Fermented beverages of pre- and proto-historic China


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Chemical analyses of ancient organics absorbed into pottery jars from the early Neolithic village of Jiahu in Henan province in China have revealed that a mixed fermented beverage of rice, honey, and fruit (hawthorn fruit and/or grape) was being produced as early as the seventh millennium before Christ (B.C.). This prehistoric drink paved the way for unique cereal beverages of the proto-historic second millennium B.C., remarkably preserved as liquids inside sealed bronze vessels of the Shang and Western Zhou Dynasties. These findings provide direct evidence for fermented beverages in ancient Chinese culture, which were of considerable social, religious, and medical significance, and help elucidate their earliest descriptions in the Shang Dynasty oracle inscriptions.

We further report chemical evidence of rice-based fermented beverages in the Western Zhou Dynasty (ca. 1250–1000 B.C.), as well as possible evidence of grape-based fermented beverages in the Zhou period (ca. 1046–221 B.C.), which were probably served in bronze vessels. Analysis of the chemical composition of the liquid inside vessel sherds indicates the presence of a mixed fermented beverage (4), including alcohol (5), fruit sugars (6), and amino acids (7). These findings are consistent with the chemical composition of rice-based fermented beverages today (8), and indicate the development of a special saccharification (amylolysis) fermentation system (5, 9) in which fungi break down the polysaccharides in rice and millet.

**Materials and Methods**

Pottery sherds from 16 vessels were extracted and analyzed from domestic contexts at Jiahu (10), an early Neolithic village in Henan province in China, radiocarbon-dated and dendro-calibrated to subperiods III (ca. 7000–6600 B.C.), II (ca. 6600–6200 B.C.), and I (ca. 6200–5500 B.C.). In addition to its repertoire of very early pottery, this site has also yielded the earliest playable musical instruments (11), the earliest domesticated rice in northern China (12), and possibly the earliest Chinese pictographic writing (13). The pottery corpus comprised perforated basins, two-handled, narrow-mouthed storage jars (e.g., Fig. 1a), and jars with high, flaring necks and rims, which were well suited for preparing, storing, and serving beverages. The sherds were primarily from vessel bases, which absorb more liquid and are where precipitates accumulate.

To assess later developments in the Chinese fermented beverage production, liquid samples of the contents of two late Shang/early Western Zhou bronze vessels from Henan province elite burials were extracted and analyzed: a lidded he “tea pot” (Fig. 1b) from the Lui Jiazhuan Tomb at the capital of Anyang (14) and a lidded you jar from the Changzikou Tomb in Luyi county (15).

Depending on the analytical technique, solvents of varying polarity (methanol, chloroform, and/or hexane) were used to extract the ancient sherds, either by sonication or by twice boiling for 20 min. The two portions were combined, filtered to remove fines, and gently evaporated to dryness. Before extraction, the sherds were washed gently in water to remove adhering soil. The total amount of solid extract obtained from each sherd ranged from ~5 to 60 mg, depending on the sherd’s size and thickness and the amount of absorbed organic material. An unextracted
aliquot of each liquid sample was retained for direct analysis of volatile compounds. Solids in the latter also were filtered out and analyzed separately.

Five analytical methods—gas chromatography–mass spectrometry (GC-MS), high-performance liquid chromatography–mass spectrometry (HPLC-MS), Fourier-transform infrared spectrometry (FT-IR), stable isotope analysis, and selective Feigl spot tests—were used to identify the chemical constituents of the pottery and liquid extracts as follows.

Briefly, the protocol for the GC-MS analyses was to run 1-μl chloroform extracts on a standard quadrupole instrument, equipped with nonpolar fused silica columns optimized for sterol analyses, in Drexel University (Philadelphia, PA) and the Eastern Regional Research Center of the U.S. Department of Agriculture. The U.S. Department of Agriculture samples were methylated and injected in a split mode; the Drexel samples, whose small sample size precluded derivatization, were injected in a splitless mode. Total-ion scans were followed up by selected-ion monitoring to identify important, low-level components. Retention times and mass spectra were calibrated by normal paraffin and plant sterol standards. Several blank extractions were carried out to simulate the entire extraction process and analyzed for contaminants and other artifacts caused by sample handling and preparation.

Highly volatile compounds in the liquid samples were detected by a modified GC-MS technique, namely, purge-and-trap ther-
nal desorption. The aqueous samples were sparged with helium gas, and the organic volatiles were trapped on a short adsorbent column attached to a Scientific Instrument Services (SIS, Ringoes, NJ) Short Path Thermal Desorption accessory. The trapped material then was desorbed onto a cryogenically focused head of a nonpolar fused silica GC column and subsequently eluted. Peaks were identified by retention time and mass spectral matches with standards.

Several types of HPLC analyses were run on the pottery and liquid extracts. At the U.S. Department of Agriculture, 100-μl chloroform extracts were run by using a gradient normal-phase set-up with an evaporative light-scattering detector (16). The same extracts were more definitively characterized by an isotropic normal-phase system, interfaced to a mass spectrometer. At the University of Pennsylvania Museum’s laboratory, isotropic normal-phase analyses of methanol extracts were carried out on an instrument equipped with a UV detector. An in-house database of several hundred ancient samples and modern reference compounds was searched for the highest probability matches. Our database includes natural products (e.g., tree resins and beeswax), processed organic materials (such as modern wine, honey, grains, etc.), synthetic compounds generally occurring in natural and processed organic materials of interest, and “ancient reference samples” (i.e., residues extracted from inscribed vessels that state they contained a particular beverage, food, spice/herb, resin, etc., and comprised of both intact and degraded components).

In the University of Pennsylvania Museum’s laboratory, diffuse-reflectance FT-IR analyses of approximately 1 mg of methanol- or chloroform-extracted pottery or liquid sample, desorbed at 8° reflectance FT-IR analyses of approximately 1 mg of methanol- or both intact and degraded components). 

Stable 13C and 15N isotope measurements (17) were made of the filtered solids from the two liquid samples, as well as chloroform and methanol extracts of the Jiahu pottery sherd, at the University of Bradford. This analytical method can readily distinguish between C3 and C4 pathway plants mainly by using the carbon isotope values, because C3 plants tend to have δ13C values of approximately −27‰, whereas C4-pathway plants have δ13C values of approximately −15‰. Primarily plant-based natural products also can be distinguished from those that are animal-derived, because plants have lower δ15N values.

Feigl chemical spot tests (18), with microgram sensitivity, were used to test methanol extracts for tartaric and oxalic acids in the University of Pennsylvania Museum’s laboratory. Samples containing tartaric acid show a dark green fluorescence when irradiated by UV light; malic acid, one of the few cross-interfering compounds, gives a nonfluorescent greenish solution. The samples were tested together with blanks and solutions of the acids at low concentrations.

Results and Discussion

A minimum requirement for establishing the original contents of an ancient vessel is to identify fingerprint compounds (biomarkers) for specific natural products and ingredients in its extracts. Sometimes unequivocal chemical confirmation, e.g., for Royal Purple dye (19), is achievable. Chemical identification and interpretation, however, is often impeded by environmental and microbial degradation, modern contamination, human processing in antiquity, and the degree to which a region’s natural resources have been adequately surveyed for biomarkers. The advantage of using a number of independent chemical techniques, as in this study, is that one’s confidence that a particular compound is present increases if the results from each method agree and reinforce one another.

Archaeological criteria also must be assessed for their bearing on the original vessel contents. The fabrication and style of a vessel are related to whether it held a liquid, semiliquid, or solid material. Narrow, high-mouthed jars and jugs, for example, were likely used to handle and store liquids. Deep, open vats or bowls, on the other hand, are most convenient for processing more viscous materials or serving solid food. Details of the residue on the interior of a vessel (possibly a precipitate from a liquid), associated archaeobotanical materials, and the archaeological context itself (whether a tomb, residence, workshop, pit, etc.) all can provide clues as to how a vessel was used. Such inferences, based on historical, ethnographic, and modern analogies, are at lower probabilistic levels than the chemical analyses. Yet, they are crucial in developing logically consistent working hypotheses, which are constrained by the limited archaeological record, and in setting the course of future archaeological and chemical research.

An Early Neolithic “Mixed Fermented Beverage.” The FT-IR and HPLC results for 13 of the 16 Jiahu extracted pottery sherd, when searched for the closest matches in our databases, showed that they were chemically most similar to one another. This result implies that all these vessels originally contained or were used to process a similar liquid. The three samples that did not match the larger group were extremely small, resulting in less definitive chemical determinations that likely account for their divergency rather than their contents having originally differed.

Besides matching one another, the Jiahu samples yielded good FT-IR and HPLC matches to modern rice and rice wine, resinated nonresinated grape wine (ancient and modern), modern phytosterol ferulate esters, modern beeswax, modern grape tannins, various tree resins and herbal constituents (ancient and modern), modern diacylglycerols, and modern calcium tartrate. These matches correlate with specific IR absorptions and HPLC retention times and UV absorptions.

Fig. 2 shows an IR spectrum characteristic of the Jiahu group and illustrates how the statistical searches and matches correlate with specific absorptions. The sharp, intense peaks at 2,920 and 2,850 cm⁻¹, as well as the absorption at 730–720 cm⁻¹, are the result of long straight-chain hydrocarbons (e.g., n-alkanes). Tartaric acid, the principal organic acid in grape wine and also occurring in other Chinese natural sources (see below), probably accounts largely for
Attributable to tartrate or other carbonyl carboxylate absorption between 1,610 and 1,560 cm⁻¹ expected to precipitate out of solution, is evidenced by a broad stretch band in the 3,450–3,500 cm⁻¹ range. Plants showing their spectra for greater complexity in the carbonyl region above 1,740 cm⁻¹ are attested in the homologous series. Carbonyl compounds derived from natural sources and of archaeological interest absorb in the 1,460–1,465 cm⁻¹ range. Similarly, a tartaric acid interpretation, because tartaric acid contains four hydroxyl groups. Most decisive for tartaric acid is the hydroxyl bending band at 1,435–1,445 cm⁻¹, because other important hydroxyl compounds derived from natural sources and of archaeological interest absorb in the 1,460–1,465 cm⁻¹ range. A large amount of tartaric acid in an ancient sample is implied that it could harbor yeast, like grape. When we first entertained the possibility that hawthorn tree fruit might explain tartaric acid in grape (28), and the modern distribution of hawthorn encompasses northern China (29). A high sugar content of tartaric acid in grape (28), and the modern distribution of hawthorn (Crataegus pinnatifida and Crataegus cuneata; Chinese herbal name Shan Zha). This fruit contains four times the amount of tartaric acid in grape (28), and the modern distribution of hawthorn encompasses northern China (29). A high sugar content implies that it could harbor yeast, like grape. When we first entertained the possibility that hawthorn tree fruit might explain tartaric acid/tartarate evidence, this species was notably absent in the archaeobotanical corpus of ancient China. In 2002, Z. Zhao

Table 1. δ¹³C and δ¹⁵N values of ancient Chinese jar extracts and modern reference samples

<table>
<thead>
<tr>
<th>Sample</th>
<th>Period</th>
<th>δ¹³C*</th>
<th>δ¹⁵N†</th>
<th>C, %</th>
<th>N, %</th>
<th>C:N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice</td>
<td>Modern</td>
<td>-26.1</td>
<td>5.4</td>
<td>39.8</td>
<td>1.1</td>
<td>41.0</td>
</tr>
<tr>
<td>Foxtail millet</td>
<td>Modern</td>
<td>-10.7</td>
<td>4.1</td>
<td>41.3</td>
<td>2.1</td>
<td>22.8</td>
</tr>
<tr>
<td>Broomcorn millet</td>
<td>Modern</td>
<td>-12.0</td>
<td>2.9</td>
<td>40.9</td>
<td>2.5</td>
<td>19.3</td>
</tr>
<tr>
<td>Changziku Tomb, Luji county</td>
<td>Shang/Western Zhou</td>
<td>-25.3</td>
<td>4.8</td>
<td>18.7</td>
<td>1.6</td>
<td>13.9</td>
</tr>
<tr>
<td>Liu Jiazhuan Tomb, Anyang</td>
<td>Shang/Western Zhou</td>
<td>-15.9</td>
<td>5.3</td>
<td>3.6</td>
<td>0.1</td>
<td>45.1</td>
</tr>
<tr>
<td>Jiahu (no. T109:8)</td>
<td>Early Neolithic</td>
<td>-28.6</td>
<td>N/A</td>
<td>90.4</td>
<td>0.1</td>
<td>1,860.1</td>
</tr>
<tr>
<td>Jiahu (no. F1/H284:16)</td>
<td>Early Neolithic</td>
<td>-21.5</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Because of changes in atmospheric carbon in the last century (the Suess effect), modern isotope values may differ from those in antiquity. Small sample size accounts for some data not being available (N/A).

*Measured relative to the Vienna PeeDee belemnite standard.

†Measured relative to air.

the major peak at 1,740 cm⁻¹ with a shoulder at 1,720 cm⁻¹. Some contribution from tannins, resins, waxes, and other compounds with carbonyl acid groups, however, cannot be ruled out. These natural products and compounds can be partly distinguished by examining their spectra for greater complexity in the carbonyl region above 1,740 cm⁻¹ (most indicative of a tree resin) or in the carbonyl region below 1,720/1,710 cm⁻¹ (most indicative of beeswax). The hydroxyl stretch band in the 3,450–3,500 cm⁻¹ region is in accord with the tartaric acid interpretation, because tartaric acid contains four hydroxyl groups. Most decisive for tartaric acid is the hydroxyl bending band at 1,435–1,445 cm⁻¹, because other important hydroxyl compounds derived from natural sources and of archaeological interest absorb in the 1,460–1,465 cm⁻¹ range. Similarly, a tartaric acid interpretation is possible because there is more insoluble than the acid and would be expected to precipitate out of solution, is evidenced by a broad carboxylate absorption between 1,610 and 1,560 cm⁻¹. Under other important carboxylate peaks (at 1,460 cm⁻¹, 1,390 cm⁻¹, etc.) might be attributable to tritate or other carboxyl/carboxylate-containing compounds. The presence of tartaric acid/tartrate was further borne out by positive Feigl spot tests for the 13 samples in the Jiahu group.

GC-MS analyses of samples in the Jiahu group also showed the uniform presence of an inclusive series of n-alkanes, C23–C36 (Fig. 1c). Stable isotope analysis (Table 1) gave δ¹³C values (average -25.1 ± 1.1) that were consistent with a C3 plant, such as rice or grape, but not a C4 plant, such as millet or sorghum. Low δ¹⁵N values and a very low proportion of nitrogen rule out an animal source.

The most straightforward interpretation of these data are that the Jiahu vessels contained a consistently processed beverage made from rice, honey, and a fruit. Taking each of these constituents and the combined evidence for their presence in turn, rice is strongly suggested from the IR and HPLC searches and matches. In fact, rice is the only cereal that has been recovered from archaeobotanical methods at Jiahu, and it is predominant in the corpus. To establish beyond doubt that rice was the principal grain in the Jiahu beverage, HPLC-MS and GC-MS analyses were run in search of cycloartenol, the principal alcohol in oryzanol (the phytoestrogen ferulate ester occurring in rice). The compound was not detected, possibly because of degradation.

Beeswax or a plant epicuticular wax, not represented in our databases but chemically similar to beeswax, was supported by the IR and HPLC matches. C23H48, C25H52, C27H56, and C29H60, attributed in the homologous n-alkane series, are especially characteristic of those in beeswax (7–21). They serve as biomarkers of honey, because beeswax is virtually impossible to filter out completely when processing honey, and its compounds can be very well preserved. By contrast, the sugars in honey, mainly fructose and glucose, rapidly degrade and are lost. Honey is a unique, concentrated source of simple sugars (60–80% by weight) in temperate climates around the world, and humans discovered and exploited it as a sweetener at an early date. It was very likely locally available in the Jiahu region.

Plant epicuticular wax, which occurs on the surfaces of leaves and fruits of many plants (22), also might account for the n-alkanes. If the C27 and C29 compounds predominate, with lesser amounts of the C23, C31, and C35 compounds and even-numbered n-alkanes at very low levels, then beeswax is indicated. However, plant epicuticular waxes also have n-alkanes within the C23–C36 range, with the C29 compound usually most prominent. Further complicating the picture, when n-alkanes constitute a small percentage of the natural product, then this odd/even preference diminishes (23). This phenomenon is especially pronounced for senescent and fossilized leaves (24) and, presumably, also degraded archaeological samples.

Given their small sample size and age, the most plausible explanation for the Jiahu samples' C23–C36 range of n-alkanes is that they derive from epicuticular wax and/or beeswax. This result is consistent with the 730–720 cm⁻¹ infrared absorption band caused by straight-chain hydrocarbons (25), accentuated in the chloroform extracts. Contamination from petroleum contaminants, possibly derived from groundwater percolation of pesticides or herbicides or laboratory-introduced, was ruled out by running blanks and because the boiling ranges of n-alkanes in modern products have different ranges of n-alkanes than those observed for the ancient series.

Grape possibly accounts for the tartaric acid/tartrate, because grape seeds of a presumed wild type constitute the primary ancient fruit remains found at Jiahu. With upwards of 40–50 native wild grape species (26), China accounts for more than half of the species in the world. At least 17 wild species grow in Henan province today, and wine is made from fruit containing up to 19% sugar by weight (e.g., Vitis amurensis and Vitis quinquangularis Rehd. = Vitis pentagona Diels and Gilg).

A large amount of tartaric acid/tartrate in an ancient sample is a strong indicator of a grape product in some parts of the world (e.g., the Middle East; ref. 1), but other sources need to be considered for China. Moreover, the scholarly consensus has been that grape wine was first made from the domesticated Eurasian grape (Vitis vinifera vinifera), which was introduced into China from Central Asia during the second century B.C. (5), some six millennia later than the Neolithic period at Jiahu. References to native grapes occur as early as the Zhou period (27) but are enigmatic. These texts do indicate, however, that grapes were appreciated for their sweetness and used in beverage-making.

An especially strong candidate for the source of the tartaric acid/tartrate in the Jiahu samples, instead of grape, is the Chinese hawthorn (Crataegus pinnatifida and Crataegus cuneata; Chinese herbal name Shan Zha). This fruit contains four times the amount of tartaric acid in grape (28), and the modern distribution of hawthorn encompasses northern China (29). A high sugar content implies that it could harbor yeast, like grape. When we first entertained the possibility that hawthorn tree fruit might explain the tartaric acid/tartrate evidence, this species was notably absent in the archaeobotanical corpus of ancient China. In 2002, Z. Zhao...
and his colleague, Zhaocheng Kong, first identified seeds of this fruit from early Neolithic levels at Jiahu, thus strengthening the case for its use in the mixed beverage (Z. Zhao and Z. Kong, unpublished data).

Tartaric acid occurs in two other fruits, although in much lesser amounts (30 mg/liter) than in grape (4 g/liter) or hawthorn tree fruit (16 g/liter), namely, longyan (Euphoria longyan; Long Yan; ref. 30) and Asiatic cornelian cherry (Cornus officinalis; Shan Chu Yu; ref. 31). The fruits of these trees, which are concentrated in southern China today, are moderately sweet and somewhat acidic. They probably grew farther north in Neolithic times when temperatures were likely milder than today.

Other possible sources of tartaric acid/tartrate cannot be ruled out but yield even lesser amounts (0.1–2 mg/liter) of tartaric acid/tartrate. The leaves of some plants (e.g., Pelargonium in the geranium family) have raphides of tartaric acid and calcium oxalate (32), which might be dispersed into a liquid by steeping. Saccharification of rice, which was the traditional method of Chinese beverage-makers since at least the Han Dynasty [ca. 202 B.C.–anno Domini (A.D.) 220], also produces tartaric acid, depending on the mold used (refs. 5 and 33–35, and see below).

The available chemical, archaeo botanical, and archaeological evidence for the Jiahu jars and basins converge to support the hypothesis that they were used to prepare, store, and serve a mixed fermented beverage of rice, honey, and a fruit. Direct chemical evidence of alcohol is lacking, because this compound is volatile and susceptible to microbial attack. Fermentation of the mixed ingredients, however, can be inferred, because the “wine yeast” (Saccharomyces cerevisiae) occurs in honey and on the skins of sugar-rich fruits. Once the juice has been exuded from the fruit or the honey diluted down, yeast begins consuming the monosaccharides and multiplying, within a day or two in warmer climates.

**Aromatic Wines of the Shang and Western Zhou Dynasties.** Analyses of proto-historic liquid samples from tightly lidded bronze vessels, dated to the late Shang/early Western Zhou Dynasties, showed that they constituted somewhat different beverages than the mixed fermented drink of early Neolithic Jiahu. Numerous bronze vessels, variously dated to the Erlitou (ca. 1900–1500 B.C.), Shang (ca. 1600–1046 B.C.), and Western Zhou periods (ca. 1046–722 B.C.), have been excavated at many urban centers along the Yellow River and its tributaries in Hebei, Henan, and Shanxi provinces of northern China, including Erlitou, Zhengzhou, Taixi, Tianhu, Anyang, and other sites (8). Most often, they have been recovered from the elite burials of high-ranking individuals. The shapes of many of the bronze vessels [ornate tripod vessels (jiu and jia), stemmed goblets (gu), vats (zun), and jars (hu, lei, and you)] imply that they were used to prepare, store, serve, drink, and ceremonially present fermented beverages, which is supported by textual evidence. Besides serving as burial goods to sustain the dead in the afterlife, the vessels and their contents also can be related to funerary ceremonies in which intermediaries communicated with the deceased ancestor and gods in an altered state of consciousness after imbibing a fermented beverage (36).

The fragrant aroma of the liquids inside the tightly lidded jars and vats, when their lids were first removed after some 3,000 years, suggests that they indeed represent Shang/Western Zhou fermented beverages. The Changzikou Tomb vessels, one of which is dated to the late Shang (ca. 1250–1000 B.C.), are moderately sweet and somewhat acidic, with a very low level only in the Changzikou Tomb, consistent with mold saccharification of rice. Although the Changzikou Tomb sample gave a δ13C value of −25.3‰ in accord with a C3 plant such as rice (Table 1), the stable isotope determination for the Anyang liquid (−15.9‰) indicated that a C4 plant was used as a principal ingredient. Millet, which is well represented in the Anyang archaeobotanical corpus, is the most likely candidate.

Thermal desorption GC-MS (Fig. 3) revealed that two aromatic compounds, camphor and α-cedrene, were present in the Changzikou Tomb liquid, in addition to benzaldehyde, acetic acid, and short-chain alcohols characteristic of rice and grape wines. Based on a thorough search of the chemical literature of Chinese herbs and other natural products, these compounds might have originated from the outside atmosphere, hermetically sealing off any liquid remaining inside the vessels.

Previous attempts to identify the compounds responsible for the aromas of the liquids contained in the Shang/Western Zhou lidded bronze vessels, as well as other basic ingredients, have been largely inconclusive or are unpublished. Positive evidence for yeast cells was obtained from an 8.5-kg solid white residue inside a weng jar at Taixi (37), probably the lees of a fermented beverage. Habitation contexts at Taixi also yielded specific pottery forms, including a funnel and a deep vat with a pointed and recessed bottom (“general’s helmet”), which were likely used in beverage-making (3, 5). Several jars at this site also contained peach, plum, and Chinese date (jujube) pits, as well as seeds of sweet clover, jasmine, and hemp, suggesting that an herbal fruit drink was prepared.

Our analyses of the liquids inside lidded jars from Anyang and the Changzikou Tomb can be summarized briefly. Beeswax and epicuticular wax compounds were absent, implying the absence of honey or a plant additive. Tartaric acid and its salts were present at a very low level only in the Changzikou Tomb, consistent with mold saccharification of rice. Although the Changzikou Tomb sample gave a δ13C value of −25.3‰ in accord with a C3 plant such as rice (Table 1), the stable isotope determination for the Anyang liquid (−15.9‰) indicated that a C4 plant was used as a principal ingredient. Millet, which is well represented in the Anyang archaeobotanical corpus, is the most likely candidate.

**Fig. 3.** Thermal desorption GC-MS analysis of lidded you jar from the Changzikou Tomb in Luyi county, Henan province, dated ca. 1250–1000 B.C. Peaks a, b, and c are caused by benzaldehyde, camphor, and α-cedrene. Possible wine-derived propanoic acid derivatives account for the two most intense peaks near 10 min. Other peaks correlate with ubiquitous environmental contaminants, especially phthalates.
from specific tree resins (e.g., China fir, *Cunninghamia lanceolata* Hook.; ref. 38), flowers (e.g., chrysanthemum spp.), or aromatic herbs, such as *Artemisia argyi* in the wormwood genus used to prepare saccharification mold (5, 39). A single open vat, filled with leaves of *Eupatorium frontinum* and holding \\(
\text{L}^\text{L}
\) was found in the tomb (15). Possibly, the beverage in the lidded containers of the tomb was steeped in the leaves, which have a floral aroma like the flowers that are used today in flavoring teas and beverages, and then transferred to the vessels. On the other hand, the absence of any wax compounds argues against this hypothesis.

According to HPLC-MS (Fig. 1d) and standard GC-MS analyses, heavier aromatic compounds were present in the Anyang liquid: the triterpenoid \(\alpha\)-amyrin and its analogue, oleanolic acid. These compounds are widespread in the Burseraceae (elemi) family of fragrant trees, although other sources (e.g., chrysanthemum) cannot be excluded.

FT-IR and HPLC matches of the Changzikou Tomb and Anyang liquids to samples in our databases provided additional indicators for their being fermented and filtered rice or millet “wines,” either *jiu* or *chang*, its herbal equivalent, according to the Shang Dynasty oracle inscriptions. Both *jiu* and *chang* were likely made by mold saccharification, a uniquely Chinese contribution to beverage-making (5, 9, 39). In brief, amylolysis fermentation, which remains the traditional method for making fermented beverages in modern China, exploits the fungi of the genera *Aspergillus*, *Rhizopus*, *Monascus*, and others, depending on environmental availability, to break down the carbohydrates of rice and other grains into simpler, fermentable sugars. A thick mold mycelium was grown historically on a variety of steamed cereals, pulses, and other materials to make the saccharification-fermentation agent (*gu*), Rice, as an early domesticate and one of the principal cereals of prehistoric China, presumably was an early substrate. Yeast enters the process opportunistically, either brought in by insects or settling on to the large and small cakes of *gu* from the rafters of old buildings. As many as 100 special herbs, including *A. argyi* (above), are used today to make *gu*, and some have been shown to increase the yeast activity by as much as 7-fold (40).

Before such a complicated system as amylolysis fermentation was developed and widely adopted by the ancient Chinese beverage-maker, the grain probably was saccharified by mastication and/or malting. Because cereals lack yeast, the initiation of fermentation required a high-sugar fruit and/or honey, as attested by the Jiahu mixed fermented beverage.

Complex urban life eventually led to more specialized beverages and the amylolysis fermentation system, which became the standard method for making rice and millet wine. This changeover likely occurred between the late Neolithic period (mid-third millennium B.C.) and the Shang Dynasty (41). As saccharifying rice and other grains with specialized fungi, the beverage-makers of proto-historic urban China had less need for the sugars or yeast provided by honey or fruit. Although the prehistoric mixed fermented beverage fell into abeyance, this well made beverage was the forerunner of later technical developments. It is probably not coincidental that what some scholars believe to be the earliest Chinese fermented beverage (*luo*) was fruit-based (5). The weng jars with fruit remains from the middle Shang site of Taixi (above) would then represent a continuation of a tradition reaching back into the Neolithic period. Even today in many parts of China, a popular drink (*shouzhou mi jiu*) has suspended fruit bits in rice wine.

For nearly 40 years, scholars have relied on the stylistic similarities of the bronze vessels and their earlier pottery counterparts to argue for the existence of a prehistoric fermented beverage, first attested textually in the proto-historic Shang Dynasty. The ancient chemical evidence now enables the later beverages to be traced back as far as 7000 B.C. and reveals how Chinese beverage-making developed over the millennia. Our results also illustrate how both religious ceremonies and activities of everyday life in which these vessels were used, and still important in modern Chinese culture, likely have their basis in prehistory.

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