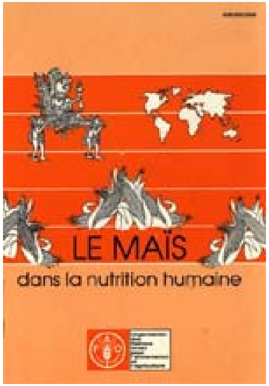

Le maïs dans la nutrition humaine

ORGANISATIONS DES NATIONES UNIES POUR L'ALIMENTATION ET L'AGRICULTURE
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Droits d'auteur

Le rédacteur en chef
FAO, Via delle Terme di Caracalla
00100 Rome, Italy
adresse e-mail: copyright@fao.org

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Pr�face

Au fil des ans, la FAO a publi� une s�rie d'�tudes sur la nutrition. C'est ainsi qu'elle a fait para�tre en 1953 une enqu�te nutritionnelle intitul�e Maize and maize diets, qui faisait le

point des informations et des connaissances disponibles � l'�poque au sujet du ma�s. Depuis lors, les chercheurs ont r�uni une masse d'informations sur la multiplication, l'am�lioration des vari�t�s, le stockage, la transformation, la consommation et l'am�lioration de la qualit� nutritionnelle du ma�s.

La FAO, consciente de la n�cessit� de mettre � jour et de r�viser cette �dition ancienne pour y faire figurer ces informations, a d�cid� de la publier sous un nouveau titre, Le ma is dans la nutrition humaine, et de viser un public plus averti sur le plan technique.

La pr�sente �dition fournit des informations plus abondantes sur la composition chimique du ma�s, notamment la structure des prot�ines et des fibres alimentaires du ma�s, la qualit� et le stockage des grains, ainsi que sur les effets de la cuisson du macs � la chaux et de la confection d'aliments tels que tortillas, arepas et ogi. Apr�s avoir fait le point des connaissances sur l'association entre la consommation de macs la niacine combin�e et la pellagre, elle �tudie les carences du ma�s, en acides amin�s et pr�sente les r�sultats des exp�riences entreprises chez l'homme et les animaux. Elle aborde l'int�r�t qu'il y a � am�liorer la qualit� prot�ique du ma�s, en y incorporant le g�ne opaque-2 et examine la contribution que cela devrait apporter � l'am�lioration du r�gime alimentaire des populations consommatrices de ma�s. Enfin, apr�s avoir fortement pr�conis� la production commerciale du ma�s, � haute qualit� prot�ique (QPM), elle propose une mise � jour des moyens d'am�liorer les r�gimes � base de ma�s selon le vieux principe de la nutrition: avoir un r�gime �quilibr� comprenant des l�gumes secs, des prot�ines d'origine animale, des fruits et des l�gumes verts.

La FAO remercie le professeur R. Bressani de l'Institut de la nutrition d'Am�rique centrale et du Panama pour l'important travail de r�vision et de remaniement auquel il s'est consacr� avec l'assistance technique de Mme Maria Antonietta Rottman. C'est M. M.A. Hussain, responsable du Service des programmes nutritionnels de la Division des politiques alimentaires et de la nutrition, qui s'est charg� de la mise au point technique et de la pr�paration du manuscrit d�finitif. De pr�cieuses suggestions ont �t� formul�es par d'autres fonctionnaires de la Division, ainsi que par des membres de la Division de la production v�g�tale et de la protection des plantes et de la Division des services agricoles.

L'ouvrage s'adresse � un large public comprenant les nutritionnistes, les agronomes, les sp�cialistes des questions alimentaires, les di�t�ticiens et tous ceux qu'int�resse le ma�s. Nous esp�rons qu'il leur para�tra int�ressant et utile.

Paul Lunven
Directeur
Division des politiques alimentaires et de la nutrition

Introduction

Types de ma�s

Dans les langues indiennes d'Am�rique, ma�s signifie litt�ralement �ce qui maintient en vie�. Apr�s le bl� et le riz, c'est la c�r�ale la plus r�pandue dans le monde. Elle fournit des �l�ments nutritifs aux humains et aux animaux et sert de mati�re premi�re � l'industrie pour la fabrication d'amidon, d'huile et de prot�ines, de boissons alcooliques, d'�dulcorants alimentaires et, plus r�cemment, de carburant. A l'�tat vert, l'ensilage de ma�s-fourrage a �t� utilis� avec beaucoup de succ�s dans l'industrie laiti�re et pour l'embouche. Apr�s la r�colte du grain, les fanes et les sommit�s, y compris les inflorescences, sont encore utilis�es � ce jour par de nombreux petits cultivateurs des pays en d�veloppement auxquels elles fournissent un fourrage d'assez bonne qualit� pour les ruminants. Quant aux tiges �rig�es qui, dans certaines vari�t�s, sont rigides, elles ont �t� utilis�es pour la fabrication de cl�tures et de parois tr�s r�sistantes.

Sur le plan botanique, le ma�s (Zea mays), de la famille des gramin�es, est une haute plante annuelle au syst�me radiculaire fibreux abondant. Il s'agit d'une esp�ce � pollinisation crois�e, o� les inflorescences femelles (�pis) et m�les (panicules) occupent des endroits distincts sur la plante. Les �pis, souvent � raison d'un par tige, sont les structures o� se d�veloppent un nombre variable de rang�es (de 12 � 16) de grains, qui fourniront de 300 � 1000 grains pesant entre 190 et 300 g par 1 000 grains. Le poids d�pend de facteurs g�n�tiques, environnementaux et agronomiques. Le grain repr�sente environ 42 pour cent du poids sec de la plante. Les grains sont le plus souvent de couleur blanche ou jaune, mais on en trouve �galement de noirs, de rouges et de m�lang�s. Il existe un certain nombre de types de grains, que distinguent des diff�rences tenant aux compos�s chimiques qui y sont d�pos�s ou emmagasin�s.

Les ma�s cultiv�s pour l'alimentation sont principalement le ma�s doux et le ma�s perl�, mais le ma�s dent�, le ma�s farineux et le ma�s vitreux sont aussi largement utilis�s dans l'alimentation. Le ma�s vitreux est �galement utilis� comme fourrage. Le macs ordinaire immature, sur l'�pi, fait l'objet d'une tr�s grande consommation, soit bouilli, soit grill�. Le macs farineux a un grain � l'albumen tendre, tr�s utilis� dans l'alimentation au Mexique, au Guatemala et dans les pays andins. Le macs dent� a un albumen corn� et vitreux sur les c�t�s et la partie arri�re de la graine, tandis que la partie centrale est tendre. Le ma�s vitreux a un albumen �pais, dur et vitreux qui entoure une petite partie centrale granuleuse et amylac�e.

Origine du ma�s

La culture du ma�s a probablement commenc� en Am�rique centrale, notamment au Mexique, d'o� elle s'est propag�e jusqu'au Canada en direction du nord, et jusqu'en Argentine vers le sud. Le ma�s le plus ancien, datant de quelque 7 000 ans, a �t� d�couvert par des arch�ologues � Teotihuac�n, une vall�e pr�s de Puebla, au Mexique, mais il se pourrait qu'il y ait eu d'autres centres secondaires en Am�rique. Le macs �tait un �l�ment essentiel des civilisations maya et azt�que, o� il jouait un r�le important dans les croyances religieuses, les f�tes et l'alimentation. Ces peuples assuraient que la chair et le sang �taient faits de ma�s. La survie du ma�s le plus ancien et sa diffusion ont �t� l'œuvre des humains, qui r�coltaient les graines pour les semis de l'ann�e suivante.

A la fin du 15e si�cle, apr�s la d�couverte du continent am�ricain par Christophe Colomb, le ma�s a �t� introduit en Europe par l'Espagne. Il s'est ensuite r�pandu sous les climats chauds du bassin m�diterran�en puis, un peu plus tard, en Europe du Nord. Mangelsdorf et Reeves (1939) ont montr� que la culture du macs se pratique dans toutes les r�gions agricoles du globe qui s'y pr�tent et que du ma�s est r�colt� quelque part dans le monde tous les mois de l'ann�e. Le ma�s pousse de 58� de latitude nord, au Canada et dans l'ex-URSS, � 40� de latitude sud, dans l'h�misph�re austral. On r�colte du macs au-dessous du niveau de la mer dans la plaine Caspienne, et � plus de 4 000 m d'altitude dans les Andes p�ruviennes.

Malgr� une grande diversit� de formes, il semble bien que tous les principaux types de ma�s cultiv�s � ce jour aient d�j� �t� connus des populations indig�nes lorsque le continent am�ricain fut d�couvert. Tous les types sont class�s sous le nom de Zea mays. En outre, la botanique, la g�n�tique et la cytologie s'accordent pour attribuer une origine commune � tous les types de ma�s existants. La plupart des chercheurs pensent que la plante tire son origine du t�osinte (Euchluena mexicana Schrod), plante annuelle qui pourrait �tre le plus proche parent du ma�s. D'autres pensent au contraire que le ma�s provient d'un ma�s sauvage aujourd'hui disparu. L'�troite parent� du t�osinte et du ma�s est attest�e par le fait qu'ils ont tous deux 10 chromosomes et qu'ils sont homologues ou partiellement homologues.

L'introgression entre le t�osinte et le ma�s s'est produite dans le pass� et se poursuit aujourd'hui, dans les r�gions du Mexique ou du Guatemala o� il arrive que le t�osinte

pousse au milieu du ma�s. Pour Galinat (1977), parmi les diff�rentes hypoth�ses relatives � l'origine du ma�s, deux possibilit�s demeurent plausibles: la premi�re, que l'actuel t�osinte soit l'anc�tre sauvage du ma�s et/ou qu'un t�osinte primitif soit l'anc�tre sauvage commun du ma�s et du t�osinte; la seconde, qu'une forme disparue de ma�s � gousse soit l'anc�tre du ma�s, le t�osinte �tant une forme mutante de ce ma�s � gousse. Quoi qu'il en soit, la plupart des vari�t�s modernes de ma�s ont �t� obtenues � partir de mat�riel v�g�tal mis au point dans le sud des Etats-Unis, au Mexique, en Am�rique centrale et en Am�rique du Sud.

La plante

La plante de ma�s peut �tre d�finie comme un syst�me m�tabolique dont le produit final est principalement l'amidon d�pos� dans des organes sp�cialis�s, les grains de ma�s.

On distingue dans le d�veloppement de la plante deux stades physiologiques. Au cours du premier stade, ou stade v�g�tatif, les diff�rents tissus se d�veloppent et se diff�rencient jusqu'� l'apparition des structures florales. Le stade v�g�tatif se compose lui-m�me de deux cycles: lors du premier, les feuilles commencent � se former et le d�veloppement est a�rien; la production de mati�re s�che est lente durant ce cycle qui prend fin avec la diff�renciation tissulaire des organes de la reproduction; le second cycle commence au moment du d�veloppement des feuilles et des organes de la reproduction; il se termine avec l'�mission des stigmates. Le second stade, ou stade de la reproduction, d�bute par la

f�condation des structures femelles qui donneront les �pis et les grains. La phase initiale de ce stade se caract�rise par l'augmentation de poids des feuilles et des autres parties florales. Pendant la seconde phase, on assiste � une rapide augmentation du poids des grains (Tanaka et Yamaguchi, 1972).

Au cours des stades v�g�tatif et reproductif, la plante manifeste des caract�ristiques morphologiques et des diff�rences qui sont des cons�quences de la s�lection naturelle et de la domestication. C'est ainsi qu'on observe des g�notypes qui, pour s'adapter � des zones �cologiques sp�cifiques, ont cr�� des barri�res; c'est le cas de la sensibilit� � la longueur du jour et de la sensibilit� � la temp�rature, qui limitent l'adaptabilit� de la plante � des latitudes et � des altitudes sp�cifiques. Il en r�sulte que les programmes d'am�lioration doivent �tre conduits � l'int�rieur des zones o� les vari�t�s am�lior�es sont appel�es � �tre cultiv�es. Cela ne signifie pas, cependant, que l'on puisse obtenir des caract�ristiques g�n�tiques sp�cifiques par croisement en retour.

Avec l'�volution, la morphologie, ou architecture de la plante, a �galement subi des pressions qui ont abouti � une grande variabilit� en ce qui concerne le nombre, la longueur et la largeur des feuilles, la hauteur de la plante, la disposition des �pis, le nombre d'�pis par plant, les cycles de maturation, les types de grains, le nombre de rang�es de grains, etc.

Cette variabilit� pr�sente un grand int�r�t lorsqu'on veut am�liorer la productivit� de la plante ou telles composantes organiques du grain. Sur le plan du rendement, les principales composantes sont le nombre et le poids des grains. Ces composantes sont sous la d�pendance

d'effets g�n�tiques quantitatifs relativement faciles � s�lectionner. Le nombre de grains d�pend de l'�pi et est d�termin� par le nombre de rang�es et le nombre de grains par rang�e. La taille et la forme du grain en d�terminent le poids, compte tenu d'autres facteurs constants tels que sa texture et sa densit�. Pour la plupart des lign�es de ma�s, le rapport entre le poids des grains et le poids total de la plante est d'environ 0,52. Avec 100 kg d'�pis on obtient environ 18 kg de grains. Un hectare de ma�s rend environ 1,55 tonne de r�sidus. Pour des plants de ma�s s�ch�s en plein champ dans trois r�gions du Guatemala, le poids sec de la plante variait entre 220 et 314 g. Sur ce total, 1,8 pour cent �tait constitu� des fleurs s�ch�es, tandis que le poids de la tige variait entre 14,7 et 27,8 pour cent du poids de la plante. En ce qui concerne les feuilles, la variabilit� �tait de 7,4 � 15,9 pour cent, celle des spathes de 1 1,7 � 13 pour cent, et le poids des �pis variait de 9,7 �11,5 pour cent. Les grains s�ch�s en plein champ repr�sentaient de 30 � 55,9 pour cent du poids sec de la plante enti�re. Ces donn�es font appara�tre toute l'importance des r�sidus, qui sont souvent laiss�s sur place. La distribution peut varier, toutefois, car on admet qu'environ la moiti� de la mati�re s�che est constitu�e des grains et l'autre moiti� des r�sidus v�g�taux, racines non comprises (Barber, 1979).

Structure du grain de ma�s

Les grains de ma�s se d�veloppent sur l'inflorescence femelle, appel�e �pi, par accumulation des produits de la photosynth�se, absorption par les racines et m�tabolisme du plant de ma�s. L'�pi peut contenir de 300 � 1000 grains, selon le nombre de rang�es, le

diam�tre et la longueur de la rafle. Le poids des grains est souvent assez variable; il peut aller d'environ 19 � 40 g pour 100 grains. Pendant la r�colte, les �pis de ma�s sont enlev�s � la main ou m�caniquement. Les spathes qui recouvrent l'�pi sont d'abord arrach�es, puis les grains sont s�par�s � la main ou, le plus souvent, � la machine.

Pour les botanistes, le grain de ma�s est un caryopse; un grain unique contient � la fois le t�gument s�minal et la semence (figure 1). La figure fait �galement appara�tre les quatre structures physiques principales du grain: le p�ricarpe; le germe ou embryon; l'albumen; et la coiffe (tissu mort � l'endroit o� le grain est attach� � la rafle). L'anatomie et la structure microscopique de ces composantes ont �t� bien d�crites par Wolf et al. (1952) et par Wolf, Koo et Seckinger (1969). Ces chercheurs ont �galement �tudi� la structure du ma�s am�lior� opaque-2 et constat� des diff�rences entre son albumen et celui du ma�s commun. Le r�seau protidique �tait plus fin et les granules prot�iques �taient plus petits et moins nombreux puisqu'il y a restriction de la synth�se de la z�ine dans le ma�s opaque-2. Robutti, Hoseny et Deyoe (1974) et Robutti, Hoseny et Wasson (1974) ont d�crit la distribution des prot�ines, la teneur en acides amin�s et la structure de l'albumen du a�s opaque-2.

FIGURE 1 - Structure d'un grain de ma�s coupe longitudinale d'un grain de ma�s agrandi environ 30 fois

La distribution en poids des diff�rentes parties du grain de ma�s est reproduite au tableau 1. L'albumen, qui est la structure la plus grande, repr�sente environ 83 pour cent du poids du

grain, tandis que le germe en repr�sente en moyenne 11 pour cent et le p�ricarpe 5 pour cent. Le reste est compos� de la coiffe, structure conique qui, avec le p�dicelle, soude le grain � l'�pi de ma�s. Le tableau 2 fait appara�tre la distribution du poids et de l'azote entre les parties anatomiques du ma�s commun et de vari�t�s s�lectionn�es, telles que les ma�s � haute teneur en huile et � haute teneur en prot�ines et trois s�lections de ma�s � haute qualit� prot�ique (QPM) (Bressani et Mertz, 1958). La principale diff�rence de la vari�t� � haute teneur en huile tient � la taille du germe, qui est pr�s de trois fois plus gros que te germe du ma�s commun, aux d�pens de l'albumen, dont le poids est r�duit. Le germe des vari�t�s � haute teneur en prot�ines est plus gros que celui du ma�s commun, mais environ deux fois moins que celui des vari�t�s � haute teneur en huile. On observe �galement des diff�rences de poids des t�guments s�minaux. Le tableau fait appara�tre un certain nombre de donn�es concernant le t�osinte, le plus proche parent du ma�s. Le poids du grain est beaucoup plus faible que celui des grains de macs et l'albumen p�se environ la moiti� de celui du ma�s. Les trois s�lections de ma�s QPM sont semblables au ma�s commun en ce qui concerne le poids par grain et le poids du t�gument s�minal, de l'albumen et du germe. Des donn�es comparables ont �t� cit�es par d'autres auteurs. Le tableau 3 r�sume les donn�es concernant deux vari�t�s de ma�s commun et une de ma�s opaque-2 (Landry et Moureaux, 1980). Les deux �chantillons de ma�s commun pr�sentaient les m�mes caract�ristiques g�n�rales que ceux cit�s plus haut: cependant, l'�chantillon d'opaque-2 avait un germe plus important fournissant davantage d'azote que les ma�s QPM du tableau 2. En ce qui concerne le germe, l'accroissement des valeurs du poids et de l'azote en termes absolus aussi bien que relatifs corrobore d'autres r�sultats (Watson, 1987).

TABLEAU 1 - Distribution en poids des principales parties du grain

Structure	Distribution du poids (%)
P�ricarpe	5-6
Aleurone	2-3
Albumen	80-85
Germe	10-12

TABLEAU 2 - Distribution du Poids et de l'azote entre les diff�rentes Parues du grain

Echantillon de ma�s	Poids de 20 grains (g)	Distribution du poids (%)			Total N (%)	Distribution de l'azote (%)		
		T�gument s�minal	Albumen	Germe		T�gument s�minal	Albumen	Germe
Am�ricain 4251	5,62	6,3	86,3	7,4	1,31	3,3	81,2	15,5
Am�ricain � haute teneur en	5,72	6,4	71,2	22,4	1,99	2,4	68,4	29,2

huile (HO)								
Am�ricain � haute teneur en prot�ines (H5)	4,32	6,9	82,7	10,4	2,24	2,2	83,2	14,6
Am�ricain � haute teneur en prot�ines (HP)	4,97	7,4	78,9	13,7	2,14	2,7	78,2	19,1
Am�ricain normal-Sh1 PT	4,38	6,7	79,6	13,7	2,14	2,7	78,2	19,1
Am�ricain normal mutant-Sh1 PT	2,50	10,7	70,6	18,7	2,21	6,1	64,6	29,3
Tiquisate (TGY) (Guatemala)	8,24	4,9	83,9	11,2	1,37	2,8	75,2	22,0
San Sebastian (SSD) (Guatemala)	8,24	4,9	83,9	11,2	1,37	2,8	75,2	22,0
142-48 du Guatemala	6,91	6,9	82,1	11,0	1,83	2,6	81,0	16,4
Cuyuta du Guatemala	5,95	5,7	82,5	11,8	1,28	2,9	72,4	24,7
T�osinte du								

Guatemala	1,56	55,6	44,4	-	1,81	8,2	91,8	-
Nutricta QPM	5,91	5,7	82,7	11,6	1,42	1,7	72,8	25,5
QPM jaune	6,49	5,9	81,6	12,5	1.48	2,4	73,4	24,2
QPM blanc	5,31	5,9	82,4	1,6	1,36	1,4	72,8	25,7

TABLEAU 3 - Distribution en poids et en azote des diff�rentes parties des grains de ma�s commun et onaque-2

Partie du grain	**Mati�re s�che (%)**			**Azote (%)**		
	Commun	**Commun**	**Opaque-2**	**Commun**	**Commun**	**Opaque-2**
Germe	13,5	8,1	35	20,1	14,9	35,1
Albumen	80,0	84,0	61	76,5	80,5	60,7
T�gument s�minal	6,5	7,9	4	3.4	4,6	4.2

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Production mondiale

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De 1979 -1981 � 1987, la production mondiale de ma�s a augment�, comme indiqu� au tableau 4. Les superficies plant�es en ma�s sont pass�es de 105 millions d'ha en 1961 � environ 127 millions d'ha en 1987. Bien qu'une partie de l'accroissement s'explique par de nouveaux ensemencements, une grande part des augmentations de production est due � l'am�lioration g�n�tique, au perfectionnement des techniques culturales, au d�veloppement des applications d'engrais, ainsi qu'� l'introduction de vari�t�s nouvelles � plus fort taux de reproduction.

Les pays en d�veloppement consacrent davantage de superficies � la culture du ma�s que les pays d�velopp�s, mais dans ces derniers les rendements sont pr�s de quatre fois sup�rieurs. Depuis 1961, aux EtatsUnis, par exemple, les rendements � l'hectare ont sensiblement progress�, alors qu'au Mexique, au Guatemala et au Nig�ria-pays o� laconsommation de ma�s par la population humaine est particuli�rement �lev�e, notamment dans les deux premiers - les rendements n'ont que tr�s peu augment�. Alors que l'essentiel de la production des pays en d�veloppement est destin� � la consommation humaine, dans les pays industrialis�s elle est surtout r�serv�e � l'usage industriel et aux aliments pour animaux. Les rendements �lev�s et l'importante production en Am�rique du Nord et en Am�rique centrale sont principalement dus aux Etats-Unis, qui produisent davantage que des pays comme le Mexique o� le ma�s est la principale c�r�ale de base.

Avec l'exode rural et l'�volution du mode de vie constat�s dans les pays en d�veloppement, on assiste � une d�rive r�guli�re au profit de la consommation de bl�, ce qui pourrait avoir une influence sur la production de ma�s. On observe une l�g�re augmentation de son utilisation dans l'industrie et dans l'alimentation pour animaux, en particulier pour la volaille et autres animaux monogastriques. La comparaison avec les donn�es concernant le bl� et le riz place le mais au second rang des c�r�ales, apr�s le bl� et avant le riz. En termes de rendements � l'hectare, toutefois, le ma�s l'emporte sur les deux autres. La seule culture vivri�re dont le rendement en tonnes � l'hectare d�passe celui du ma�s est la pomme de terre � l'�tat non transform�, mais non � �galit� de teneur en humidit�.

TABLEAU 4 - Production de ma�s dans le mande

R�gion et ann�e	**Superficie r�colt�e (miliers d'ha)**	**Rendement (kg/ha)**	**Production (milliers de tonnes)**
Afrique			
1979-1981	18 193	1 554	28 268
1985	19 099	1 522	29 069
1986	19 580	1 575	30 840
1987	19512	1 395	27225
Am�rique du Nord			

et Am�rique centrale			
1979-1981	39 399	5 393	212 384
1985	40 915	6 092	249 258
1986	37 688	6 116	230 511
1987	35187	5690	200211
Am�rique du Sud			
1979-1981	16751	1 928	32369
1985	17 813	2 182	38 859
1986	18799	2021	38001
1987	19 413	2 143	41 595
Asie			
1979-1981	36815	2296	84531
1985	35 246	2 628	92 629
1986	37 474	2 729	102 274
1987	37 399	2 788	104 269
Europe			

1979-1981	11 738	4668	54792
1985	11 556	5423	62673
1986	11 539	6207	71 621
1987	11 405	6039	68901
Oc�anie			
1979-1981	76	4 359	332
1985	124	3 804	471
1986	107	4 402	471
1987	84	4302	363
URSS			
1979-1981	3 063	2989	9076
1985	4482	3214	14406
1986	4 223	2955	12479
1987	4 600	3217	14 800
Monde			
1979-1981	126035	3 345	421 751
1985	129235	3 771	487 367

1986	129411	3 757	486198
1987	127 605	3 584	457 365

Utilisations

Comme il est indiqu� plus haut, le mais a trois utilisations possibles: aliment pour les humains, aliment pour les animaux et mati�re premi�re pour l'industrie. Dans l'alimentation humaine, on peut utiliser le grain entier, parvenu ou non � maturit�; on peut aussi le transformer au moyen des techniques de mouture s�che de mani�re � obtenir un nombre relativement important de demi-produits, tels que grits de ma�s de diff�rents calibres, farines et semoules de ma�s, et semoule pour la pr�paration des flocons. A leur tour, ces demi-produits trouvent de nombreuses applications dans des produits alimentaires tr�s divers. En agriculture de subsistance, le mais a�t�, et reste dans certaines r�gions une culture vivri�re de base. Dans les pays d�velopp�s, plus de 60 pour cent de la production sont destin�s � la fabrication d'aliments compos�s pour la volaille, les porcins et les ruminants. Depuis ces derni�res ann�es, m�me dans les pays en d�veloppement o� il fait partie de l'alimentation de base, le ma�s a �t� de plus en plus utilis� comme ingr�dient des aliments pour animaux. Ce n'est que r�cemment que le ma�s � �haute teneur en humidit� a retenu davantage l'attention dans l'alimentation animale en raison de son co�t plus faible et de sa capacit� � accro�tre le rendement des op�rations de transformation. Les sousproduits de la mouture s�che sont le germe et le t�gument s�minal. On extrait du

premier une huile comestible de grande qualit�. Le t�gument s�minal ou p�ricarpe sert surtout � l'alimentation animale, encore qu'il ait retenu l'attention ces derni�res ann�es comme source de fibres alimentaires (Earli et al., 1988; Burge et Duensing, 1989). La mouture humide est un proc�d� surtout r�serv� aux utilisations industrielles du ma�s, bien que le proc�d� de cuisson alcaline utilis� pour la fabrication des tortillas (minces galettes consomm�es au Mexique et dans d'autres pays d'Am�rique centrale) soit �galement une op�ration de mouture humide qui n'enl�ve que le p�ricarpe (Bressani, 1990). La mouture humide fournit l'amidon du ma�s et des sous-produits tels que le gluten, utilis� comme ingr�dient des aliments pour animaux. La production d'huile de ma�s � partir du germe fournit comme sous-produit la farine de germe de ma�s, employ�e pour l'alimentation animale. Des tentatives ont �t� faites pour utiliser ces sous-produits dans des m�langes et des formulations destin�s � l'alimentation humaine

Bien que la technique soit connue depuis longtemps, la hausse des prix des carburants a permis de relancer la recherche sur la fermentation du ma�s en vue de la production d'alcool, comme cela se fait dans certains Etats d'Am�rique du Nord. La fermentation produit �galement des boissons alcooliques.

Enfin, les r�sidus de plants de ma�s comportent des utilisations importantes non seulement pour l'alimentation animale mais aussi pour la production d'un certain nombre de substances chimiques telles que le furfural et la xylose, obtenues � partir des rafles. Ces r�sidus jouent �galement un r�le important dans la pr�paration des sols.

Composition chimique et valeur nutritionnelle du ma�s

Il existe de nombreuses donn�es sur la composition chimique du ma�s. Bon nombre d'�tudes ont �t� entreprises pour comprendre et �valuer les effets que peut avoir sur la composition chimique la structure g�n�tique des vari�t�s relativement nombreuses de ma�s dont on dispose, ainsi que les effets des facteurs environnementaux et des pratiques culturales sur les constituants chimiques et la valeur nutritionnelle du grain de ma�s et de ses parties anatomiques. La composition chimique apr�s transformation en vue de la consommation est un aspect important de la valeur nutritive (voir chapitre 5); elle est affect�e par la structure physique du grain, par des facteurs g�n�tiques et environnementaux, par la transformation et autres maillons de la cha�ne alimentaire. Dans le pr�sent chapitre, on s'attachera � d�crire la nature chimique du ma�s, qu'il s'agisse du type commun ou du type � haute qualit� prot�ique, pour mieux comprendre la valeur nutritive des diff�rents produits tir�s du ma�s que l'on consomme dans le monde.

Composition chimique des diverses parties du grain de ma�s

Comme l'indique le tableau 5, la composition chimique des principales parties du grain de ma�s pr�sente des diff�rences importantes. Le t�gument s�minal ou p�ricarpe se caract�rise par une forte teneur en fibres brutes environ 87 pour cent, constitu�es principalement d'h�micellulose (67 pour cent) de cellulose (23 pour cent) et de lignine (0,1 pour cent) (Burge et Duensing, 1989). D'autre part, l'albumen pr�sente une haute teneur en

amidon (87,6 pour cent) et des niveaux de prot�ines d'environ 8 pour cent. La teneur en graisses brutes de l'albumen est relativement faible. Enfin, le germe se caract�rise par une forte teneur en graisses brutes, de 33 pour cent en moyenne; il a �galement une teneur relativement �lev�e en prot�ines (18,4 pour cent) et en sels min�raux. On dispose d'un certain nombre d'informations sur la composition chimique de la couche � aleurone (figure 1), qui est une partie relativement riche en prot�ines (19 pour cent environ) et en fibres brutes. Les tableaux 2 et 3 contiennent des renseignements suppl�mentaires sur la r�partition de l'azote dans le grain de macs C'est l'albumen qui en fournit la plus grande partie, suivi du germe, et enfin du t�gument s�minal qui n'en contient que de petites quantit�s. Environ 92 pour cent des prot�ines du t�osinte proviennent de l'albumen. Des travaux ont �t� consacr�s aux prot�ines du grain de macs par un certain nombre de chercheurs tels que Bressani et Mertz, 1958.

TABLEAU 5 - Composition chimique approch�e des principales parties des grains de ma�s (pourcentage)

Composant chimique	**P�ricarpe**	**Albumen**	**Germe**
Prot�ines	3,7	8,0	18,4
Extrait � l �ther	1,0	0,8	33,2
Fibres brutes	86,7	2,7	8,8
Cendres	0,8	0,3	10,5

Amidon	7,3	87,6	8,3
Sucre	0,34	0,62	10,8

Il ressort des donn�es figurant aux tableaux 2 et 3 que la teneur en glucides et en prot�ines des grains de ma�s d�pend dans une tr�s grande mesure de l'albumen, tandis que les graisses brutes et, dans une moindre mesure, les prot�ines et les sels min�raux d�pendent du germe. Les fibres brutes du grain proviennent pour l'essentiel du t�gument s�minal. La r�partition du poids entre les diff�rentes parties du grain de macs ainsi que la composition chimique et la valeur nutritive de chacune rev�tent une grande importance dans les transformations auxquelles le ma�s est soumis en vue de la consommation. A cet �gard, deux points importants sont � relever du point de vue nutritif. L'huile du germe fournit des quantit�s relativement importantes d'acides gras (Bressani �t al., 1990; Weber, 1987). Lorsque la part du ma�s dans l'alimentation est tr�s �lev�e, comme chez certaines populations, les personnes qui consomment le grain d�germ� absorbent moins d'acides gras que celles qui consomment le ma�s entier transform�. Cette diff�rence est vraisemblablement tout aussi importante dans le cas des prot�ines, �tant donn� que la teneur en acides amin�s des prot�ines du germe est tr�s diff�rente de celle des prot�ines de l'albumen. C'est ce qui ressort du tableau 6 dans lequel les acides amin�s indispensables sont exprim�s en milligrammes pour cent en poids et en milligrammes par gramme d'azote. Comme l'indique le tableau 2, l'albumen repr�sente entre 70 et 86 pour cent du poids du grain, et le germe entre 7 et 22 pour cent. Donc, si l'on envisage le grain entier, la teneur en acides amin�s indispensables refl�te la teneur en acides amin�s des prot�ines de

l'albumen, bien que la sp�cificit� de composition en acides amin�s des prot�ines du germe soit sup�rieure et mieux �quilibr�e. Les prot�ines du germe n'en fournissent pas moins une contribution relativement importante � l'�gard de certains acides amin�s, encore qu'insuffisante pour fournir une qualit� plus �lev�e de prot�ines dans le grain entier. Le germe fournit une certaine quantit� de lysine et de tryptophane, qui sont les deux acides amin�s indispensables limitants des prot�ines du ma�s. Les prot�ines de l'albumen sont pauvres en lysine et en tryptophane, de m�me que les prot�ines du grain entier (voir le tableau 6, qui fait �galement appara�tre la sp�cificit� de composition FAO/OMS des acides amin�s indispensables). De nombreuses �tudes sur l'animal (Howe, Janson et Gilfillan, 1965) ainsi qu'un petit nombre d'�tudes sur les humains (Bressani, 1971) ont �t� consacr�es aux carences en lysine, tryptophane et isolencine.

TABLEAU 6 - Teneur en acides amin�s indispensables des prot�ines du germe et des prot�ines de l'albumen

Acide aim�	**Albumen**		**Germe**		**Combaison-type FAO/OMS**
	mg %	mg/g N	mg %,	mg/g N	
Tryptophane	48	38	144	62	60
Thr�onine	315	249	622	268	250
Isoleucine	365	289	578	249	250

Leucine	1 024	810	1 030	444	440
Lysine	228	180	791	341	340
Total des acides amin�s soufr�s	249	197	362	156	220
Ph�nylalanine	359	284	483	208	380
Tyrosine	483	382	343	148	380
Valine	403	319	789	340	310

TABLEAU 7 - Prot�ines nettes du grain entier, du germe et de l'albumen des vari�t�s de ma�s guat�malt�ques

Echantillon	**Jaune**	**Azotea**	**Cuarente�o**	**Opaque-2**
Grain entier	42,5	44,3	65,4	81,4
Germe	65,7	80,4	90,6	85,0
Albumen	40,0	42,0	46,4	77,0

Le tableau 7, qui compare la qualit� des deux parties du grain en pourcentage de la prot�ine de r�f�rence, la cas�ine en l'esp�ce, fait appara�tre la qualit� sup�rieure des prot�ines du germe par rapport � celles de l'albumen dans diff�rentes vari�t�s de ma�s. Les mais retenus comprennent trois vari�t�s de ma�s commun et une vari�t� de ma�s �

prot�ines de qualit�. Dans tous les cas, la qualit� des prot�ines du germe est nettement plus �lev�e que celle des prot�ines de l'albumen et, par suite, �videmment sup�rieure � la qualit� des prot�ines des grains entiers. La qualit� prot�ique de l'albumen est plus faible que celle du grain entier, �tant donn� la sup�riorit� de l'apport en prot�ines du germe. Ces donn�es font �galement appara�tre une moindre diff�rence de qualit� des prot�ines du germe et de l'albumen dans la vari�t� � haute qualit� prot�ique (QPM). De plus la qualit� de1`albumen et du grain entier des vari�t�s QPM est sensiblement sup�rieure � la qualit� de l'albumen et du grain entier des autres sp�cimens. Ces donn�es, l�encore, rev�tent de l'importance � l'�gard des proc�d�s de transformation du ma�s destin� � la consommation et de son incidence sur l'�tat nutritionnel des populations, Elles font �galement appara�tre � l'�vidence que la qualit� des vari�t�s QPM est sup�rieure � celle du ma�s commun. La qualit� plus �lev�e de l'albumen du ma�s QPM n'est pas non plus sans signification pour les populations qui consomment du ma�s d�germ�.

TABLEAU 8 - Composition chimique approch�e des diff�rents types de ma�s (pourcentage)

Type de macs	**Humidit�**	**Cendres**	**Prot�ines**	**Fibres brutes**	**Extrait � l'�ther**	**Glucides**
Salpor	12,2	1,2	5,8	0,8	4,1	75,9
Cristallin	10,5	1,7	10,3	2,2	5.0	70,3
Farineux	9,6	1,7	10,7	2,2	5,4	70,4

Amylac�	11,2	2,9	9,1	1,8	2,2	72,8
Doux	9,5	1,5	12,9	2,9	3,9	69,3
Eclat�	10,4	1,7	13,7	2,5	5,7	66,0
Noir	12,3	1,2	5,2	1,0	4,4	75,9

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Composition chimique approch�e

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On dispose d'informations abondantes sur la composition chimique approch�e du ma�s. Les principaux �l�ments nutritifs qui entrent dans sa composition pr�sentent une grande variabilit�. Le tableau 8 r�sume les principales donn�es dont on dispose sur les diff�rents types de ma�s, emprunt�es � plusieurs publications. La variabilit� constat�e est � la fois d'ordre g�n�tique et environnemental. Elle peut influer sur la distribution du poids et la comnosition chimique de l'albumen du germe et du t�gument des grains.

Amidon

Le principal composant chimique du grain de ma�s est l'amidon, qui constitue de 72 � 73 pour cent de son poids. Les autres glucides sont des sucres simples pr�sents sous forme de glucose, de saccharose et de fructose dans des proportions variant de1� 3 pour cent du grain. L'amidon du ma�s est constitu� de deux polym�res du glucose, l'amylose, polym�re lin�aire, et l'amylopectine, compos�e �galement d'unit�s de glucose sous forme ramifi�e. La composition de l'amidon du ma�s est g�n�tiquement d�termin�e. Dans le macs commun, qu'il soit � albumen dent� ou vitreux, les teneurs en amylose et en amylopectine sont respectivement de 25 � 30 pour cent et de 70 � 75 pour cent de l'amidon. Le ma�s cireux contient un amidon, constitu� � 100 pour cent d'amylopectine. Un mutant de l'albumen, nomm� amylose-extender (ae), induit une augmentation de la proportion d'amylose de l'amidon pouvant atteindre 50 pour cent et davantage. D'autres g�nes, seuls ou combin�s, peuvent aussi modifier la proportion entre l'amylose et l'amylopectine dans l'amidon de ma�s (Boyer et Shannon, 1987).

Prot�ines

Apr�s l'amidon, le composant chimique le plus important du grain est constitu� par les prot�ines. Dans les vari�t�s courantes, la teneur en prot�ines varie d'environ 8 �11 pour cent du poids du grain. La plus grande partie des prot�ines se trouve dans l'albumen. Les prot�ines des grains de ma�s ont fait l'objet d'�tudes tr�s nombreuses. Selon Landry et Moureaux (1970, 1982), elles sont compos�es d'au moins cinq fractions diff�rentes. Selon

eux, les albumines, les globulines et l'azote non prot�ique repr�sentent environ 18 pour cent de l'azote total, selon une distribution de 7 pour cent, 5 pour cent et 6 pour cent, respectivement. La fraction prolamine soluble dans l'isopropanol � 55 pour cent et l'isopropanol additionn� de mercapto�thanol (ME) fournit 52 pour cent de1'azote du grain. La prolamine 1 ou la z�ine 1 soluble dans l'isopropanol � 55 pour cent se trouve � la concentration la plus forte, soit 42 pour cent environ, 10 pour cent �tant fournis par la prolamine 2 ou la z�ine 2. Une solution alcaline de pH 10 avec 0,6 pour cent de mercapto�thanol permet d'extraire la fraction glut�line 2, � raison de 8 pour cent environ, tandis que la glut�line 3 est extraite avec le m�me tampon que ci-dessus au moyen de dod�cylsulfate de sodium � 0,5 pour cent, � raison de 17 pour cent pour une teneur totale en globuline de 25 pour cent des prot�ines du grain. On retrouve g�n�ralement une petite quantit�, environ 5 pour cent, d'azote r�siduel.

TABLEAU 9 - Distribution des fractions prot�iques des vari�t�s Tuxpe�o-1 et Blanco Dentado-1 QPM (grain entire)

Fraction	Blanco Dentado-1 QPM		Tuxpe�o-1	
	Proteines	Prot�ines totales	Proteines	Proteinestotales
	(mg)	(%)	(mg)	(%)
I	6,65	31,5	3,21	16,0

II	1,25	5,9	6,18	30,8
III	1,98	9,4	2,74	13,7
IV	3,72	17,6	2,39	12,0
V	5,74	27,2	4,08	20,4
R�sidu	1,76	8.3	1,44	7,1

Le tableau 9 r�sume les donn�es fournies par Ortega, Villegas et Vasal (1986) sur le fractionnement prot�ique d'un ma�s commun (Tuxpe�o- 1) et d'un ma�s QPM (Blanco Dentado- 1). Les fractions 11 et 111 sont la z�ine 1 et la z�ine 11, la z�ine 1 (fraction 11) �tant sensiblement plus �lev�e dans la vari�t� Tuxpe�o- 1 que dans la vari�t� QPM. D'autres chercheurs ont publi� des r�sultats analogues. Les quantit�s de prot�ines solubles dans l'alcool sont faibles dans le macs immature. Elles augmentent � mesure que le grain approche de la maturit�. Des analyses de ces fractions destin�es � d�terminer leur teneur en acides amin�s ont montr� que la fraction z�ine avait une tr�s faible teneur en lysine et manquait de tryptophane. Etant donn� que ces fractions z�ine constituent plus de 50 pour cent des prot�ines du grain de ma�s, il s'ensuit que les prot�ines contiennent �galement une faible quantit� de ces deux acides amin�s. Les fractions albumines, globulines et glut�lines, ont, d'autre part, des teneurs relativement �lev�es en lysine et en tryptophane. Une autre caract�ristique importante des tractions z�ine est leur tr�s forte teneur en leucine acide amin� jouant un r�le dans la carence en isoleucine (Patterson et al., 1980).

TABLEAU 10 - Teneur en acides amin�s du ma�s et du t�osinte (pourcentage)

TABLEAU 11 - Teneur en acides gras des vari�t�s de ma�s guat�malt�ques et du OPM Nutricta (pourcentage)

Vari�t� de ma�s	**C16:0 Palmitique**	**C18:0 St�arique**	**C18:1 Ol�ique**	**C18:2 Linol�nique**	**C18:3 Linol�nique**
QPM Nutricta	15,71	3,12	36,45	43,83	0,42
Azotea	12,89	2,62	35,63	48,85	
Xetzoc	11,75	3,54	40,07	44,65	
Blanc tropical	15,49	2,40	34,64	47,47	
Santa Apolonia	11,45	3,12	38,02	47,44	

Le ma�s � prot�ines de qualit� diff�re du ma�s commun par la r�partition du poids des cinq fractions prot�iques mentionn�es plus haut ainsi qu'il ressort du tableau 9. Les �carts sont variables et d�pendent du g�notype et des conditions culturales. On a constat�, toutefois, que le g�ne opaque-2 r�duit la concentration de z�ine de quelque 30 pour cent. De ce fait, la teneur en lysine et en tryptophane est plus �lev�e dans les vari�t�s QPM que dans le ma�s commun.

La qualit� nutritionnelle du ma�s alimentaire est d�termin�e par la constitution de ses prot�ines en acides amin�s. On trouvera au tableau 10 des valeurs repr�sentatives

concernant les acides amin�s, pour le macs commun et les vari�t�s � prot�ines de qualit�. Pour permettre d'�tablir l'ad�quation de la teneur en acides amin�s indispensables, le tableau fait �galement figurer la sp�cificit� de composition FAO/OMS en acides amin�s indispen.sables. La comparaison du macs commun avec les vari�t�s � prot�ines de qualit� fait appara�tre les carences du premier en lysine et en tryptophane. Une autre caract�ristique importante est la forte teneur en leucine du ma�s commun et la teneur plus faible de cet acide amin� dans les vari�t�s � prot�ines de qualit�.

TABLEAU 12 Fibres alimentaires solubles et insolubles du ma�s commun et du ma�s � prot�ines de qualit� (pourcentage)

Type de ma�s	Fibres alimentaires		
	Insolubles	Solubles	Total
Highland	10,94�1,26	1,25 � 0,41	12,19 � 1,30
Lowland	11,15 � 1,08	1,64 � 0,73	12,80 � 1,47
QPM Nutricta	13,77	1,14	14,91

TABLEAU 1 3 Fibres totales (m�thodes de s�paration acide et neutre), h�micellulose et lignine dans cinq vari�t�s de ma�s (pourcentage)

Ma�s	Fibres	Fibres	H�miccelulose	Lignine	Parois des

	(m�thode de s�paration neutre)	(m�thode de s�paration acide)			cellules
1	8,21	3,23	4,98	0,14	9,1
2	10,84	2,79	8,05	0,12	10,8
3	9,33	3,08	6,25	0,13	12,0
4	11,40	2,17	9,23	0,12	13,1
5	14,17	2,68	11,44	O,14	14,2
Moyenne	10,79�2,27	2,79�0,44	8,00�2,54	0,13�0,01	11,8�2,0

Huile et acides gras

La teneur en huile du grain de ma�s provient essentiellement du germe. La teneuren huile est d�termin�e g�n�tiquement, avec des valeurs �tag�es entre 3 et 18 pour cent. Le tableau 11 fait appara�tre la composition moyenne en acides gras de l'huile des diff�rentes vari�t�s cultiv�es au Guatemala. Ces valeurs sont quelque peu diff�rentes; il est normal que les huiles obtenues � partir de vari�t�s diff�rentes pr�sentent des compositions �galement diff�rentes. L'huile de ma�s a une faible teneur en acides gras satur�s, � savoir 11 pour cent d'acide palmitique et 2 pour cent d'acide st�arique. En revanche, elle contient des niveaux relativement �lev�s d'acides gras polyinsatur�s, essentiellement d'acide linol�nique, avec une valeur moyenne d'environ 24 pour cent. On n'a d�cel� que des

quantit�s extr�mement faibles d'acide linol�nique et d'acide arachidonique. En outre, l'huile de ma�s est relativement stable dans la mesure o� elle ne contient que des quantit�s faibles d'acide linol�nique (0,7 pour cent) et des niveaux �lev�s d'antioxydants naturels. L'huile de ma�s est tr�s pris�e du fait de sa composition en acides gras, acide ol�ique et acide linol�nique pour l'essentiel. De ce point de vue, les populations qui consomment du ma�s d�germ� en tirent moins de profit en ce qui concerne l'huile et les acides gras que les populations qui consomment des produits � base de grains entiers.

Fibres alimentaires

Apr�s les glucides, les prot�ines et les graisses, les fibres alimentaires sont le composant chimique que l'on trouve en plus grandes quantit�s. Les glucides du grain de ma�s proviennent du p�ricarpe et de la coiffe, mais ils sont �galement fournis par les parois des cellules de l'albumen et, dans une moindre mesure, les parois des cellules du germe. Le tableau 12 fait appara�tre la teneur totale en fibres alimentaires solubles et insolubles des grains de ma�s Les �carts entre les �chantillons sont faibles en ce qui concerne les fibres alimentaires solubles et insolubles, m�me si le Nutricta QPM pr�sente des teneurs plus �lev�es en fibres alimentaires totales que le ma�s commun, essentiellement en raison d'une teneur plus �lev�e en fibres insolubles. Le tableau 13 fait appara�tre les valeurs en fibres d�termin�es par les m�thodes de s�paration acide et neutre, en h�micellulose et en lignine du ma�s entier. Les valeurs de ce tableau sont semblables � celles qu'ont publi�es Sandstead et al. (1978) et Van Soest, Fadel et Sniffen (1979). Sandstead et al. ont constat� que le son de ma�s (extrait sec) se composait de 75 pour cent d'h�micellulose, de 25 pour cent de cellulose et de

0,1 pour cent de lignine. Il va sans dire que la teneur en fibres alimentaires des grains d�cortiqu�s sera inf�rieure � celle des grains entiers.

TABLEAU 14 - Toneur du ma�s on mati�res min�rales (moyenne de cinq �chantillons

Sel min�ral	Concentration (mg/100 g)
P	299,6� 57,8
K	324,8 � 33,9
Ca	48,3 � 12,3
Mg	107,9 � 9,4
Na	59,2 � 4,1
Fe	4,8 � 1,9
Cu	1,3 � 0,2
Mn	1,0 � 0,2
Zn	4,6 � 1,2

Autres glucides

Lorsqu'il est m�r, le grain de ma�s contient de petites quantit�s de glucides autres que l'amidon. Les sucres totaux du grain sont compris entre 1 et 3 pour cent, la saccharose, principal composant, se trouvant essentiellement dans le germe.

Des teneurs plus �lev�es en monosaccharides, disaccharides et trisaccharides sont relev�es dans les grains m�rissants. Douze jours apr�s la pollinisation la teneur en sucres est relativement �lev�e, alors que la teneur en amidon est faible. A mesure que le grain m�rit, les sucres diminuent et l'amidon augmente. On a constat�, par exemple, que les sucres avaient atteint un niveau de 9,4 pour cent du grain (extrait sec) dans des grains de 16 jours, mais que ce niveau diminuait sensiblement avec l'�ge. La concentration en saccharose, de 15 � 18 jours apr�s la pollinisation, �tait comprise entre 4 et 8 pour cent du poids sec du grain. Ces concentrations relativement �lev�es en sucres r�ducteurs et en saccharose pourraient expliquer la popularit� du ma�s commun immature et, plus encore du ma�s doux.

Sels min�raux

La concentration des cendres dans le grain de ma�s est d'environ 1,3 pour cent soit un peu moins seulement que la teneur en fibres brutes. Le tableau 14 fait appara�tre la teneur en sels min�raux de certains �chantillons du Guatemala. Il est vraisemblable que ce sont des facteurs environnementaux qui influent sur la teneur en sels min�raux. Le germe est relativement riche en sels min�raux, avec une valeur moyenne de 11 pour cent contre moins de 1 pour cent dans l'albumen. Il fournit environ 78 pour cent des sels min�raux du grain entier. C'est le phosphore qui vient en t�te, sous forme de phytate de potassiums suivi du magn�sium. Le phosphore est enti�rement contenu dans l'embryon, avec des valeurs

d'environ 0,90 pour cent dans le ma�s commun et d'environ 0,92 pour cent dans le ma�s opaque-2. Comme dans la plupart des c�r�ales, le mais a une faible teneur en calcium et en oligo-�l�ments.

Vitamines liposolubles

Le grain de ma�s contient deux vitamines liposolubles: la provitamine A' ou carot�no�des, et la vitamine E. Les carot�no�des se trouvent principalement dans le ma�s jaune, � des teneurs pouvant �tre g�n�tiquement contr�l�es, tandis que le ma�s blanc ne contient que peu ou pas de carot�no�des. La plupart des carot�no�des sont pr�sentes dans l'albumen corn� du grain le germe n'en contenant que de faibles quantit�s. Le b�ta-carot�ne est une source importante de vitamine A, mais malheureusement le ma�s jaune est beaucoup moins consomm� par les humains que le ma�s blanc. Squibb, Bressani et Scrimshaw (1957) ont constat� que le b�ta-carot�ne repr�sentait environ 22 pour cent du total des carot�no�des (de 6,4 � 11,3 �g par gramme) dans trois �chantillons de ma�s jaune. La teneur en cryptoxanthine repr�sentait 51 pour cent du total des carot�no�des. L'activit� de la vitamine A variait entre 1,5 et 2,6 �g par gramme. Les carot�no�des du ma�s jaune sont sujets � destruction apr�s le stockage. Watson (1962) a fait �tat de valeurs de 4,8 mg par kilogramme dans le ma�s au moment de la r�colte, valeurs qui tombaient � 1,0 mg par kilogramme apr�s 36 mois de stockage. La m�me d�perdition a �t� constat�e dans le cas des xanthophylles. Des �tudes r�centes ont montr� que l'on la transformation du b�ta-carot�ne en vitamine A en am�liorant la qualit� prot�ique du ma�s.

L'autre vitamine liposoluble, la vitamine E, sujette � un certain contr�le g�n�tique, se trouve surtout dans le germe. La source de vitamine E est constitu�e par quatre tocoph�rols, dont l'alpha-tocoph�rol est le plus actif sur le plan biologique. Toutefois le gamma-tocoph�rol est vraisemblablement plus actif comme antioxyg�ne que l'alpha-tocoph�rol.

Vitamines hydrosolubles

Les vitamines hydrosolubles se trouvent principalement dans la couche � aleurone du grain de ma�s, suivie du germe et de l'albumen. Cette distribution a son importance pour la transformation qui, comme on le verra plus loin, entra�ne des pertes de vitamines non n�gligeables. Des quantit�s variables de thiamine et de riboflavine ont �t� observ�es. La teneur est sensible davantage � l'environnement et aux pratiques culturales qu'� la structure g�n�tique. Toutefois, on a not� des �carts entre les vari�t�s dans le cas des deux vitamines. La vitamine hydrosoluble qui a fait l'objet des recherches les plus pouss�es est l'acide nicotinique, du fait de son association avec la carence en niacine ou pellagre, maladie fr�quente chez les populations consommant de grandes quantit�s de ma�s (Christianson et al., 1968). Comme pour les autres vitamines, la teneur en niacine varie selon les vari�t�s les valeurs moyennes s'�tablissant autour de 20 �g par gramme. Une caract�ristique propre � la niacine du ma�s est le fait qu'elle se trouve � l'�tat combin� sous une forme non accessible aux enzymes digestives. Certaines techniques de transformation hydrolysent la niacine et la rendent ainsi disponible. L'association de l'apport en mais et de la pellagre s'explique par la faible teneur du grain en niacine, encore que les travaux exp�rimentaux aient montr� que des d�s�quilibres des acides amin�s tels que le rapport leucine/isoleucine, et

la disponibilit� du tryptophane jouent �galement un r�le important (Gopalan et Rao, 1975; Patterson et al., 1980).

Le mais ne contient pas de vitamine B12, et le grain m�r ne contient au mieux que de faibles quantit�s d'acide ascorbique. Yen, Jensen et Baker (1976) ont observ� une teneur d'environ 2,69 mg par kilogramme de pyridoxine disponible. Les autres vitamines qu'il s'agisse de la choline, de l'acide folique ou de l'acide pantoth�nique ne se trouvent qu'� de tr�s faibles concentrations.

TABLEAU 15 - Qualit� prot�ique du ma�s et d'autres c�r�ales

C'�r�ale	**Qualit� prot�ique (pourcentage de caseine)**
ma�s comun	32,1
ma�s opaque-2	96,8
QPM	82,1
Riz	79,3
Froment	38,7
Avoine	59,0

Sorgho	32,5
Orge	58.0
Mil chandelle	46,4
Eleusine cultiv�e	35,7
Teff	56,2
Seigle	64.8

Modifications de la composition chimique et de la valeur nutritive au cours du d�veloppement du grain

Dans de nombreux pays, le mais immature est fr�quemment utilis� pour l'alimentation, soit cuit entier en �pi, soit moulu pour �liminer le t�gument s�minal, la pulpe servant � pr�parer des gruaux �pais ou autres aliments tels que les tamalitos. Les modifications de la composition chimique qui se produisent � l'�poque de la maturation sont importantes. Toutes les �tudes ont mis en �vidence sur la base de la mati�re s�che, une baisse de la teneur en azote, en fibres brutes et en cendres, et une augmentation de l'amidon et de l'extrait � l'�ther (par exemple Ingle, Bietz et Hageman, 1965). Les prot�ines solubles dans l'�thanol augmentent rapidement � mesure que le grain parvient � maturit� tandis que la teneur en prot�ines solubles dans les acides ou alcalis dilu�s diminue. Au cours de ce processus biochimique, on assiste � une augmentation des teneurs en arginine, isoleucine, leucine et ph�nylalanine (exprim�es en milligrammes par gramme d'azote), tandis que la lysine, la

m�thionine et le tryptophane diminuent avec la maturation. En outre, G�mez-Brenes, El�as et Bressani (1968) ont mis en �vidence une diminution de la qualit� des prot�ines (exprim�e en coefficient d'efficacit� prot�ique). Il en r�sulte que la consommation du ma�s immature devrait �tre encourag�e pendant le sevrage et pour l'alimentation des nourrissons.

Valeur nutritionnelle du ma�s

L'importance que rev�tent les c�r�ales pour la nutrition de millions d'habitants de la plan�te n'a pas � �tre d�montr�e. Etant donn� la consommation relativement importante dont elles font l'objet dans les pays en d�veloppement, les c�r�ales ne peuvent pas �tre consid�r�es uniquement comme une source d'�nergie puisqu'elles fournissent �galement des apports importants en prot�ines. On sait aussi que les c�r�ales ont une faible concentration de prot�ines et que la qualit� de ces prot�ines est limit�e par des carences en certains acides amin�s essentiels, la lysine principalement. Ce que l'on sait beaucoup moins, c'est que quelques c�r�ales contiennent un exc�s de certains acides amin�s indispensables ce qui a une influence sur le rendement de l'utilisation des prot�ines. Le mais en est l'exemple classique. D'autres c�r�ales pr�sentent ce m�me inconv�nient, mais � un moindre degr�.

Le tableau 15 compare la valeur nutritionnelle des prot�ines du ma�s avec la qualit� prot�ique de huit autres c�r�ales, exprim�e en pourcentage de la cas�ine. La qualit�

prot�ique du ma�s commun est semblable � celle des autres c�r�ales � l'exception du riz. Le ma�s opaque-2 aussi bien que le QPM � albumen corn� (Nutricta) ont une qualit� prot�ique non seulement sup�rieure � celle du ma�s commun, mais aussi sensiblement sup�rieure � celle des autres c�r�ales.

De nombreux chercheurs se sont attach�s � �tudier les raisons de la faible qualit� des prot�ines du ma�s. Parmi les premi�res �tudes, il faut citer celles de Mitchell et Smuts (1932) qui ont obtenu une am�lioration sensible de la croissance humaine lorsque des r�gimes alimentaires contenant 8 pour cent de prot�ines du ma�s �taient suppl�ment�s par 0,25 pour cent de lysine. Ces r�sultats devaient �tre confirm�s par la suite par plusieurs auteurs (par exemple Howe.Janson et Gilfillan, 1965), tandis que d'autres (par exemple Bressani, El�as et Braham, 1968) montraient que l'addition de lysine au macs n'entra�ne qu'une l�g�re am�lioration de la qualit� prot�ique. Ces �carts dans les r�sultats pourraient s'expliquer par des variations de la teneur en lysine des diff�rentes vari�t�s de ma�s. Des travaux consacr�s � cette question devaient d�boucher sur la d�couverte, par Mertz, Bates et Nelson (1964), du ma�s � haute teneur en lysine appel� opaque-2.

Pour certains chercheurs (Hogan et al., 1955), c'est le tryptophane, et non pas la lysine, qui est le premier acide amin� limitant du ma�s, ce qui peut �tre vrai de certaines vari�t�s � forte concentration de lysine ou de produits d�riv�s du ma�s modifi�s par tel ou tel mode de transformation. Tous les chercheurs s'accordent d'ailleurs � consid�rer que l'addition simultan�e de lysine et de tryptophane am�liore sensiblement la qualit� prot�ique du ma�s. L'exp�rimentation animale a confirm� ces r�sultats.

L'am�lioration de qualit� obtenue apr�s addition de lysine et de tryptophane a �t� faible dans le cas de certaines �tudes et plus importante dans d'autres, lorsqu'il y avait addition d'autres acides amin�s. Il semblerait qu'apr�s la lysine et le tryptophane l'acide amin� limitant soit l'isoleucine, ainsi qu'en t�moignent des �tudes sur l'alimentation animale (Benton, Harper et Elvehjem, 1955). La plupart des chercheurs qui ont communiqu� ces observations ont indiqu� que l'effet de l'addition d'isoleucine s'expliquait par un exc�s de lencine interf�rant avec l'absorption et l'assimilation de l'isoleucine (Harper, Benton et Elvehjem, 1955; Benton et al., 1956). Selon certains �crits. l'apport �lev� en leucine qu'entra�ne la consommation des prot�ines du ma�s accro�t les besoins en niacine, et cet acide amin� pourrait �tre partiellement responsable de la pellagre.

Chaque fois que l'on a observ� une r�ponse � l'addition de thr�onine, on l'a interpr�t�e comme une correction par cet acide amin� des d�s�quilibres d'acides amin�s dus � l'addition de m�thionine. Un r�le analogue peut �tre attribu� � l'isoleucine dans les cas ou l'addition de cette derni�re s'est traduite par une am�lioration des r�sultats. De m�me, l'addition de valine, qui entra�ne une baisse de la qualit� prot�ique, pourrait �tre corrig�e par l'addition d'isoleucine ou de thr�onine.

En tout cas, l'isoleucine semble plus efficace que la thr�onine, dans la mesure o� elle donne des r�sultats plus r�guliers. Ces observations pourraient s'expliquer par le fait que le mais n'est d�ficient ni en isoleucine ni en thr�onine. Toutefois, certains �chantillons de ma�s peuvent contenir des quantit�s plus importantes de leucine, de m�thionine et de valine, et requ�rir l'addition d'isoleucine et de thr�onine, en plus de la lysine et du tryptophane, pour

am�liorer la qualit� prot�ique. De toute fa�on, l'addition de 0,30 pour cent de L-lysine et de 0,10 pour cent de L-tryptophane am�liore facilement la qualit� prot�ique du ma�s de 150 pour cent (Bressani, El�as et Braham, 1968). Bon nombre des r�sultats relatifs aux acides amin�s limitants des prot�ines du ma�s sont influenc�s par la teneur en prot�ines du ma�s. Comme on l'a dit plus haut, la teneur en prot�ines du ma�s est un trait g�n�tique affect� par les engrais azot�s. L'accroissement de la teneur en prot�ines qui a �t� observ� est en �troite corr�lation avec la z�ine, prot�ine alcoolosoluble, qui a une faible teneur en lysine et en tryptophane et contient des quantit�s excessives de leucine. Frey (1951) a constat� une forte corr�lation entre la teneur en prot�ines et la z�ine du ma�s, constatation qui a �t� confirm�e par d'autres chercheurs. En utilisant diff�rentes esp�ces animales, plusieurs auteurs ont conclu que la qualit� prot�ique du ma�s � faible teneur en prot�ines est plus �lev�e que celle du ma�s � haute teneur en prot�ines lorsque les prot�ines des r�gimes utilis�s sont les m�mes. Cependant, � poids �gal, le ma�s � haute teneur en prot�ines est l�g�rement sup�rieur en qualit� au mais � faible teneur en prot�ines. Les niveaux des prot�ines alimentaires influent alors sur la r�ponse observ�e apr�s suppl�mentation par des acides amin�s, la lysine et le tryptophane pour l'essentiel, mais �galement par d'autres acides amin�s tels que l'isoleucine et la thr�onine.

Table des mati�res - □Pr�c�dente - Suivante□