
Sweet Beginnings

Stalk Sugar and the Domestication of Maize¹

by John Smalley and
Michael Blake

Elaborating on the recent suggestion by Hugh H. Iltis that the direct ancestor of maize was initially domesticated not for its grain but for its sugary pith or other edible parts, this article proposes that during the initial period of maize domestication the stalk provided a key source of sugar for many uses, including the making of alcoholic beverages, and that the social importance of alcohol production helped precipitate its early and rapid spread. Several lines of evidence are examined to evaluate the merit of this hypothesis, and topics for further archaeological research that might contribute to this effort are suggested.

JOHN SMALLEY studies the role of alcohol use in early agricultural societies and sedentarization in hunter-gatherer societies, with a focus on the Tarahumara of northern Mexico. His interest in maize stalk sugar dates to a period 20 years ago in which he grew sweet corn commercially and became aware of the very sweet taste of the sap in the stalk. Born in 1945, he has a B.A. from Simon Fraser University (1992) and a diploma in education (guidance studies) from the University of British Columbia (1996).

MICHAEL BLAKE is Associate Professor of Anthropology, Director of the Laboratory of Archaeology, and Curator of the Museum of Anthropology at the University of British Columbia (Vancouver, B.C., Canada V6T 2B2 [tmblake@interchange.ubc.ca]). He was born in 1953 and educated at the University of British Columbia (B.A., 1977) and the University of Michigan (M.A., 1979; Ph.D., 1985). Among his publications are (with R. Lesure) "Interpretive Challenges in the Study of Early Complexity: Economy, Ritual, and Architecture at Paso de la Amada, Mexico" (*Journal of Anthropological Archaeology* 21:1-24) and (with J. E. Clark) "The Power of Prestige: Generosity and the Emergence of Rank Societies in Lowland Mesoamerica," in *The Ancient Civilizations of Mesoamerica: A Reader*, edited by Michael E. Smith and Marilyn A. Masson, pp. 253-70 (Oxford: Blackwell, 2000).

The present paper was submitted 15 v 02 and accepted 8 v 03.

1. Many people have taken the time to discuss these ideas with us over the past few years, and we thank them for their insights and suggestions: Hazel Ackner, Bruce Benz, Bert Brink, Brian Chisholm, Christine Hastorf, Warren Hill, Hugh Iltis, David Kaplan, Bill Litzinger, Dana Lepofsky, R. G. Matson, Michael Oltean, Dolores Phiperno, Mary Pohl, Christia Roberts, Alf Siemens, and John Staller. We are indebted to four anonymous reviewers for their helpful comments and suggestions.

Teosinte (*Zea mays* ssp. *parviglumis*) appears now to be the most widely agreed-upon candidate for the ancestor of domesticated maize (*Z. mays* spp. *mays*), but there are, at best, only partial answers to questions of how, when, and where this process took place (Wilkes 1967, 1985; Beadle 1980; Iltis 1972, 2000; Matsuoka et al. 2002). In a break with conventional wisdom, Hugh H. Iltis (2000:36 and quoted in Crosswhite 1982) has recently suggested that the direct ancestor of maize "was initially domesticated not for its grain but for its sugary pith or other edible parts." We elaborate on his suggestion by proposing that during *Zea's* initial period of domestication the stalk provided a key source of sugar for many uses, including the making of alcoholic beverages. Furthermore, we suggest that the social importance of alcohol production was a precipitating factor in *Zea's* early and rapid spread. In this paper, we examine several different lines of historical and archaeological evidence to evaluate the merit of this hypothesis. We propose that a new research focus on the development of the sweet stalk may help to shed light on both the evolution and the dissemination of maize.

This idea is not as strange as it might initially seem. Sugar and other sweeteners have long been important components of the human diet. In the Old World, the sugarcane plant (*Saccharum officinarum*) came to dominate the commercial market for sugar—both as a general sweetener and for making alcohol—about 1,000 years ago (Mintz 1985). It was initially domesticated in the humid tropics of Pacific Asia and spread throughout the world because of the demand for sugar. In the New World there were very few indigenous sources of sugar. Surprisingly, however, one of those sources was the genus *Zea* (including various species and subspecies of maize and teosinte), a close relative of sugarcane. In fact, maize and sugarcane are both members of the Andropogoneae tribe in the grass family (Graminae or Poaceae) (Clayton and Renvoize 1986:28). Some researchers have claimed that the genus *Saccharum* can cross with *Zea*, producing infertile hybrids (Janaki-Ammal 1938; Mangelsdorf 1974: 72-73), but others consider this claim unproven (Clayton and Renvoize 1986:331). Whether or not they are able to hybridize, both sugarcane and maize stalks produce sweet juice which can be easily extracted and its sugar concentrated for use in making syrup and alcoholic beverages.

The possible use of maize's ancestor as a source of sweet juice has fascinating implications for some of the key questions about maize's domestication and spread. For many decades, researchers have focused almost exclusively on the cereal crop significance of early *Zea* use and have seldom considered that, initially at least, the plant may have had other uses. While this has not limited the extremely productive debates about maize's origins and spread, it has perhaps channeled discussions and research in such a way as to give preference to interpretations that rely on *Zea's* evolved characteristics (i.e., large cobs, many large kernels, and storability) rather than its initial ones (i.e., small, hard kernels, small cobs, and sweet stalk). We will examine ethnographic

and historical evidence for maize stalk sugar use, hypothesizing the link between the domestication of *Zea* and the need for sugar. Next, we will discuss the current archaeological evidence for maize stalk sugar use and its potential for alcohol production.

Questions about Teosinte as Maize's Ancestor

Researchers have debated the role of teosinte in maize's evolution for more than a century (cf. Wilkes 1977, McClung de Tapia 1992, Piperno and Pearsall 1998). In 1880, P. Ascherson suggested that teosinte, either on its own or in combination with another grass, was maize's ancestor (Mangelsdorf 1974:11). Subsequently, Paul Weatherwax (1923) suggested that teosinte, *Tripsacum* (a perennial range grass), and maize all arose from a common ancestor. Paul Mangelsdorf (1974:79) added to the debate by suggesting that one type of maize, pod corn, crossed with *Tripsacum* to produce teosinte. Later, Mangelsdorf proposed that a now-extinct wild maize was one of the ancestors of modern maize and that annual teosinte was not maize's progenitor. George Beadle (1932, 1972) was among the first to use genetic evidence to argue, in contradiction to Mangelsdorf, that teosinte was maize's sole ancestor (Galinat 1977a, Iltis 1983). Most genetic research confirms this, and several recent studies show just how close this connection is (Iltis and Doebley 1984:605; Doebley 1990; Buckler and Holtsford 1996; Bennetzen et al. 2001; Matsuoka et al. 2002).

Even so, archaeological evidence in the form of paleoethnobotanical remains of teosinte is exceedingly scarce. Mangelsdorf identified nine specimens of teosinte from Romero's Cave in Tamaulipas and illustrated a well-preserved example from the excavations dating from 900–400 B.C. (Mangelsdorf 1974:157). If teosinte was used extensively as a food crop, then there should be more evidence than the few rare seeds in archaeological sites (Iltis 2000:28–29). Michael Coe (1994:33), for example, stated: "The archaeological evidence . . . is thus far entirely negative: no truly early teosinte has ever been found, either as plant remains or as pollen." However, as Flannery (1986:8; 1976b:107) has noted, there are several early examples of teosinte seeds and *Zea* sp. pollen in both Archaic and Early Formative sites in Mesoamerica. Ample evidence of *Zea* phytoliths (the small opal silica bodies found in the cells of most plants) has been found in several early archaeological sites in the New World (e.g., Pope et al. 2001, Pearsall 1994).

Teosinte seeds could have provided a supplemental food source in spite of the fact that they were very difficult to harvest efficiently (Flannery 1973:290; Beadle 1980) and contained a very high percentage of roughage—up to 53% (Flannery 1973:296–97).² When mature, the

seed head tends to shatter when bumped or disturbed, thus dispersing the small, hard seeds on the ground, but this can be overcome by harvesting the seeds, when mature, over a blanket (Flannery 1973, Beadle 1972). As Flannery (1973:297) has pointed out, both teosinte and other small-seed plants such as foxtail grass (*Setaria* sp.) were, empirically, only a minor part of the diet of Late Archaic-period Mesoamericans in the highland regions; equally important were prickly pear, roasted agave, mesquite, acorns and pinyon nuts, hackberry, wild avocado, deer, cottontail, mud turtle, and dove. Coe (1994:33) notes that teosinte "was shunned by the Indians as food, probably because of its unpalatability," and Flannery (1973:290) states that it was used by some Mexican Indians as a "starvation food." Iltis (2000:23–24) has recently observed that teosinte's fruitcase "is so hard and indestructible that human use of the grain is out of the question. . . . There remains the perennial vexing question: Why would anyone bother to collect or try to grow this utterly useless grain when the grain itself is permanently imprisoned in a hard fruitcase?" Beadle (1980: 117) notes, however, that this is somewhat of a misrepresentation of teosinte's usefulness, because it can be processed by eating its green spikes or soaking, grinding, and even popping the dry seeds. In spite of these potential uses, Wilkes (1967:79) describes the following digestive journey for teosinte plants and seeds grown by present-day farmers in Mexico: "The livestock are fed entire plants and they pass teosinte seed still enclosed by the protective fruitcase in their droppings. The manure is then collected and returned to the maize fields as fertilizer. The presence of teosinte in the maize fields from year to year is thus insured by the use of teosinte-seed-infested manure."

These arguments both for and against teosinte as maize's ancestor arose from the assumption that the seed grain was the primary focus of the plant's earliest use. If this was not the case—if early *Zea* seeds were occasionally consumed and if the plant's stalks and shoots were also sought as a source of sugary juice and succulent greens—then the issues of seed harvestability and palatability fade in importance.

Richard MacNeish and Mary Eubanks (2000) have recently reworked one of Mangelsdorf's (1983, 1986) theories for the origin of maize that posited its descent from a hybrid cross between extinct maize and one of its wild ancestors. MacNeish and Eubanks label this the Tehuacán or highland model. They suggest that maize arose as a result of the crossing and backcrossing of *Tripsacum* and a newly discovered species of diploid perennial teosinte, *Z. diploperennis* (Iltis et al. 1979). Eubanks (1995, 1997) has shown that crossing diploid perennial teosinte

2. Many peoples in the Americas harvested plants with seeds containing a high proportion of indigestible fiber (e.g., *Chenopodium berlandieri*, *Iva annua*, *Setaria* spp.). However, where seeds with high roughage content were used for food and people ingested the hulls and seed coats, there is often direct archaeological evidence of their indigestibility in the form of preserved remains in coprolites

(Reinhard and Bryant 1992, Callen 1967). So far very few coprolites recovered in dry caves in Mesoamerica have been identified as containing teosinte (Mangelsdorf 1974:180). Mangelsdorf (p. 156) mentions a number of specimens of teosinte in coprolites excavated at La Perra Cave in Tamaulipas and identified by E. O. Callen. He observes that the teosinte fruits passed directly through the cave dwellers and into the archaeological record "with their hard, bony shells unchanged."

with *Tripsacum dactyloides* will produce fully fertile hybrids some of which closely resemble the archaeological specimens of maize found in the Tehuacán Valley. A group of maize geneticists and evolutionists has recently rebutted this argument, making the following three points: (1) There is overwhelming genetic evidence that teosinte was the direct ancestor of maize. (2) The modern production of *Tripsacum* and diploid perennial teosinte hybrids does not mean that such hybrids occurred in the past. (3) The maize genome contains neither *Tripsacum* nor *Z. diploperennis* genetic sequences (Bennetzen et al. 2001:84–85). Newly published genetic studies of both maize and teosinte support these interpretations (Matsuoka et al. 2002, Vigouroux et al. 2002).

This debate is certainly not yet over (Eubanks 2001), but our hypothesis suggests that, regardless of the eventual outcome, the earliest ancestors of maize were cultivated for several properties, including stalk sugar and seeds on cobs. Our hypothesis provides a new perspective on how and why *Zea* spread through the tropical Americas at such an early date.

The Spread of *Zea*

Because the earliest examples of maize were incapable of self-seeding (Benz 2001a:2105), humans must have been responsible for its spread out of its homeland—the Río Balsas drainage of West Mexico—into new habitats in Central and South America and beyond (Matsuoka et al. 2002:6084). In addition to the well-known Tehuacán cobs, evidence for this early spread has been found in Oaxaca in the form of maize cobs from Guilá Naquitz Cave dating to 5,400 B.P. (Piperno and Flannery 2001:2102) and in Panama, where Piperno and colleagues have identified maize phytoliths, pollen, and starch grains estimated to be at least 7,000 years old (Piperno and Pearsall 1998, Piperno 1999, Piperno et al. 2000). Pope et al. (2001:1372) present convincing evidence that small-grained *Zea* pollen (similar to wild teosinte) occurred as early as 6,200 B.P. and larger-grained *Zea* pollen (possibly maize) by 6,000 B.P. at the site of San Andrés, near La Venta on the Gulf coast of Tabasco, Mexico.

Bush, Piperno, and Colinvaux (1989) have identified *Zea* pollen and phytoliths dating to 5,300 B.P. from lake sediments in Ecuadorian Amazonia, contemporary with similar finds at early Valdivia sites along the Pacific coast of Ecuador (Pearsall and Piperno 1990). Piperno (2003) states that the earliest phytolith evidence for maize comes from the preceramic Las Vegas-phase site of OGSE-80, with a date of $7,170 \pm 60$ B.P. These studies suggest to Pearsall (2002) and Piperno (2003) that late preceramic—Archaic—peoples transported early domesticated maize into the region. Staller and Thompson (2002:47) and Tykot and Staller (2002), on the basis of their analysis of archaeological remains from the site of La Emerenciana, a Valdivia VII–VIII-period site in coastal Ecuador dating between ca. 4,000 and 3,500 B.P., argue that maize was not a significant component of regional subsistence before this period and that after this time it

was primarily used for ceremonial and ritual purposes, perhaps as a fermented intoxicant.

Until recently, most models for the spread of *Zea* have simply assumed that it was intentionally transported by humans primarily as a source of grain food, even though at this early time it was not particularly productive. Benz (1999:30–31), discussing the link between early forager mobility and maize dispersal, suggests that highly mobile foragers with little seasonal permanence and large territorial ranges are unlikely to have been responsible for distributing maize, probably because they would have had little use for agricultural modes. He argues that maize could have been dispersed by Archaic foragers and early agriculturalists, however, only after a fairly stable agro-ecosystem had emerged. In this scenario, people who used maize in a restricted annual range would also have occasionally traded with or moved to distant areas. Buckler et al. (1998) suggest that this stable agro-ecosystem likely arose in the Early Archaic period among peoples living at lower elevations, perhaps even the coastal lowlands. They suggest that after early maize was domesticated it was carried into the adjacent highland regions, where it eventually made its way into the archaeological cave sites exemplified by Guilá Naquitz and Coxcatlán. Early maize may also have passed along a chain of interacting horticulturalist societies that might have been eager to add the new plant to their existing suite of cultivars (Piperno and Pearsall 1998, Piperno et al. 2000).

Why, then, would Archaic foragers and/or horticulturalists have been interested in transporting early maize seeds around the countryside and adopting this new plant? The most common economic explanation has to do with the food potential of the seeds. MacNeish and Eubanks (2000:17), for example, suggest that the earliest hybrids or ancestral maize plants “with four to eight rows of paired kernels in reduced cupules that exposed the grain, making it easy to remove from the cob . . . would have provided an attractive food source for humans.” Further, many researchers, following Flannery (1973:296; 1986:4), think that early agriculture, including maize agriculture, may have been important in buffering against the unpredictability of natural resource availability. Benz (2001a, 2003) has argued that early maize cultivators selected for increased grain size and cob size, testing this hypothesis by analyzing the metric characteristics of archaeological cobs from Tehuacán and Tamaulipas, Mexico.

In spite of the evidence for human intentionality in the selection for increased cob and grain size, we argue that the nutritional value of the kernels was not the sole impetus for the spread of early *Zea*. Growing early maize outside of its natural range as a grain food supplement within an existing horticultural system would have required a great deal of investment in time and labor—at the expense of the tending or collecting of existing resources—for a small reward. The earliest maize cobs were very small and slowly increased in size for two or

three millennia after their first appearance (Benz 2003).³ Howard Walden (1966:31) put the case clearly when he stated: "An entire ear of Tehuacán Valley wild maize [now thought to be domesticated maize] produced less food than that contained in a single kernel of some modern varieties" (see also Mangelsdorf, MacNeish, and Galinat 1967:200). As Flannery (1976a:95) notes, in Oaxaca the average length of a maize cob by 3,000 B.P. would have been only about 6 cm. Even earlier, smaller varieties of maize were undoubtedly meager sources of food. Given the high cost of growing, processing, and extracting the grain and the wide range of other locally available wild and cultivated plants, maize may not have become economically attractive until it started producing larger cobs (Roosevelt 1980, Piperno and Pearsall 1998).

An additional reason we question the dietary importance of early (small) maize is that the grain is very low in protein (9.5% average), is deficient in the amino acids lysine and tryptophan, and lacks the B vitamin niacin, all of which are essential for a healthy diet (Katz, Hediger, and Valleroy 1974:766). Teosinte grains, although much more difficult to process, are in fact higher in protein than maize (Melhus, Aguirre, and Scrimshaw 1953). This suggests that the earliest maize cultivators were selecting the seeds for their carbohydrates and sugars rather than their protein content.

Considering all of the above-mentioned "problems" with early maize, we and others suspect that people must have found it useful beyond the immediate dietary potential of the seeds in order for it to have spread as it did to so many widely diverse habitats and at such an early date (e.g., Iltis 2000; cf. Johannessen and Hastorf 1994, Staller and Thompson 2002).

Paleoethnobotanical evidence from throughout the Americas suggests that *Zea* was first introduced into agricultural systems in which farmers were growing a variety of other food crops. For example, at the Aguadulce rockshelter site in Panama, Piperno and her colleagues (2000) identified starch grains of manioc (*Manihot esculenta* Crantz), yams (*Dioscorea* sp.), and arrowroot (*Maranta arundinacea* L.) on milling stones dating between 7,000 and 5,000 B.P. For many hundreds of years and in some cases millennia after its initial introduction maize remained a minor crop, and there is little evidence of its having been a staple.

Although not a staple, maize grain must have been important to the inhabitants of the Río Balsas region of southwestern Mexico, where it was domesticated before 6,000 B.P. (Benz 1994, 1999; Matsuoka et al. 2002). Benz (2001a, 2003; Benz and Long 2000) has argued that early horticulturalists in the Tehuacán Valley were certainly interested in the grain, since there is substantial evidence for early morphological changes in both the cobs and the kernels (including rachis diameter and length, row number, and cupule width). Even so, the specific uses to which the grains were being put is still not cer-

tain, and we agree with Benz (2001a:2106) that "this evidence does not reject the possibility that human use of teosinte focused on something other than grain [Iltis 2000] but does suggest that by the 6th millennium before the present era, humans were focusing their subsistence activities on maintaining readily harvestable grain-producing inflorescences." The earliest interest in grain production, where it existed, may have focused on the beer-producing potential of the seeds and the selection and saving of seeds for future planting.

Throughout the New World by about 3,000 B.P. there was a dramatic increase in maize use, and it eventually became the staple we know today. If, as we suggest, *Zea* was initially of minor importance as a food crop and was being cultivated in areas already supplied with ample food, what was it that encouraged its relatively rapid dissemination throughout the Americas?

The Stalk-Sugar Hypothesis

The hypothesis for the role of stalk sugar in maize's early evolution and spread parallels suggestions made many years ago for the origins of grain domestication in the Old World. In the early 1950s Robert Braidwood and Jonathan Sauer suggested that the earliest use of domesticated cereals in the Near East may have been for beer making and not for bread (Braidwood 1953:515). As Sauer (1953:516) put it, "Planting and harvesting small grains without the plough or other efficient tools would seem to me a game scarcely worth the candle except for a more rewarding stake than mere food." Mangelsdorf (1953:519) retorted with the acerbic observation, "Are we to believe that the foundations of Western civilization were laid by an ill-fed people living in a perpetual state of partial intoxication?" Despite Mangelsdorf's critique, we think that Braidwood and Sauer's suggestion should be expanded to include the New World as well. In other words, the extraction of stalk juice—as a sweetener and possibly for making alcohol—may have been a key factor in the domestication of *Zea*.

The stalk-sugar hypothesis allows us to propose the following steps in *Zea*'s domestication and dispersal: Initially, Early Archaic peoples in Mexico experimented with *Zea* by casually harvesting the sweet stalks and simply chewing them (Iltis 2000; see also Pearsall, cited in Piperno and Pearsall 1998:161). Later they recognized that they could produce large quantities of sweet juice by mashing and squeezing the stalks. They then fermented the juice, probably using techniques and technologies already available for other plants. They increased the predictability and productivity of *Zea* by weeding natural stands and occasionally planting new stands in favorable habitats (Flannery 1986:3–4). Next, they moved *Zea* plants to new regions where it did not grow naturally but could be cultivated. The cultivation of *Zea* to produce juice would have required the harvesting of enough seed to replant year after year and to transport to new fields. This process would have led to the selection of a tougher rachis, whether or not the seeds

3. Benz's recent measurements of the Tehuacán maize suggest that this gradual selective process was punctuated by periods of faster change.

were initially consumed. Furthermore, if people intentionally selected seeds for replanting from plants with larger stalks, then the overall size of the stalk would have gradually increased over many generations. Early cultivators' selection of sweet juice-producing stalks may also have led to the transformation of teosinte from a multibranch habit to the single stalk of modern maize—a trait which now appears to have been selected for early on in the domestication process (Iltis 2000:18–19).

In Mesoamerica, Archaic peoples would have observed several advantages of *Zea* in comparison with other plant sources of sweet fermentable juice such as *Agave* (spp.), sotol (*Dasyllirion* sp.), mesquite (*Prosopis* sp.), coyol palm (*Acrocomia mexicana*), and jocote (*Spondias purpurea*) (Bruman 2000). One is its ability to grow quickly and to be harvested once or twice a year. Most other indigenous sources of sweet juice came from plants which were very slow to mature and relatively difficult to cultivate although in some cases exceedingly abundant. Another is that its production could easily and quickly be increased simply by expanding the size of the crop area and investing more labor in its cultivation. Finally, in contrast to the situation with many agaves and coyol palm, the extraction of *Zea* stalk juice did not destroy a plant that required a decade or more to mature.

In Central and South America, *Zea* may have been a welcome supplement to root crops that also could be brewed for beer such as achira (*Canna edulis*), manioc (*Manihot esculenta*), and sweet potato (*Ipomoea batata*).

In summary, the initial spread of *Zea* from its homeland in Mesoamerica may have been extremely rapid because of a high demand for sugar. We suggest that long before *Zea* developed the large cobs with many rows of kernels that made it an attractive food staple, the ancestral sugar-producing plant passed along a chain of interconnected peoples extending into South America. It was the demand for sugar that encouraged *Zea's* initial rapid spread. It seems unlikely that early *Zea*, with its small cobs and seeds, could have spread so far so fast without some other highly desirable feature. Long after this initial spread, maize developed as a staple food source. The eventual transformation of early *Zea* into the large-cob food plant we know today (*Zea mays*) probably took many different routes as it adapted to different environments, though all modern maize races appear to be genetically derived from one ancestral species of teosinte (*Zea mays* ssp. *parviglumis*) (see Matsuoka et al. 2002, Vigouroux et al. 2002).

The Production of Maize Stalk Sugar

A modern maize stalk is, on average, 75% moisture (Freeman et al. 1972) and contains 15–50 g of sugars (sucrose, fructose, and glucose) at a concentration of 2–16% by weight (Tripath, Alam, and Misra 1978, Widstrom et al. 1984). The sugar potential of maize stalks is so great that it was extensively researched during the energy crisis of the late 20th century with the intention of producing an alcohol additive for gasoline (Widstrom et al.

1988:861). Even earlier, in the 1870s, the U.S. Department of Agriculture studied the feasibility of using the stalks of maize, sorghum (*Sorghum* sp.), and teosinte (among other plants) as sources of sugar for domestic use. After an extensive series of experiments, Peter Collier (1879:99), chemist for the Department of Agriculture, concluded: "There exists no difficulty in making from either corn or sorghum a first-rate quality of sugar, which will compare favorably with the best product from sugarcane grown in the most favorable localities." In his tables showing the sugar content of juice extracted from both maize and teosinte stalks he lists the specific gravity of each, which converts to the following percentages of sugar: corn, 12–15%, teosinte, 5–6% (Collier 1879:100–104).

Between the 1930s and the 1980s many agronomists studied the phenomenon of sugar synthesis in the maize plant (Singleton 1948:174; Van Reen and Singleton 1952:613; Hume and Campbell 1972; D'Ayala Valva, Paterniani, and de Oliveira 1980:185–86). Some researchers compared sugar production in different varieties of maize while others examined the effect of immature cob removal and pollination interruption on stalk-sugar concentration. Still others have examined the maize plant to determine where the highest concentration of sugar is located in the stalk.

In *Zea*, sugar is produced in the leaves during the growing season and stored in the stem (Iltis 1987:206). Later in the season, the tassels that subsequently produce the pollen appear at the top of the plants. Soon after this, the cobs and kernels begin to form and produce silk—or pollen receptors. Each strand of silk is attached to a single kernel which then becomes fertilized when pollen from the tassels falls onto hairs on the silk. Only those kernels which become fertilized develop and fill with the sugar previously stored in the stalk. Eventually, the sugar in the kernels is converted to starch.

This process of maize maturation has two important effects. The first is that if cobs are picked and eaten when immature, before the sugar has moved completely into the kernels and been converted to starch, the young ear of maize and its adjacent stem is very sweet and succulent. Some botanists have suggested that the first prehistoric consumers of *Zea* were more interested in this characteristic than in the ripened kernels (Harlan 1995, Iltis 2000 and quoted in Crosswhite 1982). One advantage of consuming maize in this manner is that no cooking or grinding would have been necessary. A disadvantage, however, is that the nutritional value of the plant could not be stored for later use as with dried ears of maize.

The second effect, resulting from the first, is that if immature cobs are picked before the sugar can migrate into them, then the sugar content of the stalks increases significantly (Singleton 1948:174; Hume and Campbell 1972; D'Ayala Valva, Paterniani, and de Oliveira 1980:185–86). When Van Reen and Singleton (1952:613) intentionally removed the ears of maize plants, they found that the stalk sugar remained much longer than in plants with ears. Mangelsdorf (1974:156) observed that a grow-

ing stalk from which young ears have been removed accumulates sugars in concentrations comparable to those of sugar-cane and the chewing of such stalks might have provided an appreciable amount of energy."

Intrigued by the claims that maize stalk sugar could be increased by removing the cobs before pollination, one of us (Smalley) conducted a study in 1996 involving 20 "Jubilee" (a variety of sweet corn) plants commercially grown just south of Vancouver, B.C., Canada. Cobs were removed from half of the sample plants as soon as they were visible. Compared with the untouched plants, those which had had their cobs removed had an average 18% increase in concentration of sugars in their stalks at harvest time five weeks later. We ate the immature cobs, husk and all, and can testify to their succulence. Some of the sugar had already migrated from the stalk into the small ears, and picking them stopped this process, leaving most of the sugars in the stalk (Iltis 2000:23). Our observations support Iltis's (2000) suggestion that early *Zea* farmers may have been able to harvest the immature ears, consume them immediately, and then later use the stalks for sugar.

Historical and Ethnographic Evidence of Maize Stalk-Sugar Use in the Americas

"The economic importance of cornstalk syrup has been widely attested to by the early explorers and chroniclers. . . . As far south as Peru, cornstalk syrup was manufactured, and as far north as the Iroquois the sweetness of cornstalks was recognized. Cornstalk segments were chewed for their flavor as sugar cane segments are chewed wherever sugar cane is grown" (Bruman 2000:57). The maize plant provided Native Americans with an abundant and expandable supply of sugar, whereas other sources of sugar were in much more limited supply. For example, honey, from wild bees and stingless domesticated bees, was commonly used in the Maya area, but outside of Yucatán it was apparently never very abundant (Roys 1972:53–54). In the northern Maya region honey was the main source of the sugar used to produce the alcoholic beverages important for rituals and ceremonies (Roys 1972:28). According to Roys (p. 42), "From the early Spanish writers one might infer that honey was mostly an ingredient of the intoxicating drink called *balche*; but since it appears to have been the only concentrated sweet produced in any considerable quantity, it must have been an important food article." Honey was not widely available in other parts of Mesoamerica, and consequently people turned to other sources of sugar. There was a great deal of regional variation in the types of plants used as sources of sugar, depending on the natural habitat and the availability of various plants in each region. For example, the coyol palm (*Acrocomia mexicana*) is found along the Pacific slopes of western Mexico, and the agave (maguey) plant (*Agave* spp.) is typical of drier regions and was

seldom used east of Tehuantepec (Bruman 2000:65). Most of these plants are slow-growing, requiring many years to mature, and although they were tended and cultivated their yields could not be as easily increased as those of maize.

There is ample early historical evidence for the use of maize stalk sugar both as a syrup and for making alcohol. Cortés wrote to the king of Spain in 1520 that honey from bees, cornstalk syrup, and maguey syrup were all on sale in the great marketplace of Tenochtitlan (Bruman 2000:57). Betty Fussell (1992:241) quotes the early English explorer Ralph Lane, writing from Roanoke, Virginia, in 1585: "And within these few days we have found here maize . . . whose ear yieldeth corn for bread, four hundred upon one ear; and the cane maketh very good and perfect sugar." Fussell also quotes Benjamin Franklin, addressing the French in 1785:

The stalks pressed like Sugar-Canes yield a sweet Juice, which being fermented and distill'd yields an excellent Spirit, boiled without Fermentation it affords a pleasant Syrop. In Mexico, Fields are sown with it thick, that multitudes of small Stalks may arise, which being cut from time to time like Asparagus are serv'd in Deserts, and their sweet Juice extracted in the Mouth, by chewing them.

Litzinger (1983:42) has pointed out that maize stalk beer⁴ has a wide distribution among present-day aboriginal communities throughout Mesoamerica (fig. 1) and is known as far south as the highlands of Peru and Bolivia. He also notes that it was likely even more common prior to the early 1600s, when the sugarcane introduced by the Spanish provided a cheaper source of sugar. According to Bruman (2000:57), "Cornstalk wine was mostly considered a low-class substitute beverage to be used when other sources of drinks were not in season, or, in the *tesgüino* region, to conserve the grain supply."

Several ethnographers have recorded the manufacturing process of maize stalk beer (e.g., Pennington 1963:150). One of the best examples is the description of Tarahumara maize stalk beer-making by Bennett and Zingg (1976[1935]:47; see also Bruman 2000:58) in the 1930s:

At harvest time, when there are plenty of fresh corn stalks, the stalks are used in place of the more valuable corn. Tesgüino made from stalks is called *patcili*. After the leaves are removed, the stalks are taken to a large hollow boulder and pounded with oak sledges. Then the juice is squeezed out of the stalks by means of a clever device, *mabihimala*, invented for this purpose. It is a net woven from *sóka* fiber (*Yucca* sp.) and is generally about 12 × 15 inches. This is woven to encircle a stick at either end. The sticks are about 18 inches long. One of

4. Beer is usually made from sprouting (germinating) grains, with the starches in the seed being converted to sugar by enzymes. Wine is usually produced by direct fermentation of a sweet juice or syrup. Maize stalk beer, a type of *tesgüino* called *patcili* by the Tarahumara, is technically wine but has the alcohol content of beer (3–5%) and is drunk in the same way.

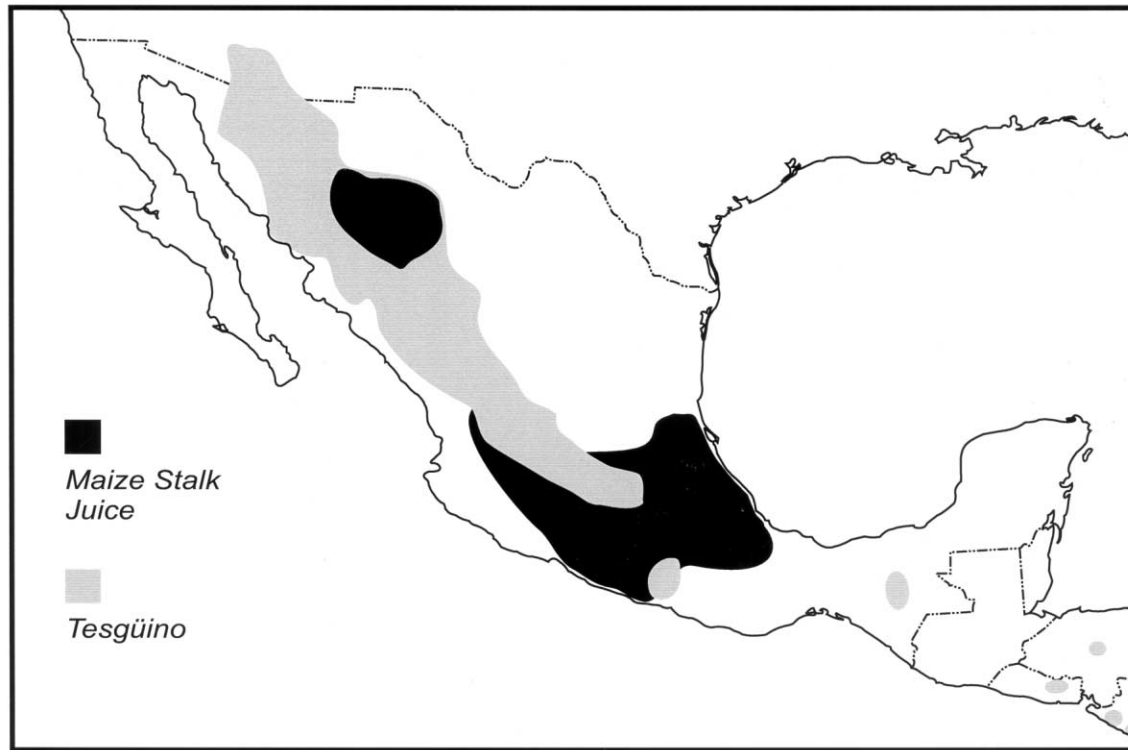


FIG. 1. Mesoamerica, showing the distribution of maize stalk beer and (*tesgüino*) use among various indigenous groups (after Bruman 2000).

them is held with the feet, while the other is held in the hands. All the juice that can possibly be twisted out of the pounded corn stalks is removed with the *mabihímala*. The juice collects in the depression in the rock, and the bagasse is thrown away.

The juice is mixed with water and is then ready to strain through the basket strainer (mentioned before). Afterward it is boiled for a couple of hours over the fire, together with the root of *gotóko* (specimen unidentified), which has been well ground. The *gotóko* root is a necessary ingredient in this preparation. The mixture is allowed to cool and left to ferment with about half a decaliter of sprouted corn to act as the ferment. Sometimes the fermentation of the cornstalk juices in the “boiling pot” serves as the only ferment. In about five days the liquor is ready to drink.

The beer was entirely consumed by the Tarahumara soon after production because without preservatives it spoiled quickly. Also, because it was difficult to transport the beer to distant locations, people usually drank it close to the place of production. This may account for the large quantities of beer consumed by individuals at ceremonial events (Litzinger 1983:8–9).

There are also many examples of the making of maize stalk beer in the Andean region. For example, David

Forbes (1870:250), writing about his observations in Aymara communities in Bolivia and Peru in the late 1850s, noted: “In some parts a fermented drink is made by the Indians from the sweet stalk of the young green Indian corn, called ‘huiru’ (wiru): this is the name of the stalk.”

As Bruman points out (2000:4), the unexpectedly wide aboriginal range of maize stalk beer sets it apart from the more local alcoholic beverages in his study, perhaps suggesting that it has a great antiquity. In Mesoamerica, this is partly reflected in the similarity of the linguistic terms for maize stalk beer among very distant groups, such as the Huastec *boc* and the Kekchi *boj* (Bruman 2000:60).

The widespread use of maize stalk beer both before and just after the conquest was rapidly superseded by the importation of sugarcane to the New World and the extensive spread of plantations. This change allowed people to have access to new and much cheaper sources of sugar—one of the primary implications of which was the increase in availability of alcohol products such as rum (Mintz 1985). Maize stalk beer-making techniques were preserved in some regions, as we have seen, but the frequency has declined now to the point where it is a relatively uncommon “traditional” method of alcohol production and closely tied to ancient ritual and ceremonial practices (for example, among the Tarahumara [Kennedy 1978]).

Archaeological Evidence of Maize Stalk Use in Mesoamerica and South America

We can infer maize stalk use from both direct and indirect archaeological evidence. So far, the only direct evidence comes from preserved maize stalks and quids in dry cave sites dating to the Archaic period and later. Indirect evidence comes from stable isotope measurements in human bone samples that reflect the relative importance of maize in the diet.

MAIZE STALK QUIDS

Well-preserved, uncharred plant remains have been reported for several dry cave sites in Mesoamerica and South America. Occasionally maize quids (the mass of plant fiber that was chewed and expectorated after sucking out the sweet juice) are found among the many other types of plant quids at several of these sites.⁵ These remains demonstrate that the ancient peoples who used the caves occasionally snacked on the sweet juicy stalks and tender husks of the maize plant. We present the following examples more to illustrate that people had long been aware of maize stalk sugar than to demonstrate large-scale sugar juice extraction as described in the previous section.

Mangelsdorf, MacNeish, and Galinat (1967:179) report on thousands of maize plant fragments found in the Tehuacán Valley cave excavations. These include “numerous quids, representing 83 chewed stalks or leaves and 140 chewed husks.” Maize quid remains come from virtually all levels and phases at five cave sites: Coxcatlán, Tecorrál, San Marcos, Purrón, and El Riego. We have summarized Mangelsdorf et al.’s data in table 1, grouping the fragments into two main categories: chewed quids of stalks, leaves, and husks and unchewed stalks, leaves, and husks (fig. 2).

In order to determine if there was any change in the

5. Agave was also chewed, and many agave quids were also found in the excavations at Tehuacán (Mangelsdorf, MacNeish, and Galinat 1967), Tamaulipas (MacNeish 1958), and Guilá Naquitz (Smith 1986).

frequency of quid chewing during the Tehuacán sequence, we calculated the ratio of *Zea* quids to unchewed fragments for each phase (table 1). In the two earliest phases (5000–2300 B.C.) there were more quids than unchewed pieces, and in the later phases (beginning at 1500 B.C.) the vast majority of maize fragments were unchewed. Thus, it appears that the relative importance of chewing maize stalks, leaves, and husks declined over time, possibly as cobs became larger and maize became an increasingly important food staple.

MacNeish’s (1958:148) excavations at a series of caves (including La Perra, Diablo, and three others) in the Sierra de Tamaulipas, Mexico, apparently produced no chewed maize stalks, but four maize quids of young ears, husk and all (one from the La Perra phase [5,000–4,200 B.P.] and three from the Laguna phase [2,600–2,000 B.P.]) were found. Of the La Perra quid MacNeish says, “One quid suggests that some of the young ears were chewed, husk and all; juice containing sugar and other nutrients were sucked out, and then the remaining mass was expectorated” (p. 146). In reference to these same specimens, Mangelsdorf (1974:154) observed that chewing “the tender, succulent, and sweet” young ears may have been a simple and quick way for people to obtain a small amount of sugar, even at the cost of sacrificing a larger ear of maize later on.

Another series of caves in Tamaulipas, known as the Infernillo Canyon caves (including Romero’s, Valenzuela’s, and Ojo de Agua Caves), provided an even larger sample of maize remains. MacNeish’s excavations at these caves in 1954 recovered some 8,525 maize plant parts other than cobs (Mangelsdorf 1974:156). These included 151 chewed maize quids, including chewed tassels, young ears, and stalks.

There is also evidence of maize stalks in dry caves in the Andean region of South America, but none so far are reported to have been chewed. Thomas Lynch’s (1980) excavations at Guitarrero Cave in the Río Santa Valley of highland Peru recovered many late preceramic and later maize remains. In his Complex III, possibly dating between 5780 and 500 B.C., only 27 cobs and no other parts of the maize plant were found (Smith 1980:122–23).

TABLE 1
Early *Zea* Evidence at Tehuacán Valley Cave Sites

Phase	Age	Quids of Stalks, Leaves, and Husks	Unchewed Stalks, Leaves, and Husks	Ratio of Quids to Unchewed Stalks, Leaves, and Husks
Venta Salada	A.D. 700–1540	78	1,349	0.1
Palo Blanco	200 B.C.–A.D. 700	86	681	0.1
Santa María	900–200 B.C.	27	89	0.3
Ajalpan	1500–900 B.C.	6	50	0.1
Purrón	2300–1500 B.C.	0	0	–
Abejas	3500–2300 B.C.	17	6	2.8
Coxcatlán	5000–3500 B.C.	9	6	1.5
Total		223	2,181	0.1

SOURCE: Mangelsdorf, MacNeish, and Galinat (1967:182).



FIG. 2. *Maize quids from the Palo Blanco phase at San Marcos Cave, Tehuacán Valley (Mangelsdorf et al. 1967:194, fig. 117). Copyright Robert S. Peabody Museum of Archaeology, Phillips Academy, Andover, Mass. All rights reserved.*

Smith, one of the project's paleoethnobotanists, suggested that "the very few husk systems found in the cave seem to indicate that the ears were shucked in the field" (p. 123). A sample of stalks, leaves, and husks was collected from the later Complex IV, but Smith does not indicate that any of them showed evidence of mastication.

This may be because, as in the Tehuacán case, maize stalk quids are not common in later periods. The same pattern may be observed in the excavations carried out in the Ayacucho Basin of Peru by MacNeish and his colleagues from 1969 to 1972. Although the detailed description of the plant remains is not available, there were occurrences of maize stalks in deposits at several caves: Pikimachay (Zones B, I, and E₅), Tambillo 240 (Zone G), and Tambillo 244 (Zones A, C, and D) (MacNeish et al. 1981:134–35; 1983:166–70, 182). However, none of the stalks or leaves is described as having been chewed, and no quids are mentioned.

So far, most archaeological evidence for casual chewing of maize plants, including stalks, comes from dry cave sites in Mesoamerica. Even on a larger scale than occasional stalk chewing, evidence of maize stalk juice extraction would be difficult to find. Perhaps the best evidence of more intensive juice extraction—as would be expected in beer making—would be the recovery of a large mass of crushed and discarded stalks. However, the chances of finding such debris are extremely low because it is highly unlikely that this activity would have taken place in caves such as those in the Tehuacán Valley or in the Sierra de Tamaulipas, where the material could be preserved indefinitely. It is much more likely to have taken place out in the open, where the maize stalks would either have disintegrated and disappeared or have been dried and used for fuel, leaving only ash.⁶

The extraction of sweet juices from fibrous plants was widespread in ancient times. Ventana Cave in southern Arizona had well-preserved quids of yucca, mesquite bean hulls, and maize husks. Haury (1950:167, pl. 19a–f) illustrates both fine and coarse fiber quids (unidentified) and one maize husk quid. It should be possible to revisit the collection and make more precise identifications of the fibers and even to date the material directly using AMS radiocarbon dating.

Farther north, outside of the range of maize, Jennings (1957) reported the extremely widespread use of desert bulrush (*Scirpus americanus*) as a possible food source. His excavations at Danger Cave and Jukebox Cave, Utah, yielded over 1,900 quids of the rhizomes and tender leaves of the bulrush plant. Jennings says that he and fellow project members tried chewing the plant and found that it produced both juice and starch that was "slightly sweet and very refreshing" (p. 224). Interesting from the point of view of the present paper is that these quids were produced between about 7800 B.C. and A.D. 20—demonstrating a very long tradition of making use of sources of sweetness.

Agave quids are common in cave sites throughout the U.S. Southwest. Hamilton (2001:83) notes that *Agave lechugilla* quids have been found in many cave sites around the Rustler Hills region of West Texas and one such quid, from Granado Cave, was dated to 1,260 ± 40 B.P. (p. 264). Prickly pear (*Opuntia* sp.) and agave were

6. Under some conditions, identifiable phytoliths may be preserved even after charring of plant material (Pearsall, Chandler-Ezell, and Chandler-Ezell 2003:624).

so commonly chewed in the Archaic period (spanning 6,000 years) by hunter-gatherers in the Pecos region of West Texas that the opal phytoliths contained in the plant material are thought to have produced increased wear on dental enamel (Danielson and Reinhard 1998).

STABLE ISOTOPE STUDIES

Until recently, archaeologists have generally assumed that the presence of maize remains—be they macrobotanical, pollen, phytoliths, and/or starch grains—at an archaeological site indicated that maize was a dietary staple. However, as Hastorf and Johannessen (1994:429) point out, “Although maize began spreading throughout the Americas soon after its domestication, quantitative paleoethnobotanical evidence suggests that maize remained a minor crop for hundreds of years alongside other plants before it rose to prominence as a common food plant.” Our analysis of stable carbon isotope studies of human bone collagen samples from archaeological sites in Latin America supports this observation. Past human diet can be partially reconstructed by measuring the ratios of stable isotopes of carbon ($^{13}\text{C}/^{12}\text{C}\%$) and nitrogen ($^{15}\text{N}/^{14}\text{N}\%$) in human bone—both collagen (the protein portion) and apatite (the mineral portion) (cf. Price 1989, Lambert 1997, Norr 1995). The stable carbon isotope ratio is particularly important for studying maize consumption in ancient times because maize has a much higher $^{13}\text{C}/^{12}\text{C}$ ratio than most other plant foods found in the Americas (van der Merwe and Vogel 1977, 1978; Chisholm 1989).⁷

Most studies of human bone isotopes demonstrate that consumption of maize played a relatively minor role in the diet until about 3,000 B.P. We looked at nine published isotope studies spanning the period from the first appearance of maize to the Spanish conquest. These included 622 individuals from well-dated sites, giving a general overview of trends of maize consumption over 8,000 years (table 2, fig. 3). In the Mesoamerican samples, $^{13}\text{C}/^{12}\text{C}$ ratios greater than -14.0% , suggesting maize as a dietary staple, appear only in Middle Formative times (i.e., after about 3,000 B.P.). There are four exceptions: two individuals from early Tehuacán and two from the Soconusco region (table 2). Samples from 16 individuals at Cerro Mangote in Pacific Panama also show $^{13}\text{C}/^{12}\text{C}$ ratios indicating moderate maize consumption at an early date (between 7,000 and 4,500 B.P. [Norr 1995]). In contrast, at most South American sites, there was a longer delay between the first appearance of maize and its increasing use as a major food crop, beginning around 3,000 B.P. in some areas and much later in others (fig. 3).

Paleoethnobotanical evidence shows the presence of domesticated *Zea* at least as early as 5,400 B.P. in Mexico (Piperno and Flannery 2001:2102) and perhaps not long after in South America. The isotopic data suggest, how-

ever, that it did not become a dietary staple until at least 2,500 years later. This discrepancy calls for an explanation. Hastorf and Johannessen (1993) point to one when they note that in the central Andean region the earliest use of maize took place at ceremonial sites, where *chicha* or maize beer was commonly consumed. It was relatively late in the prehistoric sequence that maize became an important food item as well (Murra 1960, Hastorf 1999, Staller and Thompson 2002, Tykot and Staller 2002).

The practice of converting maize to alcoholic beverages may explain the low values for stable carbon isotopes in the human bone studies just cited. Ambrose and Norr (1993:27–28; cf. Chisholm, Nelson, and Schwartz 1982; Norr 1995:205–8) have shown that protein in consumers is built from the protein portion of the diet, not from fats or carbohydrates. The carbon isotopes that make up dietary protein are directly reflected in the carbon isotopes found in bone collagen. Because the protein content of maize stalk juice is negligible (it contains mainly water and sugars), it is highly unlikely that consumption of alcoholic beverages made from it would have caused a significant amount of protein from the maize plant to have made its way into the bone collagen of consumers (Brian Chisholm, personal communication, 2000).

The same may have been true of *chicha*. Steinkraus (1996:402–7) describes *chicha* making on the basis of a wide range of ethnographic descriptions from the Andean area. For the purposes of our present analysis the main observations about its production are as follows: (1) Maize kernels (sometimes sprouted) are ground to a fine powder and then mixed with water. (2) Chewed maize flour containing saliva is added to the mixture to help fermentation and to break down the solids. (3) The clear liquid decanted for fermentation is further filtered by straining through a piece of cloth. These processes ensure that the brew contains very few solids and probably only the protein that comes from the micro-organisms remaining from fermentation. Although work remains to be done on the specific nutrient distributions in *chicha*, it is likely that people consuming it derived mostly calories and vitamins from it rather than protein.

Therefore, increased consumption of maize stalk beer and maize grain beer would have been unlikely to have led to increased stable carbon isotope ratios in bone collagen. Bone apatite carbonate, in contrast, is thought to reflect the energy portion of the diet, including carbohydrates and fats (Norr 1995:206), and therefore the stable carbon isotope ratios in bone apatite could have been significantly higher than carbon isotope ratios in people who were “drinking” their maize. It may not have been until after the increase in maize cob size and productivity that large-scale direct consumption of maize other than as *chicha* had an isotopically visible impact on both collagen and apatite (for an alternative view, see Ubelaker, Katzenberg, and Doyon 1995).

7. Maize is a C_4 plant, and such plants produce significantly larger $^{13}\text{C}/^{12}\text{C}$ ratios than the C_3 plants that constitute the vast majority of plant foods. CAM plants, such as members of the cactus family, also produce higher $^{13}\text{C}/^{12}\text{C}$ ratios (Chisholm 1989).

TABLE 2
Stable Carbon Isotope Values for Sites in Mesoamerica, Panama, and South America

Region	Number of Samples	Phase Dates	Phase Midpoint (Years B.P.)	Average $^{13}\text{C}/^{12}\text{C}\%$	Interpretation	Reference
Tehuacán Valley, Mexico						
Tehuacán	8	A.D. 700–1540	950	–6.3	High maize or CAM	Farnsworth et al. (1985)
Tehuacán	2	900–200 B.C.	2,550	–6.9	High maize or CAM	Farnsworth et al. (1985)
Tehuacán	1	5000–3500 B.C.	6,250	–6.1	High maize or CAM	Farnsworth et al. (1985)
Tehuacán	1	6800–5000 B.C.	7,900	–13.3	Moderate maize or CAM	Farnsworth et al. (1985)
Maya region						
Iximche, Guatemala	13	A.D. 1470–1520	500	–7.8	High maize	Whittington and Tykot (2000)
Belize	25	A.D. 900–1520	790	–9.3	High maize	van der Merwe et al. (2000)
Belize	89	A.D. 200–900	1,450	–9.6	High maize	van der Merwe et al. (2000)
Petén, Guatemala	153	A.D. 200–900	1,450	–9.3	High maize	van der Merwe et al. (2000)
Copán, Honduras	87	A.D. 200–900	1,450	–9.7	High maize	van der Merwe et al. (2000)
Petén, Guatemala	16	400 B.C.–A.D. 200	2,100	–10.2	High maize	van der Merwe et al. (2000)
Belize	28	900–400 B.C.	2,650	–12.9	Moderate maize and mixed	Tykot, van der Merwe, and Hammond (1996)
Soconusco: Mexico and Guatemala						
Soconusco	2	A.D. 1200–1524	590	–9.4	High maize	Blake et al. (1992)
Soconusco	1	A.D. 600–1000	1,150	–11.3	High maize	Blake et al. (1992)
Soconusco	1	A.D. 300–600	1,500	–9.5	High maize	Blake et al. (1992)
Soconusco	1	650 B.C.–A.D. 100	2,225	–11.8	High maize	Blake et al. (1992)
Soconusco	4	850–750 B.C.	2,800	–14.0	Moderate maize and mixed	Blake et al. (1992)
Soconusco	2	1000–900 B.C.	2,900	–17.5	Low maize	Blake et al. (1992)
Soconusco	1	1100–1000 B.C.	3,050	–17.8	Low maize	Blake et al. (1992)
Soconusco	2	1250–1100 B.C.	3,125	–18.0	Low maize	Blake et al. (1992)
Soconusco	1	1400–1250 B.C.	3,275	–19.3	Low maize	Blake et al. (1992)
Soconusco	2	3000–1800 B.C.	4,400	–9.8	High maize, CAM, or marine	Blake et al. (1992)
Pacific Panama						
Sitio Sierra IV	5	A.D. 1100	960	–12.4	Moderate maize and mixed	Norr (1995)
Sitio Sierra VI	7	200 B.C.	2,240	–10.5	Moderate maize and mixed	Norr (1995)
La Mula	6	1200–300 B.C.	2,750	–11.7	Moderate maize and mixed	Norr (1995)
Cerro Mangote	16	5000–2500 B.C.	5,750	–13.7	Moderate maize and mixed	Norr (1995)
Coastal Ecuador						
Valdivia	8	A.D. 1470–1580	520	–9.0	High maize	van der Merwe, Lee-Thorp, and Raymond (1993)
Valdivia	7	300 B.C.–A.D. 100	2,100	–8.0	High maize	van der Merwe, Lee-Thorp, and Raymond (1993)
Valdivia	20	800–300 B.C.	2,550	–10.9	High maize	van der Merwe, Lee-Thorp, and Raymond (1993)
Valdivia	10	1200–800 B.C.	3,000	–12.3	Moderate maize and mixed	van der Merwe, Lee-Thorp, and Raymond (1993)
La Emerenciana	2	1850–1300 B.C.	3,675	–16.3	Moderate maize and mixed	Tykot and Staller (2002)

Valdivia	1	2300–2000 B.C.	4,150	–18.8	Low maize	van der Merwe, Lee-Thorp, and Raymond (1993)
Valdivia	8	3300–2300 B.C.	4,800	–19.0	Low maize	van der Merwe, Lee-Thorp, and Raymond (1993)
Highland Andes						
Mantaro Valley, Peru	29	A.D. 1460–1532	454	–15.0	Moderate maize	Hastorf (1988, 1991)
Mantaro Valley, Peru	18	A.D. 1300–1460	570	–17.6	Low maize	Hastorf (1988, 1991)
La Florida, Ecuador	32	A.D. 100–450	1,725	–11.3	High maize	Ubelaker, Katzenberg, and Doyon (1995)
Chavín de Huantar	4	850–460 B.C.	2,655	–18.9	Low maize	Burger and van der Merwe (1990)
Chavín/Huaricoto	3	390–200 B.C.	2,320	–18.3	Low maize	Burger and van der Merwe (1990)
Huaricoto	1	2200–1800 B.C.	4,000	–18.9	Low maize	Burger and van der Merwe (1990)
Venezuela						
Parmana	3	A.D. 400	1,600	–10.3	High maize	van der Merwe, Roosevelt, and Vogel (1981)
Parmana	2	800 B.C.	2,800	–26.0	Low maize	van der Merwe, Roosevelt, and Vogel (1981)
Total	622					

Discussion

Iltis's (2000) suggestion that teosinte was first cultivated for its sweet stalk and tender ears provides an alternative approach to the problem of *Zea's* early evolution and dispersal. Elaborating on his idea, we have explored the uses of maize stalks for making alcoholic beverages among living peoples in Latin America and found that there are many examples of this process. From North America to the southern reaches of South America, maize, alcohol, and spiritual and social life are inextricably intertwined (Hastorf and Johannessen 1993, 1994; Marshall 1979; Mandelbaum 1965; Kennedy 1978). If, as we suspect, this practice is an ancient one, it likely has its roots in the Archaic period, when people first began to use *Zea*, and the spread of maize was perhaps initially related to social and spiritual concerns to a much greater degree than to subsistence and economic ones.

We have looked at two lines of archaeological evidence for the early use of maize stalks and their role in the initial domestication of maize: the remains of quids and stable carbon isotopes. We have discussed examples of quids from Tehuacán Valley, Tamaulipas, and a few other sites, but to date few of these have been found. Evidence for large-scale processing of maize stalks has yet to be discovered, but new surveys and excavations such as those being carried out in the Sayula-Zacoalco Lake basin by Bruce Benz and his colleagues may eventually provide such evidence (2001*b*).

Stable carbon isotope measurements on human bone samples suggest that maize was being grown and consumed as early as the Archaic period but may not have become a staple in most parts of tropical Latin America until after 3,000 B.P. This indirect view of the role of maize in human diet in early times leads to the question whether there could have been another role for the maize plant

between about 5,500 B.P., when domesticated maize first appeared, and 3,000 B.P. We have suggested that during this period the plant was consumed in the form of stalk juice. Consumption of beer made from the juice would not necessarily have produced higher stable carbon isotope ratios in human bone collagen.

This evidence, though intriguing, does little more than help flesh out the stalk-sugar hypothesis. Clearly, a great deal more research will be required to assess it. Among the lines of evidence that might contribute to this effort are the following:

1 *Technology of maize stalk beer production.* The different steps in maize stalk beer making require a range of tools, some of which are much more archaeologically visible than others (table 3). Of primary importance in beer production are vessels in which the juice is allowed to ferment. Pottery vessels are only one of many possibilities; others include gourds, skins, animal stomachs and intestines, tightly woven baskets, and clay-lined pits (Bruman 2000). None of these are exclusive to maize stalk beer. There remains the possibility, however, that chemical analyses will eventually be able to pick up the distinctive "fingerprints" of liquids that were fermented in particular types of containers (e.g., McGovern et al. 1996). If maize stalk beer was being made in a given container, the chemical signature of the residues may be distinctive enough for eventual identification.

The earliest ceramic technologies in areas where maize plants were used for alcohol making rather than for food consumption should exhibit much greater frequencies of drinking vessels than cooking vessels (Clark and Gosser 1995). Through time, cooking vessels would eventually have become a much more common component of the archaeological record. However, none of the tools that would have been used are specific enough to this one activity that their presence in an archaeo-

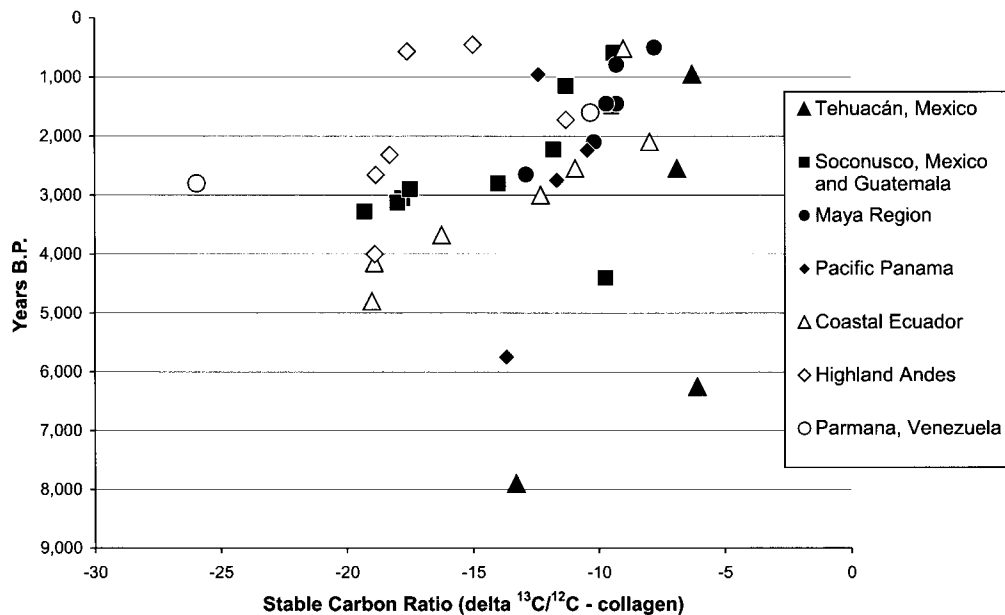


FIG. 3. Stable carbon isotope values for human bone samples from excavated sites in Mesoamerica, Panama, and South America.

logical site could be considered a definitive indicator of the practice. At present, the most we can say is that Archaic-period technology certainly includes all of the implements that would have been necessary to make maize stalk beer, but this cannot be taken as evidence that it was made.

2 *Phytoliths*. If maize stalks were being mashed and squeezed in order to extract juices, then phytoliths might have accumulated in abnormally high concentrations in and around maize stalk processing areas (Piperno 1988). These concentrations might be found in the soil and on artifacts such as grinding stones. Furthermore, during the earliest stages of maize plant use there would have been more stalk phytoliths than kernel and cob phytoliths.

At the early Valdivia site of Real Alto, Pearsall (2002) reports ubiquitous maize phytoliths from house deposits. What proportion of these phytoliths come from stalks and leaves and what proportion from cobs? The answer to this question might help resolve the debate about the timing and significance of maize in the Valdivia sequence (Pearsall 2002, Piperno 2003, Staller and Thompson 2002, Staller 2003). New studies of phytoliths from maize may soon allow this sort of comparison to be made. Pearsall, Chandler-Ezell, and Chandler-Ezell (2003) have developed protocols for identifying maize cob phytoliths and distinguishing them from teosinte and other panicoid grass phytoliths. These techniques may eventually permit testing of these suggestions and help to resolve an important methodological and interpretive debate about the timing of the introduction of maize into South America (Staller 2003, Piperno 2003, Pearsall 2002).

3 *Dental evidence*. Constant chewing on maize stalks

could have had two significant negative effects on the dentition: increased abrasion from hard particles including phytoliths in the stalks and increased caries from the sugar content of the juice. As we have seen, intensive tooth wear has been reported for Archaic hunter-gatherers of the Lower Pecos region of West Texas, where the phytoliths in both agave and prickly pear are thought to be the main culprits (Danielson and Reinhard 1998). These plants were staples, and their continuous and intensive chewing caused dental enamel to erode, exposing the pulp and leading to abscesses and tooth loss. However, this is an extreme case; dental wear from diet among Archaic populations is usually not so pronounced. As Pearsall (2000:550–52) points out, dental attrition is a complex process, and much work remains to be done on the causes, frequencies, and rates of dental wear for different diets and in different environmental conditions. We suggest that occasional chewing on green maize stalks and shoots for immediate consumption (as reported by Iltis [2000] and discussed above for Archaic caves in Mexico) would not have had a pronounced abrasive effect on teeth.

We might also expect that increased sugar consumption resulting from maize stalk chewing would cause higher frequencies of dental caries, but the reverse seems to be true. Dental researchers studying the process of caries formation in sugarcane-chewing children in Kenya have found that the chewing stimulates salivary flow, reducing oral acid levels and removing sugars from the tooth surface (Fejerskov et al. 1992). Another by-product of chewing fibrous materials such as maize stalks is that

TABLE 3
Steps in Maize Stalk Beer Making and Their Archaeological Visibility

Step	Tools Used	Archaeological Visibility
Strip the maize stalks	None	None
Place in hollow log or stone hollow	Hollow log, tools such as adzes to hollow out log	Log low, adzes high
Beat to release juices	Stones, wooden mallets or pestles	Wood low, stones high
Collect juice with a dipper	Wooden or ceramic dipper	Wood low, ceramic high
Strain juice	Cloth or basket strainer	Cloth low, basket low
Add water	Ceramic or gourd water container	Gourd low, ceramic high
Add catalysts (roots, bark, or leaves)	Stone grinders	Stone high
Boil for 24 hours	Ceramic vessels, hearth, firewood	Ceramic high, hearth high
Cool and ferment for three days	Ceramic vessels or gourds	Ceramic high, gourd low
Drink finished product	Ceramic or gourd drinking cups	Ceramic high, gourd low

SOURCE: Steinkraus (1996).

it reduces the buildup of plaque that harbors caries-causing bacteria (Pearsall 2002:551).

Large-scale processing of maize stalks to produce juice in quantities sufficient for alcohol production could not have been achieved by chewing the stalks. Therefore, stalk beer consumers should show the same wear characteristics as Archaic peoples with a mixed general diet, exhibiting relatively little phytolith-induced wear and a low incidence of dental caries.

4 *Maize starch grains.* Archaeologists have recently developed methods for identifying the remnants of starch grains from both root and seed crops preserved in ancient sites such as the Aguadulce rock shelter in Panama (Piperno et al. 2000). The presence of these maize starch grains from early deposits dating between 7,000 and 5,000 B.P. could indicate the consumption of the kernels as a food. Alternatively, the early grinding of maize kernels could have been a part of the process of *chicha* making. At present we have no way of distinguishing between the two interpretations. Future research on this topic may be able to isolate residues in vessels (gourds, for example) and help identify the actual context of maize consumption.

5 *Dating of the sequence.* A large body of data is accumulating to suggest that maize cultivation had spread throughout tropical Latin America by at least 6,200 B.P. (Pope et al. 2001). Evidence of forest clearance and plant remains including phytoliths and pollen grains from Belize (Pohl et al. 1996), Panama (Piperno and Pearsall 1998, Piperno et al. 2000), and Ecuador (Pearsall 1999) all date to millennia before there is conclusive evidence for dietary reliance on maize. The early spread of maize into such a vast and diverse area suggests that it was an extremely important plant (B. Smith 1998). This spread was more likely propelled by the desire for a ready supply of sugar than by the paltry supply of grain that the earliest varieties of maize could have provided. We would expect to see increasing evidence for early (Archaic-period) cultivation of maize throughout tropical Latin America. Studies of genetic changes in cob morphology will be particularly important in this regard. For example, Benz and Long (2000:460) suggest that the genetic changes that

maize underwent during its initial domestication indicate that humans may have been dependent on it as a grain crop much earlier than previously suspected. However, if our hypothesis is correct, then the early evidence for *Zea* cultivation will correspond with a perplexing lack of evidence for its use as a staple (e.g., Hastorf 1999: 52).

Conclusion

As the above points combine to suggest, there are several problems with our stalk-sugar hypothesis, the prime one being a lack of direct evidence—notwithstanding the presence of quids indicating the occasional extraction of the sugary stalk juice. This would, we think, be a serious problem if there were abundant evidence for the use of maize as a staple before 3,000 B.P. In fact, it is precisely because there is so little direct evidence for maize as a staple before this time that we are encouraged to look for alternative explanations of the domestication and spread of maize's ancestors.

We should be prepared to encounter significant changes in the uses of plants and animals and the roles they played in changing subsistence systems. We should also be ready to consider the unintended consequences of ancient innovations. The modern uses of many plants are far from their original ones. For example, rubber synthesis and production were first discovered and perfected by Archaic and Early Formative peoples in Mesoamerica, who used it to make balls for playing the ballgame (Hosler, Burkett, and Tarkanian 1999). The later industrialization of its production to manufacture tires for automobiles—in effect, transforming rubber from an item used only in sport and ritual to a key element of modern transportation—could never have been foreseen by its early Mesoamerican users. It is possible, too, that teosinte's initial users were quite unaware of the plant's potential to become an increasingly productive source of carbohydrates.

The utility of the approach we have taken is that it provides potentially useful new ways of thinking about

Zea's evolution. It allows us to suggest that maize was domesticated not for food but for drink—in other words, that its eventual use as a staple was an unintended consequence of its initial intensive use as source of sugar and enjoyment. This possibility, in turn, suggests that we should find very different kinds and patterns of evidence for the plant's initial history of use than would be expected if it had been domesticated for its starchy grain.

If the stalk-sugar hypothesis is correct, it suggests that the social dimension of foods—their uses in rituals, in alcohol production, and in trade—were equally important as and in some cases perhaps even more important than their strictly nutritional ones (Dietler 1990; Hayden 1990, 1992; Katz and Voigt 1986:27; Hastorf 1994:396). The following narrative by Manuel López Calixto, recorded by Gary Gossen (1974:326) in Chamula, Chiapas, gives a clear indication of the deep social significance of alcohol made both from sugarcane and from maize:

Long ago the gods had their own drinks. Our Father had sugarcane liquor, and San Juan had sugarcane and maize beer. Our Father made his drink with the juice of flowers. They had a drinking party and exchanged drinks. When they were a little drunk, they began to sing. The first drink was sugarcane liquor; the second was maize beer. The first is better for celebrating fiestas. That is why everyone all over the earth knows it and uses it. Our Father and San Juan taught us.

Could this reference to sugarcane liquor and the primordial drink be an oral historical link to ancient times when maize stalks were the “cane” and provided, as suggested by Bruman (2000), the source of alcohol for celebrating fiestas?

Maize's early ancestor was transported over a vast area of the Americas long before the plant could have been even close to the highly productive crop that was commonly cultivated by later civilizations. This trade and transport must have occurred because it had high social value (Hastorf 1994). People were in contact through vast chains of interaction, and the use of high-status products, including beverages, was a significant part of those interactions. We hope that our stalk-sugar hypothesis will encourage researchers to look for new evidence to shed light on maize's ancestry and history.

Comments

SERGIO J. CHAVEZ

Department of Sociology, Anthropology and Social Work, Central Michigan University, Mt. Pleasant, Mich. 48859, U.S.A. (chavezsj@cmich.edu). 26 VII 03

Smalley and Blake's article is an excellent summary of sources, methods, techniques, and data related to the early and rapid spread of maize from its homeland in

Mesoamerica. Equally commendable is their identification of problems in the operationalization of the hypothesis initially posed by Iltis (2000). My comments derive from my archaeological, ethnographic, and historical work in the southern highlands of Peru and the Lake Titicaca Basin, but, responding as I am from the field, I am unable to substantiate them with specific references.

Although the authors have provided good historical and ethnographic references for chewing and processing of maize stalks in Mesoamerica, those for Peru and Bolivia (Bruman 2000:57; Litzinger 1983:42) appear to be secondary sources. Well-known historical sources dealing with maize (e.g., Acosta, Cieza de León, Cobo, Garcilaso, and Guaman Poma) and the accounts of explorers such as Bandelier, Middendorf, and Squier make no mention of the manufacture of cornstalk syrup. Forbes's (1870:250) report of the making of a fermented drink from maize in Aymara communities is not confirmed by other sources. One possibility is that Forbes might have observed a rare occurrence influenced by the development of sugarcane production. My extensive interviews of Aymara- and Quechua-speaking peoples in the region have yielded no confirmation for the idea except for a single informant who had learned to make an alcoholic beverage from maize stalks in a lower valley of Bolivia, where sugar was also added in the process of fermentation. This unique case may also have been influenced by the European technology. Today, the bulk of harvested maize stalk is used as fodder for domestic animals and is rarely chewed for its sugar content. However, this comment does not preclude the possibility of more extensive use of cornstalks during the initial introduction of maize in the Andes.

Smalley and Blake's observation that in Mesoamerica the yields of other sources of sugar for the manufacture of alcoholic beverages are limited because of their slow growth is certainly a good argument for the spread of maize there, but the Mesoamerican model may not be applicable in the Andes. For example, in the Titicaca Basin there are cultivated sources for the production of alcoholic beverages whose yields could easily be increased—potato (historically documented) and quinoa, which has a higher protein, lipid, and glucose content than maize (documented ethnographically). Uncultivated sources that are still used include wild quinoa, the seeds of the molle (which grows in the valleys), and the berries of the *macha macha* shrub.

With respect to phytolith analysis, it is not made clear here whether stalk phytoliths can be differentiated from cob phytoliths. To my knowledge there are no conclusive studies on the detection of residues of maize fermentation in pottery vessels. I recently collected sediment samples from *chicha*-brewing vessels in various taverns in Cuzco, but when analyzed by Robert Thompson they proved to be the remains of fermented barley.

Of the many varieties of maize in the Central Andes, only the yellow kind is used to produce the fermented drink known as *k'usa* in Aymara or *aqha* in Quechua. Other varieties, for example, the purple and the white,

are used to produce nonalcoholic beverages. Furthermore, maize is absent from the rites and ceremonies of the region today. The only related information I collected in the Titicaca Basin is a dichotomy of food classification in which yellow maize is considered a warm food (eaten during the cold months) and white a cool food (consumed during the hot months or when one suffers from fever).

As Smalley and Blake acknowledge, the cornstalk/maize-beer hypothesis lacks direct confirmation even for the Andean region. However, the dramatic increase that they point to in the use of maize as a staple at about 3,000 B.P. seems to be also a recurrent pattern in the Andes. For example, the analysis and identification of phytoliths in food residues derived from our extensive excavations on Bolivia's Copacabana Peninsula lends support to this assertion. Specifically, Thompson was able to identify phytoliths preserved in human tooth plaque as well as in food residues preserved in cooking vessels derived from materials pertaining to the Yaya-Mama religious tradition of the Titicaca Basin (ca. 800 B.C.–A.D. 200). The identification of maize phytoliths is significant because analyses of flotation samples have failed to detect maize in this period.

A minor issue that is not addressed here is the consumption of both maize and beans to overcome the protein deficiency in the former. Another minor point is the authors' reference to Danielson and Reinhard's (1998) report of intensive tooth wear caused by chewing prickly pear. My own experiences and observations in the Andes indicate that the only hard portion of the prickly pear is the seeds, which are swallowed without chewing. In this regard, many years ago K. V. Flannery noted that humans are the main agents in the propagation of prickly pear through the undigested seeds in the feces.

WARREN R. DEBOER

Department of Anthropology, Queens College, City University of New York, Flushing, N.Y. 11367, U.S.A.
(wdeboer@qc1.qc.edu). 16 VII 03

Smalley and Blake develop Iltis's (2000:22) suggestion that teosinte, with its "uniquely useless and inaccessible grain," was exploited initially as a sugar source, only later to be catapulted in status to preeminent New World cereal. Their argument allies itself with two recurring positions in the feisty annals of "agricultural origins and dispersals," to use Carl Sauer's (1952) felicitous title. First, by divorcing present or latter-day utility from past function, it embraces the approach that Gould (2002: 1214–18) attributed to a passage in Nietzsche's *The Genealogy of Morals*. Nietzsche's principle disengages consequence from origin and thereby evades the trap of constructing the past from presentist projection. Secondly, emphasizing the appeal of sweet and fermentable stalks injects desirous human agents into the account, a palliative for the stern "food crises" and "population pressures" that haunt our angst-driven prehistories. How charming it would be to have a snack-and-party crowd,

hassled by only an occasional aggrandizer or two, at the base of the Neolithic!

Charm aside, the scenario grapples with some problematic aspects of the maize chronicle as it currently stands. One is the delay between initial maize domestication from a teosinte ancestor, identified as a variant of *Zea mays* ssp. *parviglumis* centered on the Río Balsas drainage of Mexico (Matsuoka et al. 2002), and maize's takeoff as a dietary staple millennia later. In Ecuador, Peru, and the North American Southwest and Eastern Woodlands—areas to which maize was introduced—a similar lag separates initial appearance from a later role as a major crop. The prior presence of indigenous domesticates in these recipient peripheries cannot alone explain this temporal pacing, as it also characterizes the maize homeland in Mexico. It is in this gestation period, lengthy by the standards of Old World grains (Diamond 1997), that Smalley and Blake situate their sugary, fermentable stalks. The idea is plausible and is currently undergoing scrutiny in the debate over the role and awkwardly precocious timing of maize in Formative Ecuador, the case for which leans heavily on arguable phytolith evidence (Tykot and Staller 2002, Pearsall 2002, Staller 2003).

In thinking about the dispersal of maize across the isthmus it may be instructive to consult the growing body of work on neotropical foraging. For example, Balée (1994) suggests that maize, a plant with low transport costs, is often the cultigen last to be abandoned as mobility increases among Amazonian forager-farmers. Rival (2002:2) notes that the Ecuadorian Huaorani, desultory cultivators by conventional standards, occasionally interrupt their trekking to plant, tend, and harvest manioc in order to host intergroup drinking parties; she cites approvingly Maybury-Lewis's assertion that Xavante "harvests were thought of less as providing the essentials for the life of the community than the bonuses to be used for celebration." Not only does maize stalk beer linger here and there in Middle and South America but so do ongoing practices which may offer glimpses of the processes at work in the "vast chains of interaction" which, according to Smalley and Blake, channeled the early maize diaspora.

The rarity of direct evidence for teosinte use, the spotty record of maize quids, and bone-chemistry profiles indicating a low contribution of maize to human diet can all be accommodated by the Smalley and Blake scenario but are insufficient for confirming the importance of maize beer. The authors admit this inadequacy and propose a series of tests that are not diagnostic alone but would be supportive in concert. Certainly an unambiguous chemical signature for alcoholic fermentation (Arthur 2002) or for the distinctive additives that typically accompany beer or wine production (McGovern et al. 1996) would be breakthroughs. I am dubious that a preponderance of ceramic drinking vessels acts as a signature for beer bashes. A literature survey of 70 ceramic assemblages, each the earliest pottery reported in its area, indicates a strong latitudinal gradient from bowls and jars to conoidal ollas as one moves poleward from

the equator (DeBoer 2003). I suspect that differing mobility regimes and the effect of gourd and basket skeuomorphy, with or without ostentatious feasting, are the major factors underlying this worldwide pattern.

Reference to “worldwide” patterns raises a query about the scope of Smalley and Blake’s claims. “From North America to the southern reaches of South America” certainly exceeds the aboriginal distribution of American beers, which stopped at 35° N and S latitude (Kroeber 1948: 555; Cooper 1963:map 11). Proposals for prehistoric maize beer in Utah (Coltrain and Leavitt 2002) and Florida (Widmer 2002:388) are weakly supported, and there is little substance to Driver’s (1961:96–97, map 12) attribution of aboriginal persimmon beer to the mid-Atlantic seaboard, although the chewing of sweet stalks was common practice in eastern North America as it is among many maize-farming folks (Waugh 1916:101). In America north of the Gila, the joys of ethanol apparently did not precede the need for carbohydrates.

Smalley and Blake provide guidelines for rethinking once again the story of maize. The tempo of current research suggests that in a few years we will have a much better grasp of what was brewing in the early days of this remarkable plant.

MARY W. EUBANKS

Department of Biology, Duke University, Durham, N.C. 27708-0338, U.S.A. (eubanks@duke.edu). 8 VII 03

Smalley and Blake present anthropological evidence for Iltis’s (2000) idea that teosinte was used for the sweet liquid in its stalks prior to domestication. They hypothesize that the juice was fermented into an alcoholic drink and that this could explain the widespread geographical distribution of *Zea* before it was transformed into a staple grain.

Scientists agree that teosinte is the ancestor of maize (Bennetzen et al. 2001; Bird 1984; Doebley 1990; Iltis 2000; Eubanks 2001a, b; Galinat 1977a, 2001; Mangelsdorf 1986; Mangelsdorf and Reeves 1939), but they disagree about which teosinte was the progenitor, where, when, and how it evolved into maize, and whether there was a single origin (Iltis 2000, Matsuoka et al. 2002) or multiple origins (Galinat 1992, Provan et al. 1999). As Smalley and Blake point out, the initial use of the ancestral species was not primarily for food from grain. One use of teosinte, as well as *Tripsacum*, another close maize relative whose sugar content is slightly higher than teosinte (Bargman et al. 1988), could have been for the sweet stalk juice. Production of corn syrup is a multibillion-dollar business today (Rhoades 1993), and this use has deep roots in antiquity. Other plants were used to make alcoholic beverages for ritual communion with the gods. Such use for teosinte may resolve seemingly incongruous pieces of the genesis puzzle—the absence of teosinte seeds in the archaeological record and the wide geographical distribution of *Zea* prior to adoption as a staple grain.

Fossil maize from the highlands of southern Mexico

dates to around 6,500 B.P. (Piperno and Flannery 2001). Although microfossil evidence should be interpreted with caution (Eubanks 1997, Rovner 1999), *Zea* and *Tripsacum* pollen have been reported in Oaxaca by 10,000 B.P. (Schoenwetter and Smith 1986), several thousand years before domesticated maize appeared. Microfossil evidence indicates presence in Panama (Piperno et al. 2000) and Ecuador (Piperno 2003) as early as 7,000 B.P. and in the Gulf of Mexico lowlands by 6,200 B.P. (Pohl et al. 1996, Pope et al. 2001).

Zea mays ssp. *parviglumis* is the extant teosinte most closely related to maize (Bennetzen et al. 2001, Doebley 1990, Iltis 2000, Matsuoka et al. 2002), and this has been interpreted as proof that Balsas teosinte is ancestral maize. Since other potential candidates for involvement in the origin of maize (Bird 1984; Eubanks 2001a, b; Galinat 1973, 2001; Mangelsdorf 1986; Provan et al. 1999; Wilson et al. 1999) were not included, additional comparative genomics studies are needed to test this hypothesis. A prototype of ancient maize reconstructed in crosses between teosinte and *Tripsacum* (MacNeish and Eubanks 2000) provides the first experimental evidence for how teosinte could have been transformed into maize. To address the dearth of molecular data for *Zea* and *Tripsacum*, Eubanks (2001b) genotyped all teosinte species, four indigenous maize races from Mexico and South America, and seven *Tripsacum* species. This comparative genomics study revealed that *Tripsacum* shares many polymorphisms with maize and teosinte. The finding that over 20% of maize polymorphisms are shared uniquely with *Tripsacum* and are not present in teosinte supports the hypothesis that *Tripsacum* introgression played a role in maize domestication. How does this fit the stalk-sugar hypothesis?

Tripsacum andersonii, a confirmed natural hybrid between *Zea* and *Tripsacum* (Talbert et al. 1990), is widespread from Mesoamerica to South America. It is cultivated as fodder for guinea pigs and used to mark property boundaries (de Wet et al. 1983). *T. laxum* is another cultivar used from Veracruz to Guerrero, Guatemala, and northern South America (Randolph 1970). Crosses between *T. laxum* and *Zea diploperennis* produce fertile, perennial hybrids that can be reproduced by cuttings, rhizomes, and seed. A single plant may develop over 60 culms that quickly send out new shoots when cut back. Such plants would provide a continuous source of stalks for juice extraction, which could then be fed to animals. *Tripsacum* carries a dominant allele for the sugary gene (Galinat 1977b). Its counterpart allele in *Zea* is recessive. Sugar content increases dramatically in *Zea-Tripsacum* hybrids. If species of both wild grasses were brought together as a result of human exploitation of their sweet stalk juice, this would have facilitated intergeneric hybridization. If humans discovered and cultivated sweeter hybrids, early cultivators would soon have encountered intercross hybrids with ears resembling those of early maize from the southern highlands of Mexico (see Eubanks 2001b: fig. 11). The selection and cultivation of *Tripsacum*-introgressed teosinte would have set the stage for the sudden appearance of domes-

ticated maize, followed by its rapid adoption in Mesoamerica and South America, with the subsequent explosive radiation into the genetically diverse land races in the archaeological record (Eubanks 1999). Smalley and Blake's thoughtful anthropological treatise on the early use of teosinte provides a plausible explanation for the sweet success of maize domestication.

KRISTEN J. GREMILLION

*Department of Anthropology, Ohio State University,
244 Lord Hall, 124 W. 17th Ave., Columbus, Ohio
43210, U.S.A. (kgremill@columbus.rr.com). 9 VII 03*

The case for maize-stalk sugar production as a stimulus for the initial cultivation of *Zea* is largely circumstantial, as Smalley and Blake recognize. They present the evidence in that light and include recommendations for future testing that might lead to more definite conclusions. These recommendations take advantage of a wide array of analytic techniques and data sets and represent potentially fruitful avenues of investigation. However, the widely accepted assumption that *Zea* was exploited primarily for its grains is perhaps not as problematic as they claim. They reject explanations based on economic advantages of early maize or teosinte as a source of grain on the grounds that extracting nutrients from such resources entails high processing costs. Given an "ample" food supply, such a resource will be disdained by rational foragers. The same is true (to some degree) of all the small, carbohydrate-rich seeds that have made their way into human diets. Many explanations for the adoption of small seeds as food are possible: periodic shortages of preferred foods, risk-reduction benefits of storage, changes in density or location that cut costs or increase profitability, or (as argued in this article) a preexisting relationship with the plant based not on consumption of the seeds but on some other useful property.

Discussion of the archaeological record here draws attention to the scarcity of teosinte grains as a strike against traditional "kernel-centric" assumptions about maize domestication, yet in other contexts an effort is made to explain the absence of evidence in a manner favorable to the stalk-sugar hypothesis. The scarcity of teosinte grains is taken at face value as an indicator of their dietary insignificance, whereas the absence of sugar-extraction residues from the archaeological record is explained as a product of preservation bias. The stalk-sugar argument would be more persuasive had the authors taken a more consistently critical stance.

Some of the evidence presented as support for the stalk-sugar hypothesis does not really distinguish between alternative explanations. For example, reduction of branching might represent selection for traits other than sugar content—domesticated sunflower evolved similarly, and there is little reason to question the use of this plant for its seeds and oil. Likewise, the maize-stalk quids found on archaeological sites simply demonstrate that the plant had multiple uses—a characteristic of many, perhaps the majority of, economic plants

and a fact that says nothing about the purpose for which the plant was first domesticated.

At the same time, Smalley and Blake have drawn attention to an issue that might profitably be explored for any number of domesticates and proto-domesticates. The current or dominant mode of use need not be the sole one (and, by implication, the motive or stimulus for dietary innovation). Questions remain: How would early removal of cobs from the plant to encourage sugar accumulation have affected cob size? Are larger stalks sweeter stalks? Which plants provided seed corn, and how were they selected? Predictive models might be built along these lines to shape a rigorous test of the stalk-sugar hypothesis.

M. ANNE KATZENBERG

*Department of Archaeology, University of Calgary,
2500 University Dr. N.W., Calgary, Alberta, Canada
T2N 1N4 (katzenbe@ucalgary.ca). 8 VII 03*

The ideas presented by Smalley and Blake are interesting and provocative. It appears that the practice of chewing corn stalks extended as far north as did the cultivation of maize. Waugh (1916) cites a 1751 report by Bartram in which the latter observed the Iroquois "chewing raw Indian corn-stalks, spitting out the substance after they sucked out the juice." The question is how to verify the practice beyond ethnographic references and the preservation of botanical remains. Stable carbon isotopes would seem to provide the answer, but, as Smalley and Blake point out, most nutritional information about maize is about the kernel, not the stalk. A small amount of sugar from a C₄ plant may show up in bone carbonate, but it would have a very small effect and could easily be missed if other C₄ foods are being consumed.

Saunders, DeVito, and Katzenberg (1997) analyzed stable carbon isotopes in bone collagen from 19th-century European settlers to Canada and compared changes in $\delta^{13}\text{C}$ values with historical information on the increasing importation of cane sugar beginning around 1840. Because the consumption of C₄ plants was fairly low (Katzenberg, Saunders, and Abonyi 2001), we thought that cane sugar might show up. We found a weak positive relationship ($r = 0.338$; $p = 0.067$) between year of death and $\delta^{13}\text{C}$ for 45 individuals over the age of 12 years. Adding $\delta^{13}\text{C}$ for bone carbonate to a subset of 17 individuals, we found a wider range of variation in carbonate $\delta^{13}\text{C}$ in comparison with collagen $\delta^{13}\text{C}$ but no clear correlation between year of death or year of birth and carbonate $\delta^{13}\text{C}$. Therefore, although there is clear evidence for an increase in sugar consumption from the historical literature, we did not detect it from analysis of bone carbonate. It is possible that our sample size was too small to pick up any relationship.

It is more likely that a brewed beverage from maize or teosinte would show up, particularly in bone carbonate but possibly in bone collagen as well. If fresh stalks with immature grains were used, as is reported in the ethnohistoric literature, then some protein would have

been included. Fermentation of maize may increase the amount of protein because of the growth of microorganisms (Super and Vargas 2000). Many of the amino acids in collagen are nonessential and can be manufactured in the body. This means that some of the carbon in collagen may come from sources other than protein.

As Smalley and Blake point out, stable carbon isotope ratios in bone carbonate may be a better indicator of small amounts of C_4 plants in the diet, since carbonate incorporates carbon from dietary carbohydrates, fats, and protein not used in protein synthesis. Increasingly, stable isotope studies now include stable carbon isotope ratios from both bone carbonate and bone collagen.

In our attempts to determine whether dietary protein and whole diet were isotopically similar among peoples of highland Ecuador (Ubelaker, Katzenberg, and Doyen 1995), we found that the carbon isotope ratios of collagen and carbonate were closely correlated. We included analyses of biological apatite in order to determine if some of the animal protein in the diet was from domesticated animals consuming C_4 plants. We interpreted the close correlation of stable isotope ratios in the two tissues to indicate that both protein and whole diet were similar in their stable carbon isotope ratios. We also concluded that the small difference observed between high- and low-status individuals was due to consumption of maize beer. This conclusion was based on evidence from ceramic vessels and from the stable isotope results. For beer to cause a difference in the $\delta^{13}C$ of carbonate versus collagen it would have to contribute more carbon to the carbonate (most likely as carbohydrate) than to the collagen (most likely as protein), but this does not appear to be the case. There are small but significant differences between $\delta^{13}C$ in high- and low-status individuals for both collagen and carbonate.

What these two studies suggest is that, through stable carbon isotope analysis, one would be more likely to pick up consumption of a maize or teosinte beer than to detect consumption of sugar from chewing on maize or teosinte stalks. It would be helpful to carry out nutritional analyses of traditional maize beer.

AUGUSTO OYUELA-CAYCEDO

Department of Anthropology, University of Kentucky, Lexington, Ky. 40506, U.S.A. (aocayc2@uky.edu).

23 VI 03

Explanations like the one proposed by Iltis (2000) and refined by Smalley and Blake help us to break away from the classical preconceptions of a conjectural archaeology (Stoczkowski 2002) toward more realistic views. The stalk-sugar hypothesis helps us to account for the inconsistencies in the evidence recovered from carbonized remains, pollen, starch, and phytoliths in the search for the magical yellow kernel or cob. Differences remain as to where maize was first domesticated. The early presence of maize in Peru, Ecuador, Panama, and Colombia (Piperno and Pearsall 1998) associated with a lithic technology of seed processing lends weight to the argument

that the consumption of maize occurred earlier in these locations than in Mesoamerica. Differences also exist in terms of how much maize contributed to the diet and in what form it was used.

In the case of San Jacinto 1 and 2 in the savannah lowlands of northern Colombia (at 200–500 m.s.l.), some evidence clearly supports the arguments of Smalley and Blake. San Jacinto 1 is a special-purpose site, one of a variety of sites generated in the landscape by collectors. It has the earliest fiber-tempered pottery in the New World, dating between 6,000 and 5,300 B.P. (uncalibrated), and this pottery was used for serving and even fermentation rather than for cooking (Oyuela-Caycedo 1995, Pratt 1999, Raymond, Oyuela-Caycedo, and Carmichael 1998). Cooking vessels that use sand temper appear around 5,300 B.P. in San Jacinto 2, as well as in Monsu, Puerto Chacho, and Puerto Hormiga and in Ecuador and Panama (Oyuela-Caycedo 1996, Raymond 1998). The abundant ground-stone technology, especially manos and metates, at San Jacinto 1 indicates a processing of grains for flour, and the large number of earth ovens indicates a seasonally consistent use for steam cooking (Oyuela-Caycedo 1998). New evidence indicates that the Poaceae and starchy parenchyma that were used at the site were maize (Oyuela-Caycedo and Bonzani n.d.). Judging from the case of San Jacinto, it can be indirectly argued that maize was used for the extraction of sugar and fermentation. Direct proof is lacking, but the context of the pottery seems to support its use for serving liquids on special social occasions (pottery was not abundant but was highly decorated). We have contextual evidence of the use of seeds for flour and the cooking of possible “tamales” in the earth ovens and their consumption at the site.

The cycle of mobility, territoriality (Oyuela-Caycedo 1998; Binford 2001:375), and social aggregation (see Dillehay et al. 2003) must be important in understanding the stalk-sugar hypothesis, but, surprisingly, these aspects are not considered by Iltis (2000) or by Smalley and Blake. Maize was a secondary source of food because of its limited availability in time (dry season) as well as in space (floodplain and the banks of rivers and creeks). It was probably cultivated at the end of the rains on the fertile, cleared areas of creek and river banks and collected in the dry season three to five months later. Environments with a strong dry season, such as at San Jacinto and Loma Alta or Real Alto in Ecuador, favored the occasional seasonal processing of maize as a beverage, for sugar extraction, or for consumption as a meal. Understanding of the timing or seasonal constraints of maize production is a key aspect (see Bonzani 1997, 1998) that may reinforce the stalk-sugar hypothesis of the evolution of teosinte to maize.

The process of the domestication of maize must have begun a long time before San Jacinto 1 was occupied by territorial forager populations. Much of the archaeological research on maize is concentrated on highly visible sites when the early stages of domestication of maize or wild maize or teosinte probably took place on the banks of creeks, rivers, and lakes after the water had receded

(see Denevan 2002:95). The planting or natural occurrence of this resource was most likely concentrated, making it easy to harvest during the dry season in the Tropics.

The complexity of the subsistence strategies of foragers and collectors needs to be reexamined. The importance of other plants that were exploited and managed, such as gourds, roots, and palm fruits, is only starting to emerge (Dillehay and Rossen 2002). We are still far from understanding the complex technological and cognitive capacity of “hunter-gatherers” and their patterns of food consumption in conjunction with environmental constraints (Bonzani 1998) and social storage (Binford 2001:371). With explanations like the one presented by Smalley and Blake, we can start to move along the right track of studying an unknown past without biased preconceptions. With more intensive research in the tropical lowlands we should be able to resolve the issue of the origins of maize from a biological, archaeological, and social perspective in a few years.

DEBORAH PEARSALL

Department of Anthropology, University of Missouri-Columbia, 107 Swallow Hall, Columbia, Mo. 65211-1440, U.S.A. (pearsall@missouri.edu).
7 VII 03

Smalley and Blake are to be commended for a thorough job of reviewing the ever-growing literature on maize domestication and for providing a succinct summary for this paper. The historical and ethnographic reviews of maize-stalk sugar use are also helpful and informative.

I also consider it likely that teosinte was initially harvested for its green fruits or sweet stems and that successive harvesting and planting of seeds to increase supplies of the plants led to the emergence of the nonshattering maize cob with its naked seeds and a shift in focus to use of those seeds (kernels) (Piperno and Pearsall 1998:161). I am uncertain, however, whether the hypothesis that the initial use of teosinte/early maize was as a sugar source is testable, at least through phytolith analysis. At present only maize leaves and leaf-derived tissues (such as husks) and maize cob residues (soft and hard glumes, cupules) can be identified archaeologically by phytoliths; identifying silica deposited in stalks has not been a focus of research (see Pearsall 2000 and Chandler-Ezell, and Chandler-Ezell 2003 for details on the existing identification methods). Much of the silica in maize stalks is amorphous, although some fibers, vascular elements, and epidermal cells are recognizable. The established maize diagnostics do not occur in stalks. Perhaps it might be possible to establish criteria for identifying stem-derived silica (rather than leaf- or inflorescence-derived silica) on tools or human dentitions; only future research will tell.

One aspect of the paper that particularly intrigues me is the difference in the archaeological evidence for maize-stalk chewing between Mexico and Peru. While the evidence is not abundant for either region, being limited

to dry caves in Mexico and dry caves and the desert coast in Peru, the apparent lack of evidence for the chewing of maize stalks in Peru suggests to me that human interest in maize had shifted to grain production by the time the crop was introduced into South America. (A quick review of Towle 1961 yielded no references to maize quids from coastal sites.) Once maize spread outside the range of teosinte, kernel and cob size were no longer constrained by crossing with ancestral or weedy *Zea* relatives. The subsequent increase in maize productivity—larger kernels and larger cobs—that emerged through the process of harvesting and planting eventually produced a plant that could compete in yields with native South American root and tuber crops such as manioc (*Manihot esculenta*). I believe that we need to consider the apparent delay in the emergence of maize as a dietary staple in South America in the context of the productivity of a diverse array of native root crops (and to consider that evidence for forest clearance may also be indirect evidence of these crops). Why grow some relatively unproductive maize along with root crops? Like other annual seed crops, maize is easy to store, high in protein, and quick-growing and can either be eaten green or grown for harvest of mature seeds. The dominance of maize late in prehistory in western South America may also relate to its greater ease of storage and transport in comparison with other crops.

Smalley and Blake suggest that increasing evidence of cob and kernel accumulation in and around archaeological sites could be used to argue for a shift from stalk processing to grain production. While it is true that any use of maize that requires heat (parching, toasting, roasting, stewing) would increase the likelihood that kernels and cob fragments would enter the archaeological record as charred remains, the absence or rarity of charred maize is more difficult to interpret. Was maize rarely charred earlier in prehistory because stalks, not kernels, were the focus of production, because garbage disposal practices did not include burning of food residues, or because fragile charred remains were destroyed over time in deposits?

Finally, Smalley and Blake ask what proportion of the maize phytoliths from house deposits at Real Alto reported in Pearsall (2002) came specifically from stalks and leaves and what proportion from maize cobs. The evidence for maize at Real Alto reported in Pearsall (2002) is based on the presence of cross-shaped phytoliths, which are produced in maize leaves and husks. Maize stalks do not produce these bodies. Research in progress on the analysis of food residues on stone tools and human dentitions from Real Alto should shed new light on the issue of domestic versus ceremonial use of maize and on its importance relative to other crops.

DOLORES R. PIPERNO

Smithsonian Tropical Research Institute, Balboa, Republic of Panama (pipernod@tivoli.si.edu). 22 VII 03

This fine article presents an intriguing and plausible hypothesis for why maize was disseminated out of its Mex-

ican cradle south into the tropical forest of Central and South America during the Archaic period and, indeed, why teosinte was originally brought under cultivation and domesticated. We still do not have archaeological sequences from Mexico pertaining to the earliest history of maize, so we cannot yet specify whether the fruitcases of teosinte were initial targets of selection pressure by nascent *Zea* cultivators. I have a feeling that at the outset most important domesticated plants, including maize, were used as food. Nevertheless, it is clear that *chicha* production and feasting were important aspects of social relations in many regions of the Americas. Smalley and Blake's paper lucidly and appealingly discusses these issues and will cause scholars to think about maize domestication in new and important ways.

The discussion of possible skews in bone collagen isotope ratios resulting from maize consumption primarily as calorie-rich stalk sugar or grain *chicha* is very interesting, and it highlights the growing importance to debates about maize of having good data on the bone apatite fraction. I have questioned (Piperno 1998:427–28) the appropriateness of using bone isotopes, especially collagen, from the standpoint of detecting maize consumption in the kinds of mixed tropical horticultural economies now well-evidenced from several sites in southern Central America and northern South America dating to between ca. 7,000 and 5,000 B.P. (Piperno and Pearsall 1998, Piperno et al. 2000). In these situations, many calories came from C_3 plants such as manioc, other roots and tubers, and tree crops. I was especially worried about what *chicha* drinking practiced as part of periodic ceremonial activities would do to those ratios. Smalley and Blake's consideration of how drinks made from maize stalk sugar and the grain might directly suppress a collagen bone isotope signal for maize relative to that expected for nonbeverage grain consumption adds an important new dimension to this problem.

I think that before we head straight to the ramifications of maize as an alcoholic beverage, we ought to consider more the role of *chichas* as important sources of dietary calories and fats. While it is true that one could ferment just about anything quickly in the tropical heat, nonalcoholic kinds of *chichas* made from any number of fruits and grains, including maize, are routinely consumed in the Neotropics today. These drinks, whether fermented or not, are typically high in calories and fats and may well have formed important dietary inputs and supplements in the pre-Columbian era, even if maize *chichas* were made from relatively small-grained maize cobs. One can imagine that expert horticulturalists in the tropical forest south of Mexico would have welcomed the odd maize plant and, forever seeking new ones to make drinks with, quickly experimented with its beverage-making capacities.

Bone isotope ratios on collagen from the preceramic site Cerro Mangote in Panama indicate moderate maize consumption between 7,000 and 5,000 B.P., when starch grain and phytolith evidence from nearby contemporaneous sites also clearly evidences routine processing of kernels (Norr 1995; Piperno et al. 2000, 2001). It seems

that in Panama an early and appreciable focus was put on the maize grain, but, as Smalley and Blake indicate, separating beverage from kernel consumption will be difficult even when maize kernel remains are retrieved because the processing techniques for the two were probably the same or very similar and regional variability in maize use and production was probably considerable.

In the Americas more than in southwestern Asia and Europe, the roles of specific crop plants and their dietary contributions varied across regional boundaries and changed through time in ways that we are starting to detect in archaeobotanical records (e.g., Piperno and Pearsall 1998, Perry 2002). In light of the considerable empirical evidence for maize consumption dating to the Archaic period in southern Central America and northern South America (ca. 7,000 to 5,000 B.P., depending on the region), moving from a debate about whether maize spread out of its Mexican hearth before it became a staple crop to discussions of alternative uses of early maize represents a timely shift in research direction. Smalley and Blake have made a very significant contribution.

ROBERT H. TYKOT

Department of Anthropology, University of South Florida, 4202 E. Fowler Ave., SOC 107, Tampa, Fla. 33620, U.S.A. (rtykot@cas.usf.edu). 22 VII 03

Smalley and Blake offer a very reasonable hypothesis for explaining the widespread diffusion of maize after its initial domestication from teosinte in west Mexico. Many agree that the small cobs of early maize plants would not have been very attractive substitutes for the wild and/or cultivated foods already being consumed in different regions, but few alternative explanations coherent with archaeological and other data have been proposed. While some have similarly hypothesized an early social rather than economic role for maize, particularly in the form of *chicha* beer fermented from maize kernels (e.g., Staller and Thompson 2002, Tykot and Staller 2002), their hypothesis is provocative in suggesting that it was the sugary stalk which was initially important. But is their hypothesis supported more than others by the available archaeological and other data?

The impressive assemblage of ethnohistorical examples of maize stalk sugar use presented serves as a very plausible explanation for the chewed stalks recovered at the Tehuacán Valley cave sites, but, unfortunately, quids have not been identified at early archaeological sites elsewhere, even in the dry caves of Tamaulipas, Guitarrero, and Ayacucho where maize remains have been found. Is this simply because maize was not chewed and discarded in these caves on a regular basis? (There is, of course, no question that these cave sites cannot be considered representative of habitation sites and the activities which would have occurred at them and therefore this is absence of evidence rather than evidence of absence.)

While it is also unlikely that maize macro-remains could be recovered from an open-air site, it is very possible that an area of modestly intensive maize activity

could be identified through systematic analysis of soil samples for maize phytoliths, starch grains, and carbon isotope ratios. Systematic analysis of anthrosols is becoming more common in archaeology and has potential for contributing to our understanding of early maize use, especially if stalk and cob remains can be differentiated (see Thompson and Staller 2000, Piperno et al. 2001, Pearsall, Chandler-Ezell, and Chandler-Ezell 2003).

At present, though, it is stable isotope analysis of human remains which has shed the most light on the quantitative importance of maize at different times and in different places. While significantly more published (e.g., Tykot 2002) and unpublished data are available than are presented by Smalley and Blake, their table 2 does give a fair overview of the contribution of maize to carbon isotope ratios in bone collagen. But it is not surprising that there is a major gap between the first documentation of maize by paleoethnobotanical evidence and its becoming noticeable in collagen carbon isotope ratios. The difference in ratios between C_3 plants and maize (about 14‰), the precision of a single isotopic measurement (usually no more than ± 0.2 for reference materials on most mass spectrometers but at least double that for skeletal samples), and the isotopic variation that is likely to exist within a population eating the same range of foods combine to require a positive shift of at least 1‰ to indicate the consumption of any non- C_3 foods. More important, maize would have to constitute at least 10% of the protein portion of the diet to produce noticeably different carbon isotope ratios in collagen. If maize stalks were initially important as a sugar source (fermented or not), they would contribute hardly at all to collagen, but the contribution of maize cobs to collagen would also be very minor if terrestrial and/or aquatic fauna were consumed in any quantity.

Carbon isotope ratios in bone apatite and tooth enamel would, however, reveal when maize constituted 10% of the total diet, whether in the form of protein, carbohydrates, or alcohol. Unfortunately, far fewer isotopic analyses have been done on apatite and enamel, especially for earlier time periods. Both bone collagen and apatite reflect average diets over at least several years prior to death, and therefore maize's isotopic contributions will be reduced if it is not consumed consistently from year to year. Further, it is likely that, prior to the establishment of storage facilities, maize was consumed mostly on a seasonal basis. The best way, then, to demonstrate the initial consumption of maize would be by analysis of hair or tooth enamel. Analysis of 1-cm lengths of hair would reveal dietary variation from month to month, while careful microsampling along a vertical transect of a tooth could also reveal seasonal variation. One study done of individuals from highland Ecuador shows a difference of at least 30% in maize consumption from season to season (Tykot, Ubelaker, and Wilson 2000).

Since the available evidence strongly indicates that maize did not become a staple in many areas despite being present early on at great distances from highland Mexico, I agree wholeheartedly with Smalley and Blake that we must look for explanations other than its later

importance as a cereal crop to account for its precocious spread throughout Mesoamerica and in much of South America. Their hypothesis is very sound, but more research is necessary to test whether it explains well the motivation and circumstances behind the initial domestication and spread of maize.

Reply

JOHN SMALLEY AND MICHAEL BLAKE
Vancouver, B.C., Canada. 7 VIII 03

In his 1940 doctoral dissertation, written under the direction of Carl O. Sauer and published 60 years later, Henry Bruman (2000:57) observed:

Sugarcane, entirely unknown in aboriginal America, was one of the first economic plants to be introduced by the Spaniards. However, a sweet cane in the broader sense was not only known but widely utilized prior to the Conquest. The Indians had learned that green cornstalks contained considerable sugar; and in many and widely separated areas, it was common practice to crush the stalks, collect the juice, and boil it down to a syrup.

Hugh Iltis, in his address as Distinguished Economic Botanist to the Society for Economic Botany in 1998, after decades of research on teosinte, asked why ancient Native Americans would have been interested in it and suggested that "teosinte was not grown for its grain, but for other culinary virtues," the primary one being its "sugar-containing pith" (Iltis 2000:30). We are pleased that most of the commentators assess our paper in the spirit in which it was offered—as an exploration of the archaeological intersections of these two pioneering contributions. Most of the respondents recognize that we were suggesting an initial hypothesis about why and how teosinte was domesticated and its descendant, maize, came to be one of the dominant food plants of the ancient New World. We are indebted to them for insightful suggestions and new ideas that will, we think, help guide future research on the topic.

Chavez's report of the lack of ethnohistoric and ethnographic evidence for the chewing or processing of maize stalks for sugar in Peru and Bolivia raises some important questions. It may be that in the Andean region there was a long-standing use of maize stalks as fodder for domesticated animals and that present-day herders and farmers rely on the maize plant for its fodder potential. This suggests the possibility that prior to the widespread introduction of sugarcane pre-Columbian Andean peoples extracted sugary juice from the stalks and then fed the debris to their camelids and other domesticated animals. Although Chavez says that no early South American chroniclers mention the chewing or processing of maize stalks, Garcilaso de la Vega (1966 [1609]:499) reports that "an excellent honey is made from the

unripe cane, which is very sweet. The dried canes and their leaves are of great value, and cattle are very fond of them."

Chavez observes that, in contrast to parts of Mesoamerica, the Andean region already had two sources of easily cultivable plants that could have produced fermentable sugars, potato and quinoa. Their presence may have lessened the need or desire to use maize stalks for their sugar content, and they may have retained greater value as animal fodder as he states. This point also supports Pearsall's comment that "human interest in maize had shifted to grain production by the time the crop was introduced into South America."

DeBoer, Pearsall, and Tykot also note that maize stalk quids have not been recovered in South American archaeological sites. Is this simply a matter of preservation, or could it be that the casual chewing of stalks for the sugary pith was simply not practiced south of Mesoamerica? The South American cave sites where maize remains have been recovered also contain the remains of camelids, among many other species. The increasing dominance of camelids in the faunal assemblages has led many to suggest that they were being domesticated—and certainly domesticated camelids were common by the time domesticated maize was present (e.g., at Guittarrero Cave [Wing 1980:156]). We suggest that these domesticated animals may have consumed the quids and other stalk remains as Garcilaso de la Vega reported for cattle.

DeBoer's observations about Amazonian forager-farmers' using manioc, maize, and other plants to make beer for celebrations and drinking parties rather than for sheer survival are particularly relevant to our model. This directly relates to the important social lubrication that beer may have provided and its role in facilitating seasonal aggregations of widely dispersed communities. The ethnographic literature documents this throughout Latin America where alcoholic beverages were produced. How far back this pattern extends is the subject of current research, but we should consider the possibility that maize stalk beer was but one example of this larger social process. Archaic peoples may have been eager to find ways of creating novel foods and drinks for social gatherings and feasts, and maize stalk beer may initially have been one such source of novelty (Hayden 2003).

DeBoer questions whether large numbers of ceramic drinking vessels at a site would necessarily indicate frequent or large-scale beer drinking. We agree that the presence of serving vessels in an assemblage is not sufficient for the interpretation of a beer bash, but some sort of serving mechanism is a necessity. In order to make more reliable interpretations of vessel functions, it will be necessary to study many attributes besides shape to determine which pots were devoted to serving food and drink and which were used for cooking and storage. For example, we would expect serving vessels to show much more elaborate decoration. Cooking vessels should have temper characteristics that help them resist thermal shock. Oyuela-Caycedo presents an intriguing example of this pattern. He and his colleagues have found very

early fiber-tempered pottery used for serving and fermentation. His study and others (e.g., Chavez, Arthur 2002, Staller and Thompson 2002) have identified chemical and microbotanical residues in ceramic vessels and should allow us to catalogue the range of uses of individual vessels and ultimately help distinguish vessels used for manufacturing and consuming beverages.

With regard to identifying vessels used to produce stalk beer versus maize kernel beer, Chavez reminds us of the need to develop methods of distinguishing between stalk and cob phytoliths. At present, as Pearsall points out, "only maize leaves and leaf-derived tissues (such as husks) and maize cob residues (soft and hard glumes, cupules) can be identified by phytoliths." Ongoing research by maize phytolith experts such as Pearsall, Chandler-Ezell, and Chandler-Ezell (2003) may provide new means of differentiating between stalks and the other parts of the maize plant (and also between different species and subspecies of *Zea*).

Chavez's evidence from excavations at sites on the Copacabana Peninsula in Bolivia supports our observation that the consumption of maize as a primary food staple did not become widespread until after about 3,000 B.P. Could the maize phytoliths he reports in dental plaque and in residues on cooking vessels and the low frequency of maize macrofossils in flotation samples be a result, as suggested earlier, of the use of agricultural plant debris as fodder for domesticated animals living in and around settlements? This argument is not wholly satisfying, because maize remains do become more common in later sites, when presumably there were even more animals around.

Eubanks provides an elegant hypothesis for the hybridization of *Tripsacum* and *Zea*, both of which have sugary stalks. The first implication of her suggestion is that early farmers may have used and even encouraged hybrid crosses to take advantage of the resulting increased sugar yields. The second is that this hybridization process could have accounted for the development of primitive cobs in early *Zea*. This scenario, which will undoubtedly be tested with new genetic data, fits well with Iltis's (2000:27) observations concerning Beadle's "great teosinte mutation hunt" in 1971. The absence of observable mutations in about 70,000 teosinte plants and over a million fruitcases suggests that teosinte may never have spontaneously mutated on its own to become maize. Instead, the hybridization of teosinte and *Tripsacum*, outside of teosinte's natural habitat, could have produced the early cobs that later became the object of so much human interest. The stalk-sugar hypothesis provides the mechanism for the initial planting of teosinte outside its natural habitat, leading to the opportunity for hybridization, perhaps first for sugary juice (which Eubanks points out is dramatically increased in *Tripsacum-Zea* hybrids) and only later for seed-bearing cobs.

Piperno observes that experimentation with the beverage-making capacity of maize could have accounted for the early grinding implements and starch residues in Panama. She notes that horticulturalists could have been primed to experiment with any new plant that became

available. We should not forget that people may have begun to grow maize, as a supplement to a wide range of existing cultivars, simply for its taste and its novelty—possibly at a time of the year when such foods were most appreciated (see also Oyuela-Caycedo).

Gremillion's argument that the absence of evidence for teosinte seeds in the archaeological record should not be taken as the basis for rejecting the food uses of teosinte is somewhat hard to follow. Teosinte seeds are extremely durable. If charred, they would be likely to last for millennia in the archaeological record (as are charred maize kernels). Their near absence from archaeological sites in Mesoamerica would be surprising if indeed they were an important food source. Other small seed plants that were consumed regularly leave behind macroremains—either charred in open-air sites or desiccated in dry cave sites. Where small seeds were being harvested for food, then the potential for large numbers' eventually making their way into the archaeological record by several pathways is high (Pearsall 2000:242). Even in the humid Neotropics, charred seeds 1 mm or less in diameter are regularly recovered by modern flotation techniques. Itis joked in his 2000 article (p. 27) that "[George] Beadle delighted in bringing with him a bag of Chicago-baked 'teosintillas' into the field and 'experimentally' feeding them to his captive associates, with an encouraging 'not bad-tasting, eh?' [Oh yeah? Made up of ground up grains but also woody fruitcases (cupules and glumes), they tasted nothing so much as salted, dry, brittle brown cardboard, an unacceptable candidate for human food, even if fed to us by a kindly Nobel Laureate!]"

Katzenberg points to the significance of variation in $\delta^{13}\text{C}$ values of bone carbonate versus collagen in individuals and the implications for the consumption of protein and carbohydrates. We agree that the best way to be sure about the impact of maize beer consumption on $\delta^{13}\text{C}$ values is to undertake nutritional analyses of maize beer (and, as Piperno suggests, its nonalcoholic cousins) under controlled circumstances. Another useful future study would be the analysis of feeding experiments using traditional maize beer, maize, and C_3 plant alcohol. Such experiments are currently being planned by Brian Chisholm in the Archaeochemistry Laboratory at the University of British Columbia.

Tykot's point about the large proportion of maize in the diet (> 10%) that is necessary for it to be isotopically visible is an excellent one. This is especially useful in rethinking the long-term trajectory of maize consumption in various parts of the New World. The timing of maize use as a staple may be revealed by comparing collagen with apatite $\delta^{13}\text{C}$ values. As he suggests, it will be helpful to examine much larger samples of isotope data, particularly for apatite, in order to interpret the role of maize in the whole diet and not just the protein contribution.

Oyuela-Caycedo brings up the important point of modeling the early use of maize in relation to the broader issues of hunter-gatherer mobility and subsistence strategies. His work at San Jacinto indicates that maize was used seasonally in several forms: as a beverage, for sugar

extraction, and for direct consumption. We agree that the importance of maize in this region and perhaps the key to its early adoption may have been its ability to bridge the wet-season–dry-season food gap. The various species of *Zea* were, however, grown in an exceedingly diverse range of habitats: from the arid north of Mexico and the Southwestern United States to the Northeast of North America and the tropical lowlands of Central and South America. The initial roles and uses of maize in these different geographic and social contexts must have been quite varied, and it is not possible to create one model for its earliest adoption. In the tropical lowlands it may have been planted on the banks of rivers and creeks after the waters had receded. In highland areas it may have been planted on seasonally watered hillsides or in forest clearings. There are many other possibilities besides. Maize's ability to adapt to a wide range of environmental conditions (Muenchrath and Salvador 1995) makes it uniquely well suited to transportation and spread far beyond its homeland for many uses ranging from food to drink.

References Cited

- AMBROSE, S. H., AND L. NORR. 1993. "Experimental evidence for the relationship of the carbon isotope ratios of whole diet and dietary protein to those of bone collagen and carbonate," in *Prehistoric human bone: Archaeology at the molecular level*. Edited by J. B. Lambert and G. Grupe, pp. 1–37. Berlin: Springer-Verlag.
- ARTHUR, JOHN. 2002. Pottery-use alteration as an indicator of socioeconomic status: An ethnoarchaeological study of the Gamo of Ethiopia. *Journal of Archaeological Method and Theory* 9:331–55. [WD]
- BALÉ, WILLIAM. 1994. *Footprints of the forest: Ka'apor ethnobotany—the historical ecology of plant utilization by an Amazonian people*. New York: Columbia University Press. [WD]
- BARGMAN, TRACT, GRACE HANNERS, ROBERT BECKER, ROBIN SAUNDERS, AND JOHN RUPNOW. 1988. *Compositional and nutritional evaluation of Eastern gamagrass (Tripsacum dactyloides L.), a perennial relative of maize (Zea mays L.)*. Nebraska Agricultural Research Division. Journal 8687. [MWE]
- BEADLE, G. W. 1932. The relation of crossing over to chromosome association in *Zea-Euchlaena* hybrids. *Genetics* 17: 481–501.
- . 1972. The mystery of maize. *Field Museum of Natural History Bulletin* 43:2–11.
- . 1980. The ancestry of corn. *Scientific American* 242: 112–18.
- BENNETT, W. C., AND R. M. ZINGG. 1976 [1935]. *Tarahumara: An Indian tribe of northern Mexico*. Glorieta, N.M.: Rio Grande Press.
- BENNETZEN, J., E. BUCKLER, V. CHANDLER, J. DOEBLEY, J. DORWEILER, B. GAUT, M. FREELING, S. HAKE, E. KELLOGG, R. S. POETHIG, V. WALBOT, AND S. WESSLER. 2001. Genetic evidence and the origin of maize. *Latin American Antiquity* 12:84–86.
- BENZ, B. 1994. "Reconstructing the racial phylogeny of Mexican maize: Where do we stand?" in *Corn and culture in the prehistoric New World*. Edited by S. Johannessen and C. A. Hastorf, pp. 157–80. Boulder: Westview Press.
- . 1999. "On the origin, evolution, and dispersal of maize,"

- in *Pacific Latin America in prehistory: The evolution of Archaic and Formative cultures*. Edited by M. Blake, pp. 25–38. Pullman: Washington State University Press.
- . 2001a. Archaeological evidence of teosinte domestication from Guilá Naquitz, Oaxaca. *Proceedings of the National Academy of Sciences, U.S.A.* 98:2104–6.
- . 2001b. The origins of Mesoamerican agriculture: Reconnaissance and testing in the Sayula-Zacoalco Lake Basin. Report submitted to the Foundation for the Advancement of Mesoamerican Studies, Inc. <http://www.famsi.org/reports/99074/index.html>.
- . 2003. Early evolution of maize in Mexico. Paper presented at the Monocots III Conference, Ontario, Calif.
- BENZ, B. F., AND A. LONG. 2000. Early evolution of maize in the Tehuacán Valley, Mexico. *CURRENT ANTHROPOLOGY* 41: 459–65.
- BINFORD, L. R. 2001. *Constructing frames of reference: An analytical method for archaeological theory building using ethnographic and environmental data sets*. Berkeley: University of California Press. [AO]
- BIRD, ROBERT, MC K. 1984. "South American maize in Central America?" in *Pre-Columbian plant migration*. Edited by Doris Stone, pp. 40–65. Papers of the Peabody Museum of Archaeology and Ethnology 76. [MWE]
- BLAKE, M., B. S. CHISHOLM, J. E. CLARK, B. VOORHIES, AND M. W. LOVE. 1992. Prehistoric subsistence in the Soconusco region. *CURRENT ANTHROPOLOGY* 33:83–94.
- BONZANI, R. M. 1997. Plant diversity in the archaeological record: A means toward defining hunter-gatherer mobility strategies. *Journal of Archaeological Science* 24:1129–39. [AO]
- . 1998. "Learning from the present: Constraints of plant seasonality on foragers and collectors," in *Recent advances in the archaeology of the northern Andes*. Edited by A. Oyuela-Caycedo, pp. 21–35. Institute of Archaeology, University of California, Monograph 39. [AO]
- BRAIDWOOD, R. J. 1953. Query, in symposium: Did man once live by beer alone? *American Anthropologist* 55:515–16.
- BRUMAN, H. J. 2000. *Alcohol in ancient Mexico*. Salt Lake City: University of Utah Press.
- BUCKLER, E. S., IV, AND T. P. HOLTSFORD. 1996. *Zea* systematics: Ribosomal ITS evidence. *Molecular Biology and Evolution* 13:612–22.
- BUCKLER, EDWARDS S., IV, DEBORAH M. PEARSALL, AND TIMOTHY P. HOLTSFORD. 1998. Climate, plant ecology, and Archaic subsistence. *CURRENT ANTHROPOLOGY* 39: 152–64.
- BURGER, R. L., AND N. J. VAN DER MERWE. 1990. Maize and the origin of Highland Chavin civilization: An isotope perspective. *American Anthropologist* 92:84–95.
- BUSH, M. B., D. R. PIPERNO, AND P. A. COLINVAUX. 1989. A 6,000-year history of Amazonian maize cultivation. *Nature* 340:303–5.
- CALLEN, E. O. 1967. "Analysis of the Tehuacan coprolites," in *The prehistory of the Tehuacan Valley*, vol. 1, *Environment and subsistence*. Edited by D. S. Byers, pp. 261–89. Austin: University of Texas Press.
- CHISHOLM, B. S. 1989. "Variation in diet reconstructions based on stable carbon isotopic evidence," in *The chemistry of prehistoric human bone*. Edited by T. D. Price, pp. 10–37. Cambridge: Cambridge University Press.
- CHISHOLM, B. S., D. E. NELSON, AND H. P. SCHWARTZ. 1982. Stable-carbon isotope ratios as a measure of marine vs. terrestrial protein in ancient diets. *Science* 216: 1131–32.
- CLARK, J. E., AND D. GOSSER. 1995. "Reinventing Mesoamerica's first pottery," in *The emergence of pottery: Technology and innovation in ancient societies*. Edited by W. K. Barnett and J. W. Hoopes, pp. 209–21. Washington, D.C.: Smithsonian Institution Press.
- CLAYTON, W. D., AND S. A. RENVOIZE. 1986. *Genera Graminum: Grasses of the world*. Kew Bulletin Additional Series 13. London: HMSO Publications.
- COE, M. D. 1994. 4th edition. *Mexico*. New York: Thames and Hudson.
- COLLIER, P. 1879. "Report of the chemist," in *Annual report of the Commissioner of Agriculture for the year 1878*. Edited by W. G. Le Duc, pp. 95–117. Washington, D.C.: Government Printing Office.
- COLTRAIN, JOAN BRENNER, AND STEVEN W. LEAVITT. 2002. Climate and diet in Fremont prehistory: Economic variability and abandonment of maize agriculture in the Great Salt Lake Basin. *American Antiquity* 67:453–85. [WD]
- COOPER, JOHN M. 1963. "Narcotics and stimulants," in *Handbook of South American Indians*, vol. 5. Edited by J. Steward, pp. 525–58. New York: Cooper Square. [WD]
- CROSSWHITE, F. C. 1982. Corn (*Zea mays*) in relation to wild relatives. *Desert Plants* 3:193–202.
- DANIELSON, D. R., AND K. J. REINHARD. 1998. Human dental microwear caused by calcium oxalate phytoliths in prehistoric diet of the lower Pecos region, Texas. *American Journal of Physical Anthropology* 107:297–304.
- D'AYALA VALVA, F., F. PATERNANI, AND E. R. DE OLIVEIRA. 1980. Evaluation of sugar content in corn stalks (*Zea mays* L.) for alcohol production. *Maydica* 25:185–97.
- DE BOER, WARREN R. 2003. Near-beer and no beer in the Americas. Paper presented to the opening session of the Annual Meeting of the Society for American Archaeology, "Thinking and Drinking Beer: Archaeological Perspectives," Milwaukee, Wis. [WD]
- DENEVAN, M. D. 2002. *Cultivated landscapes of Native Amazonia and the Andes*. Oxford: Oxford University Press. [AO]
- DE WET, J. M. J., G. B. FLETCHER, K. W. HILU, AND J. R. HARLAN. 1983. Origin of *Tripsacum andersonii* (Gramineae). *American Journal of Botany* 70:706–11. [MWE]
- DIAMOND, JARED. 1997. *Guns, germs, and steel*. New York: W. W. Norton. [WD]
- DIETLER, M. 1990. Driven by drink: The role of drinking in the political economy and the case of early Iron Age France. *Journal of Anthropological Archaeology* 9:352–407.
- DILLEHAY, T. D., AND J. ROSSEN. 2002. Plant food and its implications for the peopling of the New World: A view from South America. *Memoirs of the California Academy of Sciences* 27:237–53. [AO]
- DILLEHAY, T. D., J. ROSSEN, G. MAGGARD, K. STACKELBECK, AND P. NETHERLY. 2003. Localization and possible social aggregation in the Late Pleistocene and Early Holocene on the north coast of Peru. *Quaternary International* 109–110:3–11. [AO]
- DOEBLEY, J. 1990. Molecular evidence and the evolution of maize. *Economic Botany* 44(suppl.):6–27.
- DRIVER, HAROLD E. 1961. *Indians of North America*. Chicago: University of Chicago Press. [WD]
- EUBANKS, M. W. 1995. A cross between two maize relatives: *Tripsacum dactyloides* and *Zea diploperennis* (Poaceae). *Economic Botany* 49:172–82.
- . 1997a. Molecular analysis of crosses between *Tripsacum dactyloides* and *Zea diploperennis* (Poaceae). *Theoretical and Applied Genetics* 94:707–12.
- . 1997b. Reevaluation of the identification of ancient maize pollen from Alabama. *American Antiquity* 62:139–45. [MWE]
- . 1999. *Corn in clay: Maize paleoethnobotany in pre-Columbian art*. Gainesville: University Press of Florida. [MWE]
- . 2001a. An interdisciplinary perspective on the origin of maize. *Latin American Antiquity* 12(1):91–98.
- . 2001b. The mysterious origin of maize. *Economic Botany* 55:492–514. [MWE]
- FARNSWORTH, P., J. E. BRADY, M. J. DE NIRO, AND R. S. MAC NEISH. 1985. A reevaluation of the isotopic and archaeological reconstruction of diet in the Tehuacán Valley. *American Antiquity* 50:102–16.
- FEJERSKOV, O., A. AA. SCHEIE, D. BIRKED, AND F. MANJI. 1992. Effect of sugarcane chewing on plaque pH in rural Kenyan children. *Caries Research* 26:286–89.

- FLANNERY, K. V. 1973. The origins of agriculture. *Annual Review of Anthropology* 2:271-310.
- . 1976a. "The village and its catchment area," in *The early Mesoamerican village*. Edited by K. V. Flannery, pp. 91-95. New York: Academic Press.
- . 1976b. "Empirical determination of site catchments in Oaxaca and Tehuacán," in *The early Mesoamerican village*. Edited by K. V. Flannery, pp. 103-117. New York: Academic Press.
- . 1986. "The research problem," in *Guilá Naquitz: Archaic foraging and early agriculture in Oaxaca, Mexico*. Edited by K. V. Flannery, pp. 3-18. Orlando: Academic Press.
- FORBES, D. 1870. On the Aymara Indians of Bolivia and Peru. *Journal of the Ethnological Society of London*, n.s., 2:193-305.
- FREEMAN, I. E., B. J. BOCAN, AND H. F. ZOBEL. 1972. Starch: Variation associated with location in corn and sorghum. *Crop Science* 12:122-124.
- FUSSELL, B. 1992. *The story of corn*. New York: A. A. Knopf.
- GALINAT, WALTON C. 1973. Intergenomic mapping of maize, teosinte, and *Tripsacum*. *Evolution* 27:644-55. [MWE]
- . 1977a. "The origin of corn," in *Corn and corn improvement*. Edited by G. F. Sprague, pp. 1-47. Madison, Wis.: American Society of Agronomy.
- . 1977b. Hybrid seed production. U.S. Patent no. 4,051,629, issued Oct. 4. [MWE]
- . 1992. Corn, Columbus, and culture. *Perspectives in Biology and Medicine* 36:1-12. [MWE]
- . 2001. "Origin and evolution of modern maize," in *Encyclopedia of genetics*. Edited by Eric C. R. Reeve, pp. 647-54. Chicago and London: Fitzroy Dearborn. [MWE]
- GARCILASO DE LA VEGA, EL INCA. 1666 [1609]. *Royal commentaries of the Incas and a general history of Peru*. Pt. I. Translated by Harold V. Livermore. Austin and London: University of Texas Press.
- GOSSEN, G. H. 1974. *Chamulas in the world of the sun: Time and space in a Maya oral tradition*. Cambridge: Harvard University Press.
- GOULD, STEPHEN JAY. 2002. *The structure of evolutionary theory*. Cambridge: Harvard University Press. [wd]
- HAMILTON, DONNY L. 2001. *Prehistory of the Rustler Hills: Granado Cave*. Austin: University of Texas Press.
- HARLAN, J. R. 1995. *The living fields: Our agricultural heritage*. Cambridge: Cambridge University Press.
- HASTORF, C. A. 1988. "The use of paleoethnobotanical data in prehistoric studies of crop production, processing, and consumption," in *Current paleoethnobotany: Analytical methods and cultural interpretations of archaeological plant remains*. Edited by C. Hastorf and V. Popper, pp. 119-44. Chicago: University of Chicago Press.
- . 1991. "Gender, space, and food in prehistory," in *Engendering archaeology: Women and prehistory*. Edited by J. Gero and M. Conkey, pp. 132-59. Oxford: Blackwell.
- . 1994. "Cultural meanings: Introduction to part four," in *Corn and culture in the prehistoric New World*. Edited by S. Johannesen and C. A. Hastorf, pp. 395-98. Boulder: Westview Press.
- . 1999. "Cultural implications of crop introductions in Andean prehistory," in *The prehistory of food: Appetites for change*. Edited by C. Gosden and J. Hather, pp. 35-58. London: Routledge.
- HASTORF, C. A., AND S. JOHANNESSEN. 1993. Pre-Hispanic political change and the role of maize in the Central Andes of Peru. *American Anthropologist* 95:115-38.
- . 1994. "Becoming corn-eaters in prehistoric America," in *Corn and culture in the prehistoric New World*. Edited by S. Johannesen and C. A. Hastorf, pp. 427-43. Boulder: Westview Press.
- HAURY, E. W. 1950. *The stratigraphy and archaeology of Ventana Cave, Arizona*. Tucson and Albuquerque: University of Arizona Press and University of New Mexico Press.
- HAYDEN, B. 1990. Nimrods, piscators, pluckers, and planters: The emergence of food production. *Journal of Anthropological Archaeology* 9:31-69.
- . 1992. "Models of domestication," in *Transitions to agriculture in prehistory*. Edited by A. B. Gebauer and T. D. Price, pp. 11-19. Monographs in World Archaeology 4.
- . 2002. Were luxury foods the first domesticates? Ethnoarchaeological perspectives from Southeast Asia. *World Archaeology* 34:458-69.
- HOSLER, D., S. L. BURKETT, AND M. J. TARKANIAN. 1999. Prehistoric polymers: Rubber processing in ancient Mesoamerica. *Science* 284:1988-91.
- HUME, D. J., AND D. K. CAMPBELL. 1972. Accumulation and translocation of soluble solids in corn stalks. *Canadian Journal of Plant Science* 52:363-68.
- ILTIS, H. H. 1972. The taxonomy of *Zea mays* (Gramineae). *Phytologia* 23:248-49.
- . 1983. From teosinte to maize: The catastrophic sexual transmutation. *Science* 222:886-93.
- . 1987. "Maize evolution and agricultural origins," in *Grass systematics and evolution*. Edited by T. R. Soderstrom, K. W. Hilu, C. S. Campbell, and M. E. Barkworth, pp. 195-213. Washington, D.C.: Smithsonian Institution Press.
- . 2000. Homeotic sexual translocations and the origin of maize (*Zea mays*, Poaceae): A new look at an old problem. *Economic Botany* 54(1):7-42.
- ILTIS, H. H., AND J. F. DOEBLEY. 1984. "Zea: A biosystematical odyssey," in *Plant biosystematics*. Edited by W. F. Grant, pp. 587-616. Toronto: Academic Press Canada.
- ILTIS, H. H., J. F. DOEBLEY, R. GUZMAN M., AND B. PAZY. 1979. *Zea diploperennis* (Gramineae): A new teosinte from Mexico. *Science* 203:186-88.
- JANAKI-AMMAL, E. K. 1938. A *Saccharum-Zea* cross. *Nature* 142:618-19.
- JENNINGS, J. D. 1957. *Danger Cave*. University of Utah Anthropological Papers 27.
- JOHANNESSEN, S., AND C. A. HASTORF. Editors. 1994. *Corn and culture in the prehistoric New World*. Boulder: Westview Press.
- KATZ, S. H., M. L. HEDIGER, AND L. A. VALLEROY. 1974. Traditional maize processing techniques in the New World. *Science* 184:765-73.
- KATZ, S. H., AND M. M. VOIGT. 1986. Bread and beer: The early use of cereals in the human diet. *Expedition* 28(2):23-34.
- KATZENBERG, M. A., S. R. SAUNDERS, AND S. ABONYI. 2001. "Bone chemistry, food, and history: A case study from 19th-century Upper Canada," in *Biogeochemical approaches to paleodietary analysis*. Edited by S. H. Ambrose and M. A. Katzenberg, pp. 1-22. New York: Kluwer Academic/Plenum Press. [MAK]
- KENNEDY, J. G. 1978. *Tarahumara of the Sierra Madre: Beer, ecology, and social organization*. Arlington Heights: AHM Publishing.
- KROEBER, ALFRED L. 1948. *Anthropology*. New York: Harcourt, Brace and World. [wd]
- LAMBERT, J. B. 1997. *Traces of the past: Unraveling the secrets of archaeology through chemistry*. Reading, Mass.: Helix Books, Addison-Wesley.
- LITZINGER, W. J. 1983. The ethnobiology of alcoholic beverage production by the Lacandon, Tarahumara, and other aboriginal Mesoamerican peoples. Ph.D. diss., University of Colorado, Boulder, Colo.
- LYNCH, T. F. Editor. 1980. *Guitarrero Cave: Early man in the Andes*. New York: Academic Press.
- MC CLUNG DE TAPIA, E. 1992. "Overview of Mesoamerican agriculture," in *The origins of agriculture: An international perspective*. Edited by C. W. Cowan and P. J. Watson. Washington, D.C.: Smithsonian Institution Press.
- MC GOVERN, P. E., D. L. GLUSKER, L. J. EXNER, AND M. M. VOIGT. 1996. Neolithic resinated wine. *Nature* 381: 480-81.
- MAC NEISH, R. S. 1958. *Preliminary archaeological investigations in the Sierra de Tamaulipas, Mexico*. Transactions of the American Philosophical Society 48(6).
- MAC NEISH, R. S. AND M. W. EUBANKS. 2000. Compar-

- tive analysis of the Río Balsas and Tehuacán models for the origin of maize. *Latin American Antiquity* 11:3–20.
- MAC NEISH, R. S., A. GARCIA COOK, L. G. LUMBRERAS, R. K. VIERRA, AND A. NELKEN-TERNER. 1981. *Prehistory of the Ayacucho Basin, Peru*. Vol. 2. *Excavations and chronology*. Ann Arbor: University of Michigan Press.
- MAC NEISH, R. S., R. K. VIERRA, A. NELKEN-TERNER, R. LURIE, AND A. GARCIA COOK. 1983. *Prehistory of the Ayacucho Basin, Peru*. Vol. 4. *The preceramic way of life*. Ann Arbor: University of Michigan Press.
- MANDELBAUM, D. 1965. Alcohol and culture. *CURRENT ANTHROPOLOGY* 6:281–93.
- MANGELSDORF, P. C. 1953. Comments, in symposium: Did man once live by beer alone? *American Anthropologist* 55: 519–22.
- . 1974. *Corn: Its origin, evolution, and improvement*. Cambridge: Harvard University Press.
- . 1983. The mystery of corn: New perspectives. *Proceedings of the American Philosophical Society* 127:215–47.
- . 1986. The origin of corn. *Scientific American* 255:80–86.
- MANGELSDORF, P. C., R. S. MAC NEISH, AND W. C. GALINAT. 1967. "Prehistoric wild and cultivated maize," in *The prehistory of the Tehuacán Valley*, vol. 1, *Environment and subsistence*. Edited by D. S. Byers, pp. 178–200. Austin: University of Texas Press.
- MANGELSDORF, P. C., AND R. G. REEVES. 1939. The origin of Indian corn and its relatives. *Texas Agricultural Experiment Station Bulletin* 574:1–315. [MWE]
- MARSHALL, M. Editor. 1979. *Beliefs, behaviors, and alcoholic beverages: A cross-cultural survey*. Ann Arbor: University of Michigan Press.
- MATSUOKA, Y., Y. VIGOUROUX, M. M. GOODMAN, J. SANCHEZ, G. E. BUCKLER, AND J. DOEBLEY. 2002. A single domestication for maize shown by multilocus microsatellite genotyping. *Proceedings of the National Academy of Sciences, U.S.A.* 99:6080–84.
- MELHUS, I. E., F. AGUIRRE, AND N. S. SCRIMSHAW. 1953. Observations on the nutritive value of teosinte. *Science* 117:34–35.
- MINTZ, S. W. 1985. *Sweetness and power: The place of sugar in modern history*. New York: Viking.
- MUENCHRATH, D. A., AND R. J. SALVADOR. 1995. "Maize productivity and agroecology: Effects of environment and agricultural practices on the biology of maize," in *Soil, water, biology, and belief in prehistoric and traditional Southwestern agriculture*. Edited by H. W. Toll, pp. 303–33. Albuquerque: New Mexico Archaeological Council.
- MURRA, J. V. 1960. "Rite and crop in the Inca state," in *Culture in history*. Edited by S. Diamond, pp. 393–407. New York: Columbia University Press.
- NORR, L. 1995. "Interpreting dietary maize from bone stable isotopes in the American tropics: The state of the art," in *Archaeology in the lowland American tropics: Current analytical methods and recent applications*. Edited by P. W. Stahl, pp. 198–223. Cambridge: Cambridge University Press.
- OYUELA-CAYCEDO, A. 1995. "Rocks vs. clay: The evolution of pottery technology in the case of San Jacinto 1 (Colombia)," in *The emergence of pottery*. Edited by W. K. Barnett and J. W. Hoopes, pp. 133–44. Washington, D.C.: Smithsonian Institution Press. [AO]
- . 1996. The study of collector variability in the transition to sedentary food producers in northern Colombia. *Journal of World Prehistory* 10:49–93. [AO]
- . 1998. "Seasonality in the tropical lowlands of northwestern South America: The case of San Jacinto 1, Colombia," in *Seasonality and sedentism: Archaeological perspectives from Old and New World sites*. Edited by Thomas R. Rocek and Ofer Bar-Yosef, pp. 165–79. Peabody Museum Bulletin 6. [AO]
- OYUELA-CAYCEDO, A., AND R. M. BONZANI. n.d. San Jacinto 1: A tripartite investigation into the origins of pottery, sedentism, and food production in the Tropics. MS. [AO]
- PEARSALL, D. M. 1994. "Investigating New World tropical agriculture: Contributions from phytolith analysis," in *Tropical archaeobotany: Applications and new developments*. Edited by J. G. Hather, pp. 115–38. London: Routledge.
- . 1999. "Agricultural evolution and the emergence of Formative societies in Ecuador," in *Pacific Latin America in prehistory: The evolution of Archaic and Formative cultures*. Edited by M. Blake, pp. 161–70. Pullman: Washington State University Press.
- . 2000. 2d edition. *Paleoethnobotany: A handbook of procedures*. San Diego: Academic Press.
- . 2002. Maize is still ancient in prehistoric Ecuador: The view from Real Alto, with comments on Staller and Thompson. *Journal of Archaeological Science* 29:51–55.
- PEARSALL, D. M., K. CHANDLER-EZELL, AND A. CHANDLER-EZELL. 2003. Identifying maize in Neotropical sediments and soils using cob phytoliths. *Journal of Archaeological Science* 30:611–27.
- PEARSALL, D. M., AND D. R. PIPERNO. 1990. Antiquity of maize cultivation in Ecuador: Summary and reevaluation of the evidence. *American Antiquity* 55:324–37.
- PENNINGTON, C. W. 1963. *The Tarahumara of Mexico: Their environment and material culture*. Salt Lake City: University of Utah Press.
- PERRY, L. 2002. Starch analyses reveal multiple functions of quartz "manioc" grater flakes from the Orinoco Basin, Venezuela. *Interciencia* 27:635–39. [DRP]
- PIPERNO, D. R. 1988. *Phytolith analysis*. San Diego: Academic Press.
- . 1998. Paleoethnobotany in the Neotropics from microfossils: New insights into ancient plant use and agricultural origins in the tropical forest. *Journal of World Prehistory* 12: 393–449. [DRP]
- . 1999. "The origins and development of food production in Pacific Panama," in *Pacific Latin America in prehistory: The evolution of Archaic and Formative cultures*. Edited by M. Blake, pp. 123–34. Pullman: Washington State University Press.
- . 2003. A few kernels short of a cob: On the Staller and Thompson late entry scenario for the introduction of maize into northern South America. *Journal of Archaeological Science* 30. In press.
- PIPERNO, D. R., AND K. V. FLANNERY. 2001. The earliest archaeological maize (*Zea mays* L.) from Highland Mexico: New accelerator mass spectrometry dates and their implications. *Proceedings of the National Academy of Sciences, U.S.A.* 98:2101–3.
- PIPERNO, D. R., I. HOLST, A. J. RANERE, P. HANSELL, AND K. E. STOTHERT. 2001. The occurrence of genetically-controlled phytoliths from maize cobs and starch grains from maize kernels on archaeological stone tools and human teeth, and in archaeological sediments from southern Central America and northern South America. *The Phytolitharien* 13:1–7. [DRP, RHT]
- PIPERNO, D. R., AND D. M. PEARSALL. 1998. *The origins of agriculture in the lowland Neotropics*. San Diego: Academic Press.
- PIPERNO, D. R., A. J. RANERE, I. HOLST, AND P. HANSELL. 2000. Starch grains reveal early root crop horticulture in the Panamanian tropical forest. *Nature* 407:894–97.
- POHL, M. D., K. O. POPE, J. G. JONES, J. S. JACOB, D. R. PIPERNO, S. D. DE FRANCE, D. L. LENTZ, J. A. GIFFORD, M. E. DANFORTH, AND J. K. JOSSER-AND. 1996. Early agriculture in the Maya lowlands. *Latin American Antiquity* 7:355–72.
- POPE, K. O., M. D. POHL, J. G. JONES, D. L. LENTZ, C. VON NAGY, F. J. VEGA, AND I. R. QUITMEYER. 2001. Origin and environmental setting of ancient agriculture in the lowlands of Mesoamerica. *Science* 292:1370–73.
- PRATT, J. A. F. 1999. Determining the function of one of the New World's earliest pottery assemblages: The case of San Jacinto, Colombia. *Latin American Antiquity* 10:71–85. [AO]
- PRICE, T. D. Editor. 1989. *The chemistry of prehistoric human bone*. Cambridge: Cambridge University Press.

- PROVAN, JIM, PAT LAWRENCE, GEORGE YOUNG, FRANK WRIGHT, ROBERT BIRD, GIANPAOLO PAGLIA, FEDERICA CATTONARO, MICHELE MORGANTE, AND WAYNE POWELL. 1999. Analysis of the genus *Zea* (Poaceae) using polymorphic chloroplast simple sequence repeats. *Plant Systematics and Evolution* 218:245–56. [MWE]
- RANDOLPH, L. F. 1970. Variation among *Tripsacum* populations of Mexico and Guatemala. *Brittonia* 22:305–37. [MWE]
- RAYMOND, J. S. 1998. "Beginnings of sedentism in the lowlands of northwestern South America," in *Advances in the archaeology of the northern Andes*. Edited by A. Oyuela-Caycedo and J. S. Raymond, pp. 10–19. Institute of Archaeology, University of California, Monograph 39. [AO]
- RAYMOND, J. S., A. OYUELA-CAYCEDO, AND P. CARMICHAEL. 1998. "The earliest ceramic technologies of the Northern Andes: A comparative analysis," in *Andean ceramics: Technology, organization, and approaches*. Edited by I. Shimada, pp. 153–72. MASCA Research Papers in Science and Archaeology 15 suppl. [AO]
- RHOADES, ROBERT E. 1993. The golden grain corn. *National Geographic*, June, pp. 92–117. [MWE]
- RIVAL, LAURA M. 2002. *Trekking through history: The Huaroni of Amazonian Ecuador*. New York: Columbia University Press. [WD]
- ROOSEVELT, A. C. 1980. *Parmana: Prehistoric maize and manioc subsistence along the Amazon and Orinoco*. New York: Academic Press.
- ROVNER, I. 1999. Phytolith analysis. *Science* 283:488–89. [MWE]
- ROYS, R. L. 1972. *The Indian background of colonial Yucatan*. Norman: University of Oklahoma Press.
- SAUER, CARL O. 1952. *Agricultural origins and dispersals*. Cambridge: MIT Press. [WD]
- SAUER, J. D. 1953. Comments, in symposium: Did man once live by beer alone? *American Anthropologist* 55:516–17.
- SAUNDERS, S. R., C. DE VITO, AND M. A. KATZENBERG. 1997. Dental caries in nineteenth-century Upper Canada. *American Journal of Physical Anthropology* 104:71–87. [MAK]
- SCHOENWETTER, JAMES, AND LANDON D. SMITH. 1986. "Pollen analysis of the Oaxaca Archaic," in *Guilá Naquitz: Archaic foraging and early agriculture in Oaxaca, Mexico*. Edited by Kent V. Flannery, pp. 179–237. New York: Academic Press. [MWE]
- SINGLETON, W. R. 1948. Sucrose in the stalks of maize inbreds. *Science* 107:174.
- SMITH, B. D. 1998. Research: Origins of agriculture—between foraging and farming. *Science* 279:1651–52.
- SMITH, C. E., JR. 1980. "Ancient Peruvian highland maize," in *Guitarrero Cave: Early man in the Andes*. Edited by T. F. Lynch, pp. 121–43. New York: Academic Press.
- . 1986. "Pre-ceramic plant remains from Guilá Naquitz," in *Guilá Naquitz: Archaic foraging and early agriculture in Oaxaca, Mexico*. Edited by K. V. Flannery, pp. 265–74. Orlando: Academic Press.
- STALLER, J. E. 2003. An examination of the paleobotanical and chronological evidence for an early introduction of maize (*Zea mays* L.) into South America: A response to Pearsall. *Journal of Archaeological Science* 30:373–80.
- STALLER, J. E., AND R. G. THOMPSON. 2002. A multidisciplinary approach to understanding the initial introduction of maize into coastal Ecuador. *Journal of Archaeological Science* 29:33–50.
- STEINKRAUS, K. H. 1996. *Handbook of indigenous fermented foods*. New York: Marcel Dekker.
- STOCZKOWSKI, WIKTOR. 2002. *Explaining human origins: Myth, imagination, and conjecture*. Cambridge: Cambridge University Press. [AO]
- SUPER, J. C., AND L. A. VARGAS. 2000. "The history and culture of food and drink in the Americas: Mexico and Highland Central America," in *The Cambridge world history of food*, vol. 2. Edited by K. F. Kiple and K. C. Ornelas, pp. 1248–54. New York: Cambridge University Press. [MAK]
- TALBERT, L. E., J. F. DOEBLEY, S. LARSON, AND V. L. CHANDLER. 1990. *Tripsacum andersonii* is a natural hybrid involving *Zea* and *Tripsacum*: Molecular evidence. *American Journal of Botany* 77:722–26. [MWE]
- THOMPSON, R. G., AND J. E. STALLER. 2000. An analysis of opal phytoliths from food residues of selected sherds and dental calculus from excavations at the site of La Emerenciana, El Oro Province, Ecuador. *The Phytolitharian* 13:8–16. [RHT]
- TOWLE, MARGARET A. 1961. *The ethnobotany of pre-Columbian Peru*. Chicago: Aldine. [DP]
- TRIPATH, B. K., M. ALAM, AND G. P. MISRA. 1978. Sucrose content in stalks of three maize varieties from Meghalaya. *Indian Journal of Agricultural Science* 48:106–7.
- TYKOT, R. H. 2002. "Contribution of stable isotope analysis to understanding dietary variation among the Maya," in *Archaeological chemistry: Materials, methods, and meaning*. Edited by K. Jakes, pp. 214–30. American Chemical Society Symposium Series 831. [RHT]
- TYKOT, R. H., AND J. E. STALLER. 2002. The importance of early maize agriculture in coastal Ecuador: New data from La Emerenciana. *CURRENT ANTHROPOLOGY* 43:666–77.
- TYKOT, R. H., D. H. UBELAKER, AND J. W. WILSON. 2000. Microsampling and understanding variation in stable carbon isotope ratios in tooth enamel. Paper presented to the 32d International Archaeometry Symposium, Mexico City, May 15–19. [RHT]
- TYKOT, R. H., N. J. VAN DER MERWE, AND N. HAMMOND. 1996. "Stable isotope analysis of bone collagen and apatite in the reconstruction of human diet: A case study from Cuello, Belize," in *Archaeological chemistry: Organic, inorganic, and biochemical analysis*. Edited by M. V. Orna, pp. 355–365. ACS Symposium Series 625. Washington, D.C.: American Chemical Society.
- UBELAKER, D. H., M. A. KATZENBERG, AND L. G. DOYON. 1995. Status and diet in precontact Highland Ecuador. *American Journal of Physical Anthropology* 97:403–11.
- VAN DER MERWE, N. J., J. A. LEE-THORP, AND J. S. RAYMOND. 1993. "Light, stable isotopes, and the subsistence base of Formative cultures in Valdivia, Ecuador," in *Prehistoric human bone: Archaeology at the molecular level*. Edited by J. B. Lambert and G. Grupe, pp. 63–97. Berlin: Springer-Verlag.
- VAN DER MERWE, N. J., A. C. ROOSEVELT, AND J. C. VOGEL. 1981. Isotopic evidence for prehistoric subsistence change at Parmana, Venezuela. *Nature* 292:536–38.
- VAN DER MERWE, N. J., R. H. TYKOT, N. HAMMOND, AND K. OAKBERG. 2000. "Diet and animal husbandry of the Preclassic Maya at Cuello, Belize: Isotopic and zooarchaeological evidence," in *Biogeochemical approaches to paleodietary analysis*. Edited by S. Ambrose and A. Katzenberg, pp. 23–38. New York: Kluwer Academic/Plenum Publishers.
- VAN DER MERWE, N. J., AND J. C. VOGEL. 1977. Isotopic evidence for early maize cultivation in New York state. *American Antiquity* 42:233–42.
- . 1978. ^{13}C content of human collagen as a measure of prehistoric diet in Woodland North America. *Nature* 276:815–16.
- VAN REEN, R., AND W. R. SINGLETON. 1952. Sucrose content in the stalks of maize inbreds. *Agronomy Journal* 44:610–14.
- VIGOUROUX, Y., M. MC MULLEN, C. T. HITTINGER, K. HOUGHINS, L. SCHULZ, S. KRESOVICH, Y. MATSUOKA, AND J. DOEBLEY. 2002. Identifying genes of agronomic importance in maize by screening microsatellites for evidence of selection during domestication. *Proceedings of the National Academy of Sciences, U.S.A.* 99:9650–55.
- WALDEN, H. T. 1966. *Native inheritance: The story of corn in America*. New York: Harper and Row.
- WAUGH, F. W. 1916. *Iroquois foods and food preparation*. Geological Survey, Canada Department of Mines, Memoir 86. [WD, MAK]
- WEATHERWAX, P. 1923. *Story of the maize plant*. Chicago: University of Chicago Press.
- WHITTINGTON, S. L., AND R. H. TYKOT. 2000. Analysis of Kaqchikel skeletons: Iximché, Guatemala. Report submitted

- to the Foundation for the Advancement of Mesoamerican Studies, Inc. <http://www.famsi.org/reports>.
- WIDMER, RANDOLF J. 2002. "The Woodland archaeology of South Florida," in *The Woodland Southeast*. Edited by D. G. Anderson and R. C. Mainfort Jr., pp. 373-97. Tuscaloosa: University of Alabama Press. [WD]
- WIDSTROM, N. W., M. O. BAGBY, D. M. PALMER, L. T. BLACK, AND M. E. CARR. 1984. Relative stalk sugar yields among maize populations. *Crop Science* 24:913-15.
- WIDSTROM, N. W., M. E. CARR, M. O. BAGBY, AND L. T. BLACK. 1988. Distribution of sugar and soluble solids in the maize stalk. *Crop Science* 28:861-63.
- WILKES, H. GARRISON. 1967. *Teosinte: The closest relative of maize*. Cambridge: Bussey Institution of Harvard University.
- . 1977. "The origin of corn: Studies of the last hundred years," in *Crop resources*. Edited by D. S. Seigler, pp. 211-23. New York: Academic Press.
- . 1985. Teosinte, the closest relative of maize revisited. *Maydica* 30:209-23.
- WILSON, WILLIAM A., SANDRA E. HARRINGTON, WENDY L. WOODMAN, MICHAEL LEE, MARK E. SORRELLS, AND SUSAN R. MC COUCH. 1999. Inferences on the genome structure of progenitor maize through comparative analysis of rice, maize, and the domesticated panicoids. *Genetics* 153:453-73. [MWE]
- WING, E. S. 1980. "Faunal remains," in *Guitarrero Cave: Early man in the Andes*. Edited by T. F. Lynch, pp. 149-43. New York: Academic Press.