# Traditional Maize Processing Techniques in the New World

Traditional alkali processing enhances the nutritional quality of maize.

S. H. Katz, M. L. Hediger, L. A. Valleroy

Three major agricultural revolutions, each closely associated with the origins of great civilizations, have occurred within the last 10,000 years. These subsistence changes, marking the beginning of a dependency on cereal crops, have had a profound effect on the evolutionary course of modern humans. They have allowed, among other things, considerable shifts in diet, rapid increases in population size, major changes in the social and cultural organizations of various populations, and the laying of the developmental foundations for modern technology. In many respects, these changes are associated with both the biological and cultural evolution of modern man. Each of these revolutions was associated with particular cultigens. Wheat and other cereal grains were first domesticated in the Middle East, rice in Western Asia, and maize (Indian corn) (*1*) in the Western Hemisphere.

The earliest reported archeological evidence of maize dates back to the wild precursors that existed some 7000 years ago in central Mexico (*2*). By 1500 to 2000 years later, maize was already under cultivation and was very much involved in the subsequent rise of the great Mesoamerican civilizations. In South America, maize (*3*) was also involved, along with other major cultigens, in the rise of the Andean civilizations. However, it did not have as important a role as in Mesoamerica. Over this period of time, maize became an obligatory cultigen, which in modern times has been hybridized to produce strains of corn capable of yielding a variety of characteristics of nutritional and agricultural value. Corn is still the largest single crop in the United States, and it is still the largest source of calories and protein for many of the people of Central America (*4*).

Each of the plants domesticated in the various geographical areas has its nutritional limitations, and maize is no exception, especially in terms of the quantity and quality of its essential amino acids and niacin. In fact, unless corn is prepared by specific techniques, its nutritional value as a dietary source is at best marginal, and any human population that attempted to depend on it as a major staple would suffer some degree of malnutrition. To demonstrate the precise role of alkali cooking techniques in the freeing of otherwise unavailable nutrients in corn, we give a brief description of the biology and biochemistry of corn, and discuss the effects of alkali treatment upon its indigestible protein fractions. We also describe some hypotheses concerning the use of alkali for cooking corn, and provide cultural data from 51 societies recorded in the Human Relations Area Files (HRAF) (*5*) to test these hypotheses. Finally, we discuss the cultural, evolutionary, and other anthropological implications of the data.

## The Biology and Biochemistry of Corn

The importance of corn in the Western Hemisphere and elsewhere around the world has led to thorough studies of the nutritional value of this plant food and, especially, of its implications in Mexico and Central America where it predominates as a chief source of nutrition. In general, studies in Mexico and Central America have paid particular attention to the extensive use of tortillas, a food made from corn cooked with alkali, as the major dietary staple of the people (*6, 7*). A number of experiments with rats (*8, 9*) and pigs have demonstrated that diets consisting of tortillas yield better growth patterns than diets of raw corn (*10*). Nevertheless, it has been demonstrated by chemical analyses that, in the process of preparing tortillas, a certain amount of the nutritional value of the corn is lost (*7*). This has led investigators to question how the preparation of tortillas enhances the biologically effective nutritional value of corn while simultaneously reducing its total nutritional content. Since the nutritional value of corn is limited chiefly by the quality and quantity of its proteins, it is necessary to identify the composition and nutritional characteristics of corn proteins.

The corn kernel has several anatomical parts. These include the outer covering, consisting of the pericarp and aleurone; the endosperm, comprising the largest fraction of the kernel; and the germ consisting of the embryo and scutellum (see Fig. 1). The dried corn kernel contains approximately 6.8 to 12.0 percent protein by weight, 74.5 percent starch, 12.0 percent water, 3.4 percent fat, and 1 percent ash and crude fibers (*11*). Proteins of several different classes, categorized on the basis of solubility, have been identified in corn, principally in the endosperm and germ portions of the kernel. Together, these two portions contain 90 to 95 percent of the protein in corn (*12*). Within these two portions, there are four classes of proteins: (i) albumins and (ii) globulins, extractable in dilute saline solutions; (iii) zein, a heterogeneous protein with a molecular weight of 20,000 to 50,000, which is classed as a prolamine and is extractable in an ethanol solution; and (iv) glutelin, a heterogeneous protein varying in molecular weight from 20,000 to 1,000,000 and extractable in alkali solution (see Table 1) (*12*). This wide range of the glutelin's molecular weight is due to the extensive disulfide linkages between cysteine residues which account for the protein's tertiary structure and its particular sensitivity to denaturation in dilute alkali (*13*).

Dr. Katz is the director of the W. M. Krogman Center for Research in Child Growth and Development, is an associate professor in the departments of pediatric dentistry and anthropology at the University of Pennsylvania, and a member of the department of clinical research at the Eastern Pennsylvania Psychiatric Institute. M. L. Hediger and L. A. Valleroy are graduate students in the department of anthropology at the University of Pennsylvania.

Table 1. Lysine, leucine,, and isoleucine in the protein fractions of the endosperm and embryo of corn. Data are expressed as percentages of total nitrogen (*12*). The measurements were made by Mertz *et al.* (*12*) according to a copper extraction-fractionation method. The acid soluble fraction is similar to, but not exactly the same as, the albumins and globulins. The data were obtained from the normal type of corn. New varieties of corn, such as opaque-2, have a higher lysine content and a more favorable isoleucine to leucine ratio (*12*). Values for tryptophan were not obtained. Tryptophan and niacin comprise 0.044 percent and 0.0018 percent of the protein in the corn kernel (*14*).

| Amino acid | Endosperm | | | | Embryo | | | |
|---|---|---|---|---|---|---|---|---|
| | Acid soluble fraction | Zein | Glutelin | Total endosperm | Acid soluble fraction | Zein | Glutelin | Total endosperm |
| Lysine | 1.8 | 0.3 | 3.6 | 2.0 | | | | 6.1 |
| Leucine | 10.1 | 20.3 | 8.6 | 14.3 | | | | 6.5 |
| Isoleucine | 3.0 | 4.2 | 3.4 | 3.8 | | | | 3.1 |
| Total nitrogen | 16–26 | 41–60 | 17–31 | 98 (residue, 2-11) | 30–40 | 5–10 | 49–54 | 98 (residue, 0–11) |

In general, corn is deficient in the essential amino acids lysine and tryptophan, and in niacin, a member of the vitamin B complex. Approximately two-thirds of the lysine is within the glutelin fractions of the endosperm and germ, and in many nonruminant animals, including humans, the glutelin fractions are normally indigestible. Even under ideal laboratory conditions, the quantity of lysine that can be extracted from corn is nutritionally inadequate relative to the other essential amino acids that corn contains. Thus, any way of increasing the availability of the lysine in corn would enhance its nutritional value.

In the case of tryptophan, a precursor to niacin, Aguirre *et al.* (*14*) demonstrated in some 23 varieties of Guatemalan corn that the average daily intake of 500 grams supplies only 88 percent of the estimated adult requirement for this amino acid. On the other hand, the niacin content of the same corn varieties would supply only 59 percent of the dietary intake recommended by the National Research Council (*15*), based on a daily consumption of 500 grams. Because the metabolism of tryptophan is associated with the endogenous production of niacin, a population whose diet consisted mainly of maize would be likely to develop pellagra as a result of niacin deficiency, if other dietary constituents were not present on a seasonal basis to supplement the tryptophan or niacin, or both (*16, 17*). Indeed, pellagra was rampant in the southern United States through the Depression (*18*) and is still a major disease in South Africa and India. The disease has a very low rate of occurrence in Mesoamerica (*19, 20*).

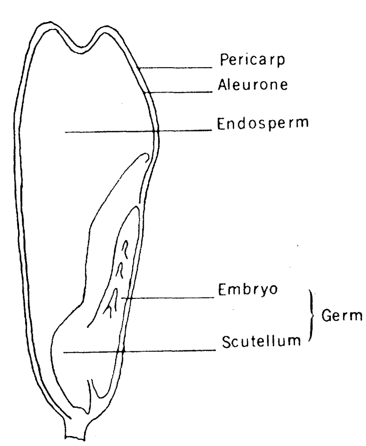


Fig. 1. Longitudinal section of corn kernel (*Zea mays*).

There is evidence to suggest that pellagra can also be induced by an unfavorable isoleucine to leucine ratio, that is, by an excessive amount of leucine in the diet. Such is the case in a diet heavily dependent on corn (*16, 21*). In 500 grams of corn there is approximately twice the recommended adult intake of leucine, and the leucine to isoleucine ratio is nearly three times greater than that which is considered optimal (*22*). Since the antagonistic effect of leucine on the conversion of tryptophan to niacin is ameliorated by increases in isoleucine, then any rise in the ratio of isoleucine to leucine as a result of cooking with alkali would help to minimize the effects of niacin deficiency.

Two important experiments by Bressani and his co-workers (*7, 22*) demonstrated the effects of the alkali cooking processes on corn, with particular reference to the changes that take place with respect to low levels of lysine, tryptophan, and niacin, as well as the high levels of leucine. In the first experiment, Bressani *et al.* (*7*) documented overall losses of significant quantities of thiamin, riboflavin, niacin, nitrogen, fat, and crude fiber resulting from the preparation of tortillas from raw corn (*23*). Tortillas are made in Central America by heating dried corn to almost boiling in a 5 percent solution of lime in water for 30 to 50 minutes; the mixture is then cooled, the supernatant is discarded, and the corn is washed thoroughly, and drained. The remaining corn is finely ground into a dough called *masa*, which is subsequently formed into pancake shapes and cooked on a hot clay griddle for approximately 2 minutes on each side. The effect of the lime is to yield a dilute calcium hydroxide solution which is basic or alkaline. While this cooking process, and particularly the lime treatment, clearly decreases the overall nutrient content of the corn, Bressani and Scrimshaw (*22*) demonstrated that cooking with lime selectively enhances the nutritional quality of corn. This qualitative change probably results from a relative decrease in the solubility of the

Table 2. Ratios of essential amino acids in cooked (alkali-treated) and uncooked (raw) corn subjected to chemical hydrolysis and enzymatic digestion in vitro with pepsin for 12 hours. Computed from data of Bressani and Scrimshaw (*22*). The raw data were expressed as milligrams of amino acid per gram of nitrogen in raw corn and tortillas.

| Amino acid | Ratio* of amino acid in cooked and uncooked corn | |
|---|---|---|
| | Chemical hydrolysis (cooked: uncooked) | Enzyme digestion in vitro (cooked: uncooked) |
| Histidine | 0.86 | 2.33 |
| Isoleucine | 0.79 | 2.14 |
| Leucine | 0.43 | 1.16 |
| Lysine | 1.04 | 2.80 |
| Methionine | 0.71 | 2.09 |
| Phenylalanine | 0.42 | 1.14 |
| Threonine | 0.96 | 2.63 |
| Tryptophan | 0.50 | 1.29 |
| Valine | 0.38 | 1.02 |

* While chemical hydrolysis yields the absolute quantities of essential amino acids, for purposes of constructing these ratios, it is perhaps more significant to point out that the enzymatic digestion in vitro more closely parallels the ratios that would be obtained after digestion in vivo.

zein portion of the corn proteins. The zein portion is deficient in lysine and tryptophan compared to the glutelin fraction, which is rich in proteins that yield essential amino acids.

Because the chemical procedures, used in determining amino acid content, are more effective than digestion in vivo, Bressani and Scrimshaw (*22*) subjected alkali cooked and uncooked corn samples to both chemical extraction and in vitro digestion with pepsin for 12 hours to determine whether the outcome of the two procedures differed. The results of the chemical procedures on the two samples showed no differences in the amounts of amino acids, expressed in milligrams per gram of nitrogen, except for the lowering of the leucine content in both samples. However, the results (Table 2), which are calculated from the data of Bressani and Scrimshaw (*22*), indicate that there are a number of relative changes in the alkali-treated corn digested with pepsin, which improve its overall nutritional quality. These results are expressed as ratios of the amounts of amino acids in alkali-treated tortillas to the amounts extracted from raw corn.

When expressed on the basis of grams of amino acids per 100 grams of corn, the data indicate that in the lime-treated tortillas there is absolute lowering of most of the essential amino acids, with the exception of lysine. However, this is not unexpected because there are considerable losses of total nitrogen during the cooking process. What is most interesting is the relative enhancement of the ratios when the data are calculated on the basis of milligrams of amino acid per gram of nitrogen. Any increase in the ratios obtained on this basis would indicate that cooking with lime selectively enhances the quality of the corn protein that is available for enzymatic digestion. Under these conditions, the relative amount of lysine is increased 2.8 times, tryptophan is increased slightly, and both the relative and absolute ratios of isoleucine to leucine are increased 1.8 times. Other essential amino acids such as histidine, methionine, and threonine are also relatively doubled in concentration. Not only are the relative amounts of essential amino acids significantly improved by this process, but also the availability in vivo of both the precursors to niacin and niacin itself appear to be enhanced (*9*). Thus, as long as maize is the major component of the diet, then cooking techniques in which alkali and heat are used clearly enhance the balance of essential amino acids and free the otherwise almost unavailable niacin.

## Significance of Alkali Cooking Techniques

In effect, without alkali processing of corn, there would be a considerable degree of malnutrition in societies where corn is the major part of the diet; this malnutrition could only be avoided if the diet were supplemented with foods rich in essential amino acids. While it is conceivable that increases in the quantity of corn consumed might enable adults to overcome some of the problems of malnutrition (*24*), it is unlikely that young children during phases of rapid growth and development could eat enough corn to compensate for its nutritional deficiencies. Such children would therefore suffer from significant effects of malnutrition. Societies whose cooking techniques did not include the use of alkali must either have adopted patterns of nutrition that included supplements to the maize diet, thereby decreasing its agricultural potential, or have become decimated by malnutrition, especially among the young children. We therefore hypothesized that all societies that depend on maize as a major dietary staple practice alkali cooking techniques.


Fig. 2. Map showing the locations of the 51 societies that we investigated. The numbers correspond to the societies listed in Table 3.

*Cultural data.* To test our hypothesis, we selected from the New World a large number of societies, that are described extensively in the ethnographic literature, and determined the extent to which they cultivate and consume maize, and whether or not they use some form of alkali treatment in the preparation of corn for consumption.

The 51 societies that we investigated are represented in the HRAF (*5*) and

Table 3. Summary of cultural information (*49*). Names of subgroups of societies are shown in parentheses when appropriate. The designations from the HRAF are those indicated by Murdock (*28*). For maize cultivation, the ratings 0, 1, 2, and 3 represent the estimated relative amount of maize cultivation practiced by each society in relation to the total crop production obtained by means of cultivation. The ratings are defined as follows: 0, none; 1, there are other major cultigens whose produce contributes to diet, and maize plays an insignificant role in the agricultural effort; 2, maize is cultivated intensively, but there is also substantial or comparable cultivation of other crops; 3, maize is cultivated intensively as the major subsistence item with little or no cultivation of other crops. For maize consumption, the ratings represent the estimated relative amount of maize in each society's total diet. It does not account for seasonal variation but only dietary intake within a yearly span. The ratings are defined as follows: 0, none; 1, in conjunction with the rating 1 for maize cultivation, or maize is not cultivated but obtained as a trade item from other peoples; 2, maize may be the major agricultural crop, but there is also dietary dependency on other forms of subsistence, such as hunting or gathering; 3, maize, being the major cultigen, is also the major food staple with only minor supplementation by other crops, wild plants, or animal produce. The column for alkali treatment indicates the presence (plus) or absence (minus) of alkali treatment during the processing of corn. This can include lime, wood ash, or lye in soaking or boiling. It does not include the process of exclusively roasting or baking under ashes because its value for alkali hydrolysis would be questionable. The digits in the column for Murdock's subsistence economy have values that were assigned by Murdock (*50*). Each digit represents the relative dependency of the society on the five major types of subsistence economy: 1st digit, the gathering of wild plants and small land fauna; 2nd digit, hunting, including trapping and fowling; 3rd digit, fishing, including shellfishing and the pursuit of large aquatic animals; 4th digit, animal husbandry; 5th digit, agriculture. The digits in each column are defined on the basis of dependence, and the values are percentages: 0, 0 to 5; 1, 6 to 15; 2, 16 to 25; 3, 26 to 35; 4, 36 to 45; 5, 46 to 55; 6, 56 to 65; 7, 66 to 75; 8, 76 to 85; 9, 86 to 100. The comments are brief notes on the major subsistence staples of each society, and on how maize is obtained by those who utilize it in their diets but do not cultivate it. References are for the ethnographic sources consulted in the HRAF (*49*).

| Name of society | HRAF designation | Maize cultivation | Maize consumption | Alkali treatment | Murdock subsistence economy | Comments | References (*49*) |
|---|---|---|---|---|---|---|---|
| | | | | *Eastern and northern North America* | | | |
| 1. Ojibwa (Chippewa) | NG 6 | 2 | 1 | + (soda, lye) | 22402 | Gather wild rice; equally cultivate beans, squash, pumpkins | Densmore 1929 |
| 2. Micmac | NJ 5 | 0 | 0 | – | 15400 | Hunting, gathering, fishing | Parsons 1928; Speck and Dexter 1951; Wallis and Wallis 1955 |
| 3. Delaware (Munsee) | NM 7 | 3 | 2 | + (hardwood ashes) | 22204 | Hunting, fishing, gathering | Heckewelder 1819; Tantaquidgeon 1942; Kinietz 1946; Newcomb 1956 |
| 4. Iroquois (Seneca) | NM 9 | 3 | 2 | + (lye, ashes) | 13204 | Hunting, fishing, gathering | Morgan 1901 (1850); Waugh 1916; Quain 1937; Lyford 1945; Speck 1945 |
| 5. Comanche | NO 6 | 0 | 1 | – | 19000 | Buffalo hunters; maize obtained as trade item from Kiowas, Witchitas, and other eastern tribes | Wallace and Hoebel 1934; Hoebel 1940 |
| 6. Natchez | NO 8 | 3 | 2 | + (ashes) | 03205 | Hunting, fishing | Swanton 1911 |
| 7. Winnebago | NP 12 | 3 | 2 | + (ashes) | 23203 | Hunting, fishing, gathering | Radin 1915/1916; Lurie 1961 |
| 8. Crow | NQ 10 | 0 | 1 | + (ashes) | 28000 | Maize obtained as trade item from the Hidatsa; buffalo hunters | Lowie 1935; Morgan 1959 |
| 9. Dhegiha (Omaha) | NQ 12 | 3 | 2 | + (ashes) | 14104 | Hunting, fishing, gathering | Dorsey 1881/1882; Fletcher and La Flesche 1905/1906 |
| 10. Gros Ventre | NQ 13 | 0 | 0 | – | 28000 | Buffalo hunters | Kroeber 1908; Flannery 1953 |
| 11. Mandan | NQ 17 | 3 | 2 | + (ashes) | 03205 | Tubers mainly cultivated | Will and Spinden 1906; Will and Hyde 1917 |
| 12. Pawnee | NQ 18 | 3 | 2 | + (ashes) | 14005 | Gathering, buffalo hunting | Lesser 1933; Wedel 1936; Weltfish 1965 |
| | | | | *Intermediate and intermountain North America* | | | |
| 13. Northern Paiute (Paviotso) | NR 13 | 0 | 0 | – | 52300 | Acorn gatherers | Lowie 1924 |
| 14. S. E. Salish (Coeur d'Alene) | NR 19 | 0 | 0 | – | 34300 | Acorn gatherers | Teit 1927/1928 |
| 15. Pomo (Eastern Pomo) | NS 18 | 0 | 0 | – | 43300 | Acorn gatherers | Loeb 1926 |
| 16. Tübatulabal | NS 22 | 0 | 0 | – | 53200 | Acorn gatherers | Wheeler-Voegelin 1938 |
| 17. Yokuts | NS 29 | 0 | 0 | – | 43300 | Acorn gatherers | Gayton 1948 |
| 18. Yurok | NS 31 | 0 | 0 | – | 41500 | Acorn gatherers | Heizer and Mills 1952 |
| 19. Washo | NT 20 | 0 | 0 | – | 43300 | Acorn gatherers | Barrett 1917; d'Azevedo *et al.* 1963 |

| Name of society | HRAF designation | Maize cultivation | Maize consumption | Alkali treatment | Murdock subsistence economy | Comments | References (*49*) |
|---|---|---|---|---|---|---|---|
| | | | | *Southwestern North America* | | | |
| 20. E. Apache (Chiricahua) | NT 8 | 0 | 0 | — | 64000 | Hunting, gathering | Opler 1941 |
| 21. Navaho | NT 13 | 3 | 2 | + (ashes) | 21304 | Pastoralists | Hill 1938; Leighton and Leighton 1944; Kluckhohn and Leighton 1946; Reichard 1950 |
| 22. Plateau Yumans (Havasupai) | NT 14 | 3 | 2 | + (ashes) | 32005 | Maize is major crop | Curtis 1908; Spier 1928; Smithson 1959 |
| 23. River Yumans | NT 15 | 2 | 2 | + (lye, ashes) | 41203 | Shifting to wheat cultivation | Spier 1933 |
| 24. Tewa | NT 18 | 3 | 3 | + (ashes, lime) | 01018 | Maize is major crop | Robbins *et al.* 1916; Whitman 1940; Laski 1958 |
| 25. Zuñi | NT 23 | 3 | 3 | + (ashes, lime) | 11008 | Maize is major crop | Stevenson 1901/1902; Cushing 1920; Bunzel 1929/1930 |
| 26. Papago | NU 28 | 2 | 2 | — | 32005 | Shifting to wheat cultivation | Castetter and Underhill 1935; Castetter and Bell 1942; Pijoan *et al.* 1943 * |
| 27. Seri | NU 31 | 0 | 0 | — | 22600 | Hunting, gathering, fishing | McGee 1895/1896 |
| | | | | *Mexico and Central America* | | | |
| 28. Aztec | NU 7 | 3 | 3 | + (ashes, lime) | 01207 | Maize is major crop | Bandelier 1876/1879; Vaillant 1941; Sahagún 1957 |
| 29. Tarahumara | NU 33 | 3 | 3 | + (ashes, lime) | 01207 | Maize is major crop | Bennett and Zingg 1935; Fried 1953; Pennington 1963; Champion 1963 |
| 30. Tarasco | NU 34 | 3 | 3 | + (ashes, lime, soda) | 01207 | Maize is major crop | Beals and Hatcher 1943; Beals 1946; West 1948 |
| 31. Tzeltal | NV 9 | 3 | 3 | + (lime) | Not coded | Maize is major crop | Brom and LaFarge 1927; Villa Rojas 1969; Nash 1970 |
| 32. Yucatec Maya | NV 10 | 3 | 3 | + (lime) | 01207 | Maize is major crop | Gann 1918; Redfield and Villa Rojas 1934; Villa Rojas 1945 |
| 33. Mosquito | SA 15 | 1 | 1 | — | 32212 | Plantain is major crop | Conzemius 1932 |
| | | | | *Andean and tropical forest* | | | |
| 34. Talamanca | SA 19 | 1 | 1 | — | 11215 | Tubers mainly cultivated | Gabb 1876; Stone 1962 |
| 35. Cuna | SB 5 | 1 | 1 | — | 01306 | Plantain is major crop | Densmore 1926; Wafer 1934; McKim 1947 |
| 36. Cagaba | SC 7 | 2 | 2 | — | 00028 | Also cultivate beans and yuca extensively | Bolinder 1925; Reichel-Dolmatoff 1949/1950 |
| 37. Goajiro | SC 13 | 1 | 1 | — | 01171 | Pastoralists | Armstrong and Métraux 1948; Santa Cruz 1960 |
| 38. Páez | SC 15 | 3 | 2 | + (ashes) | 11026 | Maize is major crop | Bernal Villa 1954 |
| 39. Cayaba | SD 6 | 2 | 2 | — | 11215 | Also cultivate potatoes extensively | Barrett 1925; Murra 1948; Altschuler 1965 |
| 40. Jivaro | SD 9 | 1 | 1 | — | 12106 | Maize is major crop | Karsten 1935; Sterling 1938 |
| 41. Inca | SE 13 | 2 | 2 | — | 01027 | Also cultivate potatoes and guinea | Rowe 1946 |
| 42. Aymara | SF 5 | 1 | 1 | — | 00136 | Cultivate potatoes and guinea | Tschopik 1946; La Barre 1948 |
| 43. Chiriguano | SF 10 | 2 | 2 | — | 11215 | Cultivate variety of crops as well | Schmidt 1938; Métraux 1948 |
| 44. Ura (Chippewa) | SF 24 | 0 | 0 | — | Not coded | Cultivate pumpkins and guinea | Métraux 1935; Métraux 1935/1936; LaBarre 1946 |
| 45. Araucanians (Mapuche) | SG 4 | 1 | 1 | — | 10126 | Wheat is major crop | Titiev 1951; Hilger 1957 |
| 46. Mataco | S 17 | 1 | 1 | — | 22411 | Cultivate pumpkins and watermelons | Pelleschi 1896 |
| 47. Choroti | SK 6 | 1 | 1 | — | 43201 | Principally hunters | Rosen 1924 |
| 48. Callinago | ST 13 | 1 | 1 | — | 01504 | Cultivate bitter and sweet manioc | Rouse 1948; Hodge and Taylor 1957 |
| 49. Puerto Rico | SU 1 | 1 | 1 | — | Not coded | Variety of crops | Steward *et al.* 1956 |
| 50. Haiti | SV 3 | 1 | 1 | — | Not coded | Cultivate yams | Courlander 1960 |
| 51. Jamaica | SY 1 | 2 | 2 | + (ashes) | Not coded | Corn is major crop along with cassava | Beckwith 1929 |

* Pijoan *et al.* (*51*) have noticed subclinical signs of avitaminoses among the Papago, which are caused by dietary deficiencies.

Table 4. Results of statistical analyses of data from societies that consume or cultivate maize, or both. Societies that were rated zero for consumption were not included in the Student's *t*-test because they would have to consume corn in order to use alkali cooking methods. A similar consideration was made for cultivation.

| Items | Consumption | | Cultivation | |
|---|---|---|---|---|
| | Alkali $N=21$ | No alkali $N=18$ | Alkali $N=20$ | No alkali $N=17$ |
| Mean rating | 2.24 | 1.28 | 2.85 | 1.29 |
| Standard deviation | $\pm$ 0.63 | $\pm$ 0.46 | $\pm$ 0.37 | $\pm$ 0.47 |
| Student's *t*-test | 5.52 | | 11.11 | |
| *P* | $\ll .001$ | | $\ll .001$ | |

are located within defined cultural and geographical areas between 47°N and 43°S (*25–27*) where ecological conditions are suitable for the cultivation of corn (see Fig. 2). We restricted our investigation in this way because we assumed that maize cannot become a dietary staple of a society unless that society either cultivates its own corn or is in direct contact with another society that cultivates corn. The areas in which these societies are located include, for North and Central America, Kroeber's (*26*) (i) East and North, (ii) Intermediate and Intermountain, (iii) Southwest, and (iv) Mexico and Central America. Excluded from the North and Central American sample are those societies in the Arctic Coast and Northwest Coast areas. For South America, the relevant areas are Murdock's (*27*) larger ones that he terms (i) the Andean, encompassing the Isthmus, Colombian, Peruvian, and Chilean coasts and highlands, as well as the Caribbean, and (ii) the central western portion of the Tropical Forest area, excluding the Amazon basin, steppe-hunting area. Populations in the smaller peripheral hunting and fishing areas were not included in our studies because in these areas little or no maize was cultivated aboriginally.

In conducting our investigation, two researchers jointly rated the societies (see Table 3) according to (i) the extent to which they practice maize cultivation, (ii) the relative percentage of maize in their diets, and (iii) whether or not they use alkali when preparing maize for consumption. In these ratings the alkali used for cooking could include lime, which yields calcium hydroxide in solution; wood ashes, which yield potassium hydroxide; or lye, which yields sodium hydroxide. We used the HRAF categories that relate to tillage, cereal agriculture, diet, and food preparation. The ratings could only be inferred from the files since no absolute figures are available, and therefore our quantitative estimates were divided into only four categories including the designation "none," indicating that corn was neither cultivated nor consumed. As corroborative evidence, we consulted Murdock's (*28*) coding of subsistence economies for measures of dependence on agriculture (see Table 3 and Fig. 4).

There is a seasonal dimension to the processing and preparing of maize for consumption which our results in Table 3 do not indicate, but they bear mentioning in conjunction with the cultural explanations of alkali processing. With few exceptions, societies that use alkali cooking techniques as well as societies that do not use such techniques roast some of their maize. However, this roasting is done principally when the maize is green or not fully ripened, and it is done under ashes with the maize still in the husk. Although such roasting might have important effects on the corn, these effects have not been fully investigated (*8*, *23*). Furthermore, the roasting is done only in those seasons when crops of all sorts are being harvested, wild flora is abundant, and a variety of foods are available for consumption. It is the fully ripened or stored maize that is generally processed with alkali, the treatment usually being described as a way of softening the tough outer kernel (*17*).

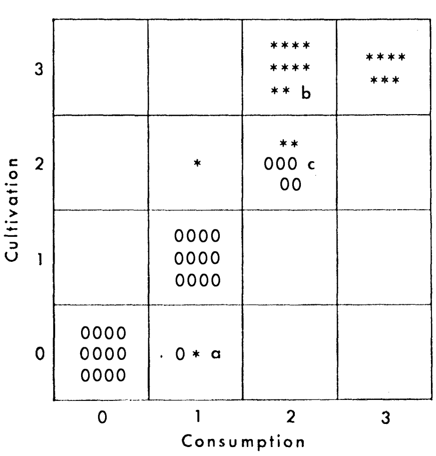


Fig. 3. The relationship between the use of alkali for processing maize and the extent to which societies cultivate or consume maize. An asterisk indicates a society that uses alkali to process maize; a zero indicates that a society does not use alkali. The degrees of cultivation and consumption were rated: 0, none; 1, low, less than one-third of crops, or diet, respectively; 2, moderate, one-third to two-thirds; 3, high, more than two-thirds. The symbols *a*, *b*, and *c* indicate the Crow, Páez, and Papago societies, respectively.

Of the 51 societies that we rated, 7 that are classified as both high consumers and high cultivators of maize also use alkali in preparing it for consumption. Conversely, none of the 12 societies classified as both low cultivators and consumers use alkali. Table 4 indicates the overall mean difference between users and nonusers of alkali at the levels of both cultivation and consumption. Data are shown only for those societies that either consume or cultivate some maize. Those societies where maize is a potential cultigen but is neither cultivated nor consumed (rated 0 for consumption and 0 for cultivation) were excluded from the statistical analyses. On this basis, the mean difference between users and nonusers was highly significant ($P \ll .001$) for both consumption and cultivation. Figure 3 shows that there is a striking, almost one-to-one relationship between those societies that both consume and cultivate large amounts of maize and those that use alkali treatment. On the other hand, those societies consuming and cultivating smaller quantities of maize almost invariably do not use alkali cooking techniques.

Figure 4 shows the ratings for maize cultivation and consumption for each of the societies investigated and indicates whether or not each society uses alkali. It is important to note that not all of the 51 societies studied either consume or cultivate maize. For example, the seven Indian tribes in California gather vast quantities of acorns, and this seems to reduce their need for a staple such as corn. Note also that lime use is restricted to Mesoamerica and the southwestern United States. As well as being an important source of alkali, lime is also an excellent source of calcium (*22*). This is unlike the high concentrations of potassium in wood ashes or sodium in lye. Finally, the overall lack of alkali treatments in most Andean populations may have implications for the history of maize cultivation.

## Discussion

We have attempted to explain the use of alkali for cooking maize as a necessary concomitant of intensive maize agriculture and high maize consumption. We will now show that this simple cooking technique for maize may have important implications for certain anthropological theories. For example, the data we have presented might help to substantiate a number of theories about the origins, development, and spread of maize cultivation in the New World, and about various sociocultural systems that are associated with the cultivation of maize.

One question that is of considerable interest is whether or not the lower rates of maize production and consumption in South America can be attributed directly to the lack of the discovery of alkali cooking techniques. Since alkali treatment is not used, and apparently has not been used in that area, one can postulate that it was necessary for other crops to be developed to supplement the otherwise inadequate maize diet. Such crops might not have been as successful, in terms of production, as maize. In Yucatan maize is the predominant crop, and the ratio of nonagricultural to agricultural workers is reported to be 12:1 (*29, 30*). However, it is difficult to test such hypotheses at this time, since this would involve complicated assumptions about ecological variables, the timing of discovery and the use of other cultigens, and other socioeconomic factors.

The data from our statistical analyses are strongly supported by descriptive historical data. Descriptive data are available that explain and account for several important exceptions (see the Papago, Crow, and Páez societies in Table 3) to the almost universal relationship between the production and consumption of maize and the use of alkali cooking techniques.

The Papago of the southwestern United States were classified as moderate producers and consumers of maize aboriginally but, unlike the remaining societies of the Southwest, there is no evidence that they processed corn with alkali. The Crow do use alkali, but they cultivate no corn and only sporadically consume it, obtaining it as a trade item from the neighboring Hidatsa, who are agriculturists. The Páez, on the other hand, deviate from the apparent South American pattern by cultivating maize as their major subsistence item and processing it with alkali.

The lack of alkali cooking techniques among the Papago can be explained on an ecological basis. According to Castetter and Bell (*31*) the Papago are seminomadic, living in an arid environment that prohibits year-round cultivation and sedentism. The land is not fertile enough to allow large harvests. Because food is scarce during most seasons, and because of their nomadism during the dry seasons, the Papago do not store their maize nor do they allow it to fully ripen. They eat most of it roasted in the husk during seasons when supplementary foods are available.

The use of an alkali processing technique by the Crow bears a simple historical explanation. The Crow once formed a single people with the Hidatsa (*32*), splitting off from that society to take up existence as nomadic buffalo hunters on the plains. This is supported both ethnohistorically and linguistically. Like the other sedentary village farmers of the upper Missouri River, the Mandan and the Arikara, the Hidatsa process maize by using alkali (*33*). The Crow continued to have contact with the Hidatsa, trading their buffalo meat for maize, and it follows that they merely continued their tradition from sedentary days of processing maize with alkali.

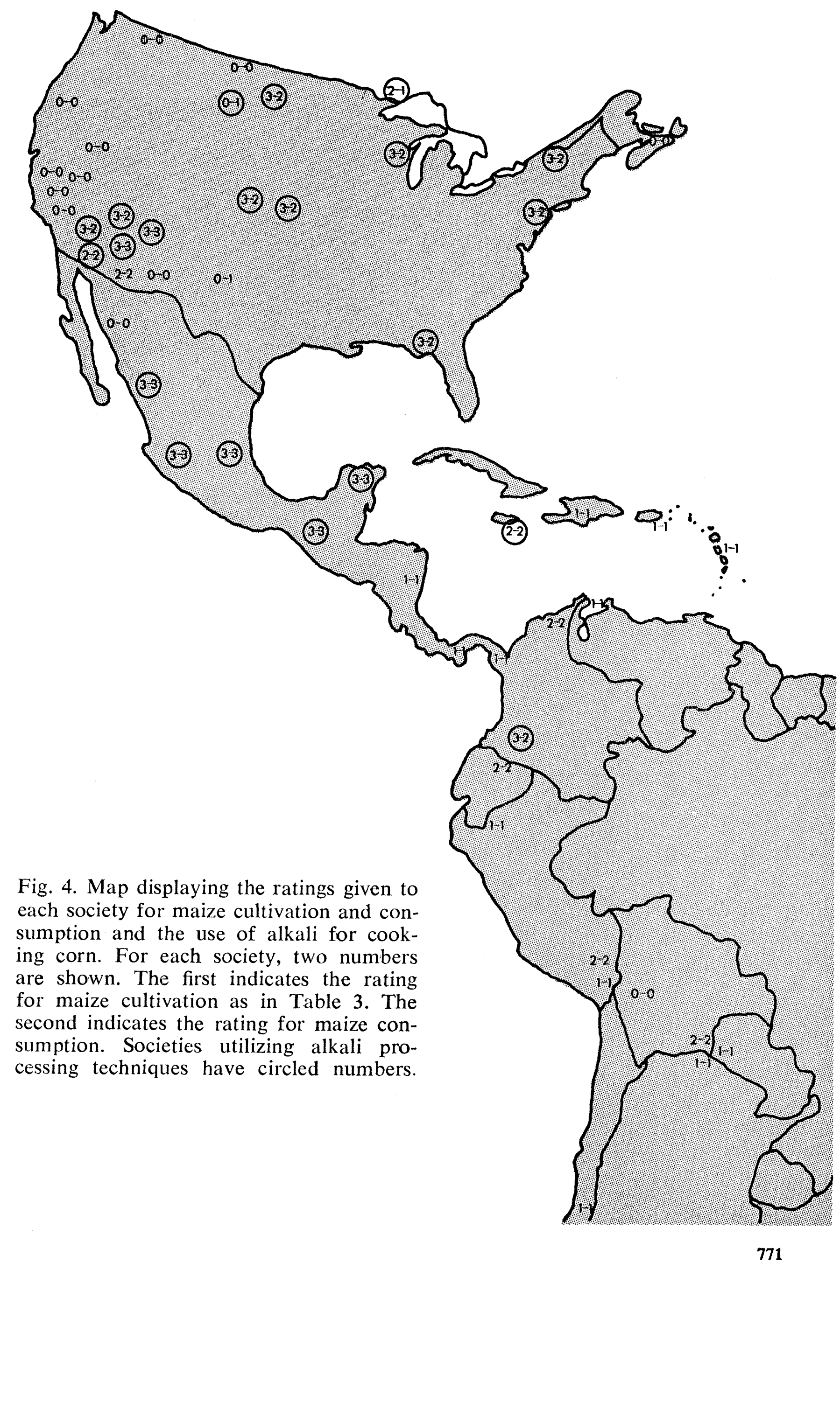

Fig. 4. Map displaying the ratings given to each society for maize cultivation and consumption and the use of alkali for cooking corn. For each society, two numbers are shown. The first indicates the rating for maize cultivation as in Table 3. The second indicates the rating for maize consumption. Societies utilizing alkali processing techniques have circled numbers.

To explain the cultivation of maize by the Páez, and their use of alkali, it is necessary to utilize archeological data. The Páez are Chib-chan speakers, living in the highland basins of Colombia. Archeological evidence supports the theory (*34*) that there was a late introduction of maize in Colombia, and that the maize came not from the Andes, but from Mesoamerica. Maize arrived simultaneously with other Mesoamerican cultigens as a fully developed complex, probably with an actual influx of peoples from Mesoamerica. The alkali processing technique most probably came into Colombia in conjunction with the cultigen.

Evidence for the use of alkali cooking techniques by certain societies may provide us with further insight into questions surrounding the origin of these techniques and enable us to determine whether they were invented independently by different societies or diffused along with maize cultivation in the Americas. It is interesting that the Páez are the only South American society in our sample that process maize with alkali, and that for this purpose they use wood ashes. Evidence in this instance points to a late introduction of maize, probably from Mesoamerica (*34*). Thus it is likely that the maize processing technique was introduced in conjunction with a cultigen complex. This is further suggested by the fact that all the North American producers and consumers of maize obtain alkali for maize preparation from wood ashes whereas none, except the Páez, do so in South America (see Fig. 4). The evidence from North America also favors diffusion of the alkali cooking technique, since all moderate (and heavy) cultivators and consumers use the same process. While this is not proof of independent domestication and invention of maize agriculture in the Andean areas, or elsewhere in South America, it does seem to raise new questions about these theories. Lime, as a source of alkali, is found predominantly in Mesoamerica and sporadically in the southwestern United States. Ashes and lye as sources of alkali are used elsewhere. This fact may have ecological significance regarding the presence and availability of limestone.

Since our evidence indicates that maize becomes an extensive part of the diet only when alkali cooking techniques are used, it should also be possible to obtain further archeological evidence to support this hypothesis. There is evidence (*35*) that lime-soaking pots were already in use by 100 B.C. at Teotihuacan, the first urban center in Mesoamerica. The economic implications of the early utilization of lime suggest important questions about its production, distribution, sale (*36*), and trade throughout Mesoamerica.

While most of the societies in our sample use either lime, lye, or wood ashes as a source of alkali, it has recently been observed that the Lacandon Maya of Chiapas, Mexico, after eating fresh water mussels, cremate the shells and use the ashes as a source of alkali (*37*). This practice may have important archeological implications in other lowland jungle areas of Yucatan and Guatemala, where natural sources of limestone are available but may not be used because alkali made from shells is preferred. With this evidence it is interesting to juxtapose the reports of plentiful supplies of fresh water shells from snails during the Pre-Classic period (ending in A.D. 250) in Copan (*38*) and in the Mayan Belize River valley (*39*). However, Longyear (*38*) has also noted that, by the Classic period, a steady and sharp decline had occurred in the abundance of shells and small animal bones in Copan.

Elsewhere in the Mayan region, Haviland (*40*) has documented from human skeletal remains at Tikal both a reduction in stature from Pre-Classic through Late Classic times (A.D. 550 to 900) and an increasing problem of malnutrition as demonstrated by radiological analyses of long bones. He attributed these findings to malnutrition stemming from increasing population density and decreasing sources of high quality protein from wild game. Similar malnutrition and high population densities occurred in the Belize River valley (*30*).

As a whole, the evidence from small animal bones and snail shells suggests that there was a parallel decline in these two protein resources and that this decline was probably due to overconsumption in the regions where the population densities were rising beyond the capacities of the ecosystems to support them. If the decrease in snails was also associated with a decrease in the availability of shells for alkali production in those areas where other alkali resources such as limestone were unused or scarce, then such developments could have had serious implications for those societies that might have become dependent on maize as the major part of their diet. Of course, these suggestions must be investigated further, because to our knowledge there are no published reports on the use of shells in the preparation of alkali for the treatment of maize during these times.

It is important to consider the nature of previous explanations of alkali cooking techniques for corn, since these techniques have been described extensively in the ethnographic literature. The explanation that most anthropologists and their informants have offered for the significance of this treatment in each society is that alkali softens and "hulls" the tough pericarp of the maize. At one level, this explanation is both accurate and plausible, and it may be for these reasons that only a few ethnographers have extended the explanation further, postulating, for example, that alkali treatment aids in the general digestive process. According to Beals (*41*), the Tarascans grind maize on the *metate* with bicarbonate of soda in order to prevent constipation. Tantaquidgeon (*42*) notes that the Delaware utilize hominy as the appropriate food for the sick. In describing the practices of the same society, Lindestrom (*43*) states that the ashes in which bread is baked function, as sand does for birds, "to clean their stomachs." However, among the Yucatec Maya the maize which is offered to the gods during various ceremonies is never treated with alkali, varying in this respect from the usual preparation of maize for human consumption (*44*). Bennett and Zingg (*45*) are among the few anthropologists who mention the cross-cultural significance of alkali treatment. They comment that boiling with alkali "is an essential corn preparation technique" which has migrated northward with the diffusion of maize.

What emerges from this brief review of anthropological explanations of the alkali processing of corn is the lack of a significant biological dimension in the conceptual paradigm of the ethnographic anthropologist (*46, 47*). By juxtaposing the latent biological dimension with the cross-cultural literature, alkali processing techniques assume highly significant proportions by apparently setting a type of critical limit on the consumption of maize. This concept of a critical limit can be used to enhance our understanding of the past and present distribution of maize agriculture and to suggest ways by which we can examine all aspects of such basic anthropological theories as those concerned with independent invention and diffusion.

## Adaptive and Evolutionary Implications

It is evident that in studies of human adaptability and evolution the sciences of man must consider in greater detail the interacting relationships of human biology and culture. The importance of these relationships has been well demonstrated from the genetic level in studies of diseases such as sickle cell anemia (*48*). Yet, in the case presented here, if the alkali cooking techniques used by societies consuming large quantities of maize are examined in the cultural context alone, then they would seem only to be innocuous methods for softening the outer kernel and would carry no adaptive or evolutionary significance. However, the evidence presented here implies that without these cooking techniques a high degree of dependence on corn produces serious malnutrition. Alternatively, if one considers the implications of raw maize for genetic evolution, it is unlikely that specific adaptations to diets of maize cooked without alkali would occur because any genetic change would have to involve the biosynthetic pathways of many essential nutrients.

Instead, one of the chief adaptations which allowed for the intensification of maize agriculture was a cultural one associated with the technology of food processing. In turn, the intensification of maize agriculture allowed for the evolution of further social complexity based on the reliability of subsistence, the concomitant residential stability, and the ability to support nonagricultural producing members of the society. This evolving social complexity undoubtedly affected adaptation at a variety of other demographic, ecological, and social levels which probably influenced the genetic composition of the population. Although the possible evolutionary changes that this example suggests may not be necessarily the same as one which might have occurred at the genetic level, such as sickle cell anemia, their implications for human adaptability may be no less important. This suggests that it is increasingly difficult to accept evolutionary studies where biological and cultural adaptation are treated independently.

### References and Notes


1. Throughout this article, the term "corn" refers collectively to both the modern hybrid and aboriginal races of *Zea mays*, while "maize" refers specifically to the aboriginal races.
2. R. MacNeish, in *The Prehistory of the Tehuacan Valley*, D. Byers, Ed. (Univ. of Texas Press, Austin, 1967), vol. 1, pp. 3–33, 114–131, and 290–310.
3. There is a long-standing controversy over the question of whether domesticated Andean maizes diffused into the Andes from Mesoamerica, or whether there was an independent focus of domestication in this area.
4. H. G. Wilkes, *Science* **177**, 1071 (1972).
5. Human Relations Area Files, Inc. (New Haven, Conn., 1949).
6. R. O. Cravioto, R. K. Anderson, E. R. Lockhart, F. de Miranda, R. S. Harris, *Science* **102**, 91 (1945).

R. Bressani, R. Paz y Paz, N. S. Scrimshaw, *J. Agric. Food Chem.* **6**, 770 (1958).

8. It should be noted that experiments with rats have not been as definitive as those with pigs. For example, W. N. Pearson [*J. Nutr.* **62**, 445 (1957)] reported that rats fed boiled corn thrived almost as well as rats fed alkali-treated corn. Two other reports also indicate that rats eating raw corn had the same growth rate as those on a diet of alkali-treated corn [see McDaniel and Hundley (*9*); W. A. Krehl *et al.*, *J. Biol. Chem.* **166**, 1531 (1946)]. This discrepancy is probably due to the fact that rats are more efficient in the conversion of tryptophan to niacin than man [E. Kodicek, R. Braude, S. K. Kon, K. G. Mitchell, *Br. J. Nutr.* **10**, 51 (1956)].
9. E. G. McDaniel and J. M. Hundley, *Fed. Proc.* **17**, 484 (1958).
10. J. Laguna and K. Carpenter, *J. Nutr.* **45**, 21 (1951).
11. H. J. Heinz Company, *Nutritional Data* (H. J. Heinz Company, Pittsburgh, Pa., 1963).
12. E. T. Mertz, O. E. Nelson, L. S. Bates, in *Adv. Chem. Ser.* **57** (1966).
13. J. W. Paulis, C. James, J. S. Wall, *J. Agric. Food Chem.* **17**, 1301 (1969).
14. F. Aguirre, R. Bressani, N. S. Scrimshaw, *Food Res.* **18**, 273 (1953).
15. *WHO Tech. Rep. Ser.* 477 (World Health Organization, Geneva, 1971).
16. L. V. Hankes, J. E. Leklern, R. R. Brown, R. C. Mekel, *Am. J. Clin. Nutr.* **24**, 730 (1971).
17. Another important nutritional supplement to the marginally deficient status of tryptophan in maize is the rather plentiful supply that occurs in beans. Thus a reciprocal relationship frequently exists with respect to beans or squash and the effective utilization of corn. However, it should be pointed out that corn tends to be more stable with respect to production and storage. On this basis, there could have been more seasonal variation in the availability of these important supplements. It is interesting in this context, that beans were domesticated considerably after maize in Mesoamerica, but this does not seem to be the case in Peru.
18. This can probably be associated with the extensive consumption of corn grits which were not treated with alkali.
19. J. M. May and D. L. McClellan, *The Ecology of Malnutrition in Mexico and Central America* (Hafner, New York, 1972). Since this manuscript was submitted, an excellent review of this problem has been published by D. A. Roe [*A Plague of Corn: The Social History of Pellagra*, Cornell Univ. Press, Ithaca, N.Y., 1973].
20. In various contemporary Latin American countries, such as Guatemala, the high consumption of coffee, which is rich in niacin, and the consumption of beans, which have a high tryptophan content, probably explain the apparent absence of pellagra.
21. C. Gopalan, *Nutr. Rev.* **26**, 323 (1968).
22. R. Bressani and N. S. Scrimshaw, *J. Agric. Food Chem.* **6**, 774 (1958).
23. While it is not our intent to discuss the benefits of cooking with lime as opposed to other alkali yielding salts, it is important to point out that Bressani and Scrimshaw (*22*) reported a very significant increase in the calcium content of maize that occurred as a result of the lime treatment [S. H. Katz and E. Foulks, *Am. J. Phys. Anthropol.* **32**, 299 (1970)].
24. It is important to point out, however, that the leucine to isoleucine ratio would continue to rise in uncooked corn (*22*) and, therefore, would tend to nullify the effects of the increased quantity of tryptophan consumed.
25. H. Driver, *Indians of North America* (Univ. of Chicago Press, Chicago, ed. 2, 1969).
26. A. L. Kroeber, *Cultural and Natural Areas of Native North America* (Univ. of California Publications in American Archaeology and Ethnology, No. 48, Berkeley, 1939).

G. P. Murdock, *Southwest. J. Anthropol.* **7**, 415 (1951).

28. ———, *Ethnographic Atlas* (Univ. of Pittsburgh Press, Pittsburgh, Pa., 1967).
29. M. D. Coe, *The Maya* (Praeger, New York, 1966).
30. J. Marcus, *Science* **180**, 911 (1973).
31. E. F. Castetter and W. H. Bell, *Pima and Papago Indian Agriculture* (Univ. of New Mexico Press, Albuquerque, 1942).
32. R. H. Lowie, *The Crow Indians* (Farrar and Rinehart, New York, 1935).
33. G. F. Will and G. E. Hyde, *Corn among the Indians of the Upper Missouri* (Univ. of Nebraska Press, Lincoln, 1917).
34. G. Reichel-Dolmatoff, *Excavationes Archeologias en Puerto Hormiga* (Ediciones de la Universidad de los Andes, Bogotá, 1965).
35. C. C. Kolb, personal communication.
36. That there were specific agents who sold lime in urban centers is well documented for Aztec times [B. de Sahagún, *Florentine Codex Books 4 and 5*, C. E. Dibble and A. J. Anderson, Translators, School of American Research and Univ. of Utah, Santa Fe, (1957)].
37. S. H. Katz, unpublished data.
38. J. M. Longyear, *Copan Ceramics: A Study of Southeastern Maya Pottery* (Carnegie Institution of Washington, Publ. 597, Washington, D.C., 1951).
39. G. R. Willey, W. R. Bullard, J. B. Glass, J. C. Gifford, *Prehistoric Maya Settlements in the Belize Valley* (Peabody Museum Series 54, Harvard Univ. Press, Cambridge, Mass., 1965).

W. A. Haviland, *Am. Antiquity* **32**, 316 (1967).

41. R. L. Beals, *Cherán: A Sierran Tarascan Village* (Smithsonian Institution, Washington, D.C., 1946).
42. G. Tantaquidgeon, *A Study of Delaware Indian Medicine Practice and Folk Belief* (Pennsylvania Historical Commission, Harrisburg, 1942).
43. P. Lindestrom, *Geographica Americae with an Account of the Delaware Indians* (Swedish Colonial Society, Philadelphia, 1925).
44. R. Redfield and A. Villa Rojas, *Chan Kom; A Maya Village* (Univ. of Chicago Press, Chicago, 1934).
45. W. C. Bennett and R. M. Zingg, *The Tarahumara: An Indian Tribe of Northern Mexico* (Univ. of Chicago Press, Chicago, 1935).
46. For a review of this concept see Katz (*47*); M. Winton [*Am. J. Phys. Anthropol.* **32**, 293 (1970)] has also reviewed this problem as it relates to the ethnographic literature on the Colombian Indians.
47. S. H. Katz, paper presented at an international seminar, under the auspices of the Centre International d'Etudes de Bio-Anthropologie et d'Anthropologie Fondamentale, on the "Unity and Diversity of Man from the Point of View of Social and Cultural Anthropology," Paris, 1972.
48. ———, in *Methods and Theories in Anthropological Genetics*, M. Crawford and P. Workman, Eds. (Univ. of New Mexico Press, Albuquerque, 1973).
49. References for the societies in Table 3 may be found in the *Biblography of Sources Processed for the Files* (Human Relations Area Files, Inc., New Haven, Conn., 1961). The following sources that are not in the Human Relations Area Files were also consulted: J. R. Swanton, *Indian Tribes of the Lower Mississippi Valley and Adjacent Gulf Coast of Mexico* (Bureau of American Ethnology, Washington, D.C., 1911); N. Lurie, Ed., *Mountain Wolf Woman, Sister of Crashing Thunder* (Univ. of Michigan Press, Ann Arbor, 1961); G. Weltfish, *The Lost Universe* (Basic Books, New York, 1965).
50. G. P. Murdock, *Outline of World Cultures* (Yale Univ. Press, New Haven, Conn., 1972).
51. M. Pijoan, C. A. Elkin, C. O. Eslinger, *J. Nutr.* **25**, 491 (1943).


52. Evidence of the nutritional advantages of processing corn with alkali was first presented in 1972 (see *47*). This article is adapted from a paper presented at the Ninth International Congress of Anthropological and Ethnological Sciences, Detroit and Chicago, 1973. We acknowledge the advice and suggestions of Drs. Robert Sharer, University of Pennsylvania; V. Young and N. Scrimshaw, Massachusetts Institute of Technology; R. Netting, University of Arizona; O. F. Linares, University of Texas; and C. Dohan, Eastern Pennsylvania Psychiatric Institute. Part of this research was supported by NIDR training grant DE109-10 and a travel grant from the School of Dental Medicine, University of Pennsylvania.