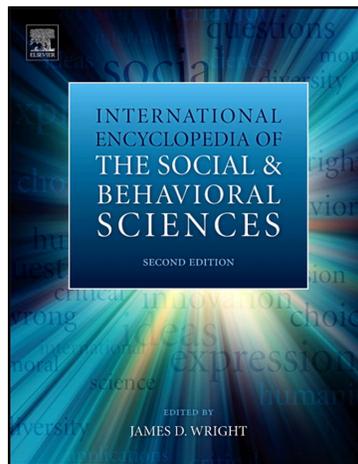


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Paleoethnobotany

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Abstract

Paleoethnobotany is the study of human–plant interrelationships through the archaeological record. Paleoethnobotanists recover, identify, and interpret evidence of past plant use documented through macroremains, pollen, starch, and phytoliths. Not all human activities involving plants result in the deposition and preservation of plant remains in archaeological sites, and natural processes may also introduce plant remains into sites. Paleoethnobotanical data and methods are reviewed, and examples of paleoethnobotanical research presented, including the topics of food and human evolution, the origins of agriculture, uses of food and drink in ritual and feasting, and the case of ‘Ötzi,’ the Tyrolean Iceman, and his environment.

Paleoethnobotanical Data

Paleoethnobotany, the study of human–plant interrelationships through the archaeological record, provides direct evidence on how past populations met subsistence and other daily needs and contributes to understanding human interactions with their environments, and with each other. Human activities involving plants often leave traces, such as charred seeds, fruit rind fragments, wood charcoal, tuber or root peels, pollen and starch grains, and phytoliths (plant opal silica bodies), which become incorporated into archaeological and geological records. Recovery, identification, and interpretation of such plant remains are the tasks of paleoethnobotanists.

Macroremains

Seeds, fruits, nuts, roots/tubers, and wood recovered from archaeological sites are called macroremains – plant tissues visible to the naked eye or under low magnification (Pearsall, 2000; Hastorf and Popper, 1988). Since such materials deteriorate rapidly under most conditions, survival of macroremains depends on slowing the agents of decay by charring, waterlogging, mineralizing, or desiccation. Incomplete accidental or deliberate burning, resulting in charring of plant tissues, is the most common mode of preservation.

Macroremains are recovered by collection of material *in situ*, through screening, and by a water recovery technique called flotation (Pearsall, 2000). *In situ* recovery preserves the association of macroremains and nonbotanical artifacts, but limits recovery to materials that can be easily seen. Screening allows for more systematic recovery of macroremains larger than the screen mesh, but can damage fragile remains. Water flotation, a technique that uses differences in density of organic and inorganic materials to achieve separation of organic remains from soil, greatly enhances the quantity and size range of macroremains that can be recovered (Figure 1). Manual and machine-assisted flotation has become routine in archaeology. Fine-sieving is often substituted for flotation in waterlogged or desiccated deposits, since waterlogged materials are not buoyant, and desiccated remains may be damaged by immersion in water.

Macroremains are identified by comparing unknown archaeological materials to known modern comparative specimens, augmented by published and online sources (Pearsall, 2000). Characteristics important for identification vary by type of remains. For example, seeds are identified by distinctive features of the seed coat, the amount of endosperm and its position in the seed relative to the embryo, and overall size and shape, while wood is identified by its internal structure (vessels and their arrangement, size



Figure 1 Students learning to operate a water flotation system that uses water pressure to separate organic materials from soil matrix.

and arrangement of rays, and abundance and nature of parenchyma). Common challenges to the identification include fragmentation, damage and loss of key characteristics, redundancy of characteristics among related plants, and lack of comparative materials.

Not all human activities involving plants result in the deposition and preservation of macroremains, creating interpretive challenges for paleoethnobotanists. For example, foods consumed or processed away from an occupation site may never become deposited in a garbage midden, while foods eaten raw or prepared as beverages may never be exposed to fire and preserved. This makes interpretation of absence especially difficult. Natural processes, rather than human behavior, may bring plants into what will become archaeological deposits, creating other interpretive challenges. For example, weedy plants may contribute substantial numbers of seeds to midden areas or abandoned dwellings, and wind or water may bring botanical materials into sites. If macroremain preservation is through charring, then material deposited through natural processes, being rarely charred, may have minimal impact on assemblages. Natural processes may also remove macroremains, for example, through erosion of site sediments.

Phytoliths

Phytoliths are produced by the deposition of silica from groundwater into plant tissues. There is a strong genetic component to phytolith formation; orders and families show tendencies for deposition or lack of deposition of silica (e.g., Pearsall, 2000; Piperno, 2006; Runge, 2000; among others). While silicification patterns are redundant in some groups, distinctively shaped phytoliths are formed in many, providing a means of identifying plants at family, genus, or species level. Most phytoliths are the size of silt soil particles (2–250 μm).

Phytoliths are recovered in a specialized laboratory setup for chemical processing from small samples taken for that purpose (Pearsall, 2000; Piperno, 2006). Basically, phytoliths are floated from the matrix using a heavy liquid of specific gravity 2.3 after samples have been treated with a series of chemicals that break down chemical bonds between phytoliths and the matrix. Phytolith extracts are slide mounted and examined under 200–400 power magnification or higher. Phytoliths are identified by comparison of unknowns to phytoliths extracted from identified plant specimens, augmented by online and published sources. Characteristics useful for identification vary widely among plant groups but include three-dimensional morphology, size, surface characteristics, and attachments. Typically, slides are examined until a predetermined count or sum is reached.

Since phytoliths are inorganic, they survive in circumstances under which organic tissues may be lost (Pearsall, 2000; Piperno, 2006). Phytolith representation in archaeological and geological sediments is thus impacted chiefly by phytolith production patterns, i.e., whether or not plants and plant tissues targeted by humans are silica accumulators and produce diagnostic phytoliths. Phytoliths are not indestructible, however. Lightly silicified tissues may break up in soil, and phytoliths may dissolve in highly alkaline environments (pH 9 and higher). Unlike pollen and seeds,

phytoliths are not involved in plant reproduction, and so do not have a dispersal mechanism. Phytoliths are released back into the soil by processes that break down plant tissues: organic decay, burning, and digestion. Because phytoliths are released into soil, a large proportion of phytoliths deposited in sediments or soils represent *in situ* deposition. Research indicates, however, that if soil, especially silt and fine sand fractions, moves, phytoliths move. Phytoliths are part of wind-blown dust and soil washed into lakes and swamps, for example. Because both natural processes and human behavior result in deposition of plant remains in archaeological sites, phytoliths become deposited through both these pathways.

Pollen

Pollen is formed in the anthers of seed plants. Most are regular rotation ellipsoids (i.e., symmetrical around an axis) that usually have three concentric layers. The outermost, the exine, contains sporopollenin. This is one of the most resistant natural organic compounds, and is preserved in fossil pollen (Faegri et al., 1989). Although all seed plants produce pollen, pollen abundance and morphology are affected by pollination mechanism. For example, wind-pollinated plants produce many more pollen grains than do animal-pollinated plants, whose pollen has features that ensure that grains stick to the pollinator. Pollen varies in size from 5 to 200 μm .

Like phytoliths, pollen is extracted from small samples in a specialized laboratory. The basic aim is to concentrate pollen and render grains as visible as possible. Concentration is the process of removing everything else from a sample with a series of chemicals, leaving only pollen and spores; rendering the grains visible involves removing clays and other soil components, mounting residue in a suitable medium, and staining (Faegri et al., 1989; Moore et al., 1991). Identification follows the approach already described for phytolith analysis. Features of the exine, as well as grain shape and size, are important for identifying pollen (Kapp, 1969).

The likelihood that pollen will become deposited in archaeological sediments, on artifacts, or in a lake and swamp sediments is affected by pollination mechanism. For example, a major pathway by which pollen is deposited on the landscape is through pollen rain, the mix of pollen transported by air currents (Faegri et al., 1989). Thus, pollen of wind-pollinated plants is highly likely to become deposited in open-air contexts, less likely in closed contexts (e.g., inside structures), while pollen of animal-pollinated plants may only be introduced through the deposition of flowers or fruits with pollen adhering to them. Once pollen is deposited, sporopollenin is tough, but not indestructible. Pollen damage or destruction is reduced in arid or waterlogged soils and in deposits covered by peat formation (acid conditions) because of lower microbial activity (Dimbleby, 1985). Burial of archaeological deposits (by volcanic ash, sand, under-earth mounds, pavements, and within burials) and contact of pollen with artifact surfaces (grinding stones, ceramic vessels, and metal objects) may enhance preservation. In many cases, however, pollen representation in archaeological sediments is a matter of preservation; conditions encountered in many sites are not ideal for pollen preservation (Faegri et al., 1989).

Starch

Starch serves as a plant energy reserve (Gott et al., 2006). It forms in amyloplasts, beginning at a point called the hilum, and grows by successive layers (lamellae), which may remain visible on the granule. Starch is semicrystalline and exhibits strong birefringence, i.e., under polarized light it appears white against the black background, and an extinction cross, a dark cross centered on the hilum, is visible. Starch designed for long-term energy storage is what humans target for food. It tends to be concentrated in seeds and underground storage organs (USOs), but it may also be found in fruits. Storage starch morphology is largely under genetic control, and many plants can be identified by their starch.

Like phytoliths and pollen, starch is extracted in a specialized laboratory from small samples taken for that purpose. The general methodology follows that of phytoliths and pollen, to remove other particles and concentrate the starch (Torrence, 2006). Identification follows the approach already described. Among the characteristics used for identification of starch are granule shape and size, hilum location, extinction cross characteristics, fissure presence and shape, surface and edge characteristics, and whether granules are simple or compound (Gott et al., 2006).

Like phytoliths, starch is not involved in plant reproduction, and does not have a dispersal mechanism. A number of different pathways have been proposed by which starch enters the archaeological record: directly from starchy plant part to soil (e.g., through decay of tubers in an agricultural field); by being consumed or altered by people, then discarded (e.g., decay of tuber peelings in a midden); and by deposition on artifacts used to process starch-rich tissues (Beck and Torrence, 2006). The last named has been the focus of much archaeological research, as well as experiments to investigate how starch is modified by common food preparation techniques. But starch granules have been recovered from a wide range of archaeological contexts, including soils, coprolites, and human dental calculus (Barton and Torrence, 2006). Factors that influence starch survival in archaeological contexts are not yet well understood.

Paleobotany in Archaeology

In the limited space remaining, it is impossible to do justice to the diverse and significant insights into human-plant interrelationships gained through the study of ancient plant remains. A 'taste' will have to serve to illustrate what paleobotany contributes to archaeology.

Human Evolution and the Emergence of Modern Behavior

Understanding early hominin diet is an important component of studying human evolution. Dental calculus traps food particles, including phytoliths and starch grains, and provides direct evidence of diet. Recovery of phytoliths from dental calculus of two 2 million-year-old *Australopithecus sediba* individuals from Malapa, South Africa, revealed consumption of dicotyledonous leaf, fruit, and wood/bark as well as sedge, grass, and palm (Henry et al., 2012). In combination with dental microwear analysis and carbon isotope data, these

results revealed consumption of some hard foods and nearly exclusive feeding on a wide variety of C₃ resources, in preference to more widely available C₄ grasses, providing insight into the nature of the environmental relationships of *A. sediba*.

Paleobotany has provided considerable insight into the nature of diet of early *Homo sapiens*. A study of phytoliths from Amud Cave, Israel, suggested that a broadening of diet, including utilization of wild grasses and other seeds, began with Neanderthals (Madella et al., 2002). Cemented sediment patches and intact hearths were sampled, and abundant phytoliths were recovered. Among the plants identified were dicot wood and leaves, grasses, including phytoliths from mature grass seed heads, palm, and fig-tree family (Moraceae), reflecting in large part plant-related human activities, including seed gathering. The evidence indicated broad-spectrum plant foraging during the Middle Paleolithic. Research at the Ohalo II site (23 000 BP), Israel, demonstrated through the study of plant macroremains (Weiss et al., 2004) and starch grains (Piperno et al., 2004) that by the Upper Paleolithic the plant component of human diet in southwest Asia was dominated by an array of wild grasses, and augmented by nuts, olives, fruits, and berries, among other plants. Grass seeds were processed by grinding.

Additional insights into plant-based subsistence strategies in the Middle Paleolithic of southwest Asia come from paleobotanical studies at Kebara cave, Israel. Lev et al. (2005) analyzed charred macroremains from the site. Charred remains were found primarily near hearths. The vast majority of the 3956 identified seeds were legumes (Papilionaceae), but a wide variety of seeds were found in small numbers, including grass, goosefoot, safflower, seeds of several plants producing USOs, including wild radish and nut grass, and several species known for medicinal uses. Acorn and pistachio nut fragments were also recovered. The presence of charring suggested cooking of vegetal foods. Albert et al. (2012) studied phytoliths and thin sections taken from hearths and combustion features at Kebara. The generally high number of phytoliths present in samples suggested that plants were abundant in the cave. Those most directly related to anthropogenic deposition were from wood used as fuel for fires and grasses used to help start fires (or adhering to wood). Abundance of phytoliths from grasses and seed coats of the Boraginaceae in samples near the entrance of the cave was likely due to their growth at the entrance.

Study of microfossils in dental calculus of Neanderthal individuals provides further support for breadth of Neanderthal diet (Henry et al., 2011). Henry studied dental calculus from three teeth from Shanidar III, Iraq, and two each from Spy I and II, Belgium. Numerous starch grains were recovered and some phytoliths. In the warm Mediterranean region, Neanderthal individuals consumed grass seeds of the Triticeae tribe, including some that appeared to have been cooked, legume seeds, an unknown USO, and date palm. In cold northwestern Europe, consumption included an unknown USO and grass seeds (Andropogoneae tribe). These results showed that two major hominin dietary adaptations, cooking and incorporation of a diversity of relatively costly plant foods, had taken place by the Middle Paleolithic.

Beyond diet, paleoethnobotany contributes to understanding the emergence of other modern behaviors in the Middle Paleolithic. For example, research at Tor Faraj, a rock shelter site in Jordan, provided insight concerning the extent to which Neanderthal behavior resembled that of modern humans (Henry, 2003). Rosen (2003) conducted a study of plant microfossils, focused on reconstructing local vegetation, paleoclimate, and pattern of plant use by the shelter's inhabitants. Samples were taken horizontally across the living floor. Abundant phytoliths were recovered, as well as some spores, starch grains, and calcium oxalate crystals. Among the plants identified were pooid (festucoid) grasses, reed, sedge, date palm, and abundant phytoliths from trees or shrubs, suggesting that much moister conditions existed in the area at the time of site occupation than at present. Date palm fruits and/or leaves were likely used. Several kinds of starch grains were found, likely indicative of nuts, such as pistachio, roots, and tubers brought into the shelter. The distribution of microbotanical remains across the living floor indicated that grasses were spread on the floor near the back wall and in between the hearths, perhaps indicating prepared sleeping areas. Phytoliths from grass seeds and palm were concentrated near a hearth, suggesting a food preparation area, while high concentrations of dicot phytoliths beyond the drip line of the shelter suggested a brush windbreak. The microbotanical results contributed significantly to the overall finding that the inhabitants organized their activities essentially along the lines of modern hunter-gatherers (Henry, 2003).

A phytolith study conducted at Esquilleu Cave, Spain, by Cabanes et al. (2010) also documented the use of grass as bedding during the Late Mousterian. Most of the phytoliths recovered from samples were of grasses (leaf and inflorescence) but several hearth samples had abundant wood and bark phytoliths. Phytolith dissolution occurred in some areas. In areas of good preservation, accumulation was related to use of grass in bedding (in repetitive layers) and wood/bark for combustion. Interpretation of such layers of phytoliths as bedding is supported by an experimental study by Miller and Sievers (2012). They studied the micromorphological signatures of burned bedding, in order to gain insight into how laminated layers of carbonized material and phytoliths were produced, in this case, at the Sibudu site, South Africa. The experiment revealed that large volumes of vegetal material could have produced thin archaeological deposits of burnt bedding, and that if carbonized material was present, burning was most likely deliberate.

Origins of Food Production

Paleoethnobotany is at the heart of research into the origins of food production. The American tropics provide an example that illustrates the power of combining multiple indicators of plant use to document early agriculture. The early history of American plant domestication begins in lower Central America and northwestern South America, and is known in large part from phytolith, starch grain, and pollen evidence. Pollen and phytolith sequences from lakes indicated that populations began modifying landscapes in the early Holocene. Burning of

forests and small-scale land clearance was documented then at Lake La Yeguada in Panama, for example (Piperno and Pearsall, 1998). Phytoliths also fill in the record at early sites with poor preservation of macroremains. For example, arrowroot, llerén (two root/tuber crops), gourd, squash, and maize (corn), all identified by phytoliths, were found at two early sites in Panama, Cueva de los Vampiros and Aguadulce.

Research at Xihuatoxtla shelter in the Central Balsas River valley, west Mexico, has now documented early maize in the dry tropical forest setting of its wild ancestor (Piperno et al., 2009). Maize phytoliths were recovered from site sediments, and maize starch and phytoliths from grinding stones, dating to 6700 BC. The spread of maize through the lowland tropics from its area of origin has been documented in part by pollen and phytoliths in sediment cores. Evidence for maize was found, for example, at 5100–5000 BC in a sediment core on the Gulf coast, and maize pollen and/or phytoliths documented the crop in south Pacific coastal Mexico, Pacific coastal Guatemala, northern Belize, and Honduras by 3500 BC (Piperno and Pearsall, 1998). Maize was carried south through the tropical lowlands prior to this time, however, as it is documented earlier in Panama, Colombia, and Ecuador. Perhaps the best known maize remains come from two caves, Coxcatlán and Guilá Naquitz, each located in the semiarid highlands of central Mexico. Maize macroremains were well preserved in these dry sites, but when directly dated, not all were as ancient as expected from site stratigraphy. Maize has been direct-dated to 3600 BC at Coxcatlán and 4250 BC at Guilá Naquitz (Long et al., 1990; Piperno and Flannery, 2001).

The emergence of agriculture in the dry tropical forests of southwest coastal Ecuador has also been documented largely through microfossil data (Piperno and Pearsall, 1998). Squash phytoliths were recovered from terminal Pleistocene and early Holocene strata at preceramic Vegas sites; other Vegas crops included gourd and llerén, and eventually maize. Maize, identified by phytoliths and starch grains, continued to be grown at Real Alto and Loma Alta, two later, Valdivia tradition farming villages, along with cotton and jack bean (preserved as macroremains), achira, manioc, chili pepper, llerén, and arrowroot (identified by phytoliths and/or starch grains) (Chandler-Ezell et al., 2006; Zarillo et al., 2008). Agriculture in coastal Ecuador remained broad-based for many millennia, incorporating wild/managed tree fruits as well as annual crops (Pearsall, 2004).

Research at early preceramic sites in the Ñanchoc valley, located in the lower western slopes of the Andes in northern Peru, has provided the first detailed look at early farming communities in the Andes. Recovery of macroremains from sealed house floors and hearths has documented cultivation of squash, peanut, quinoa (all by 7500 BP or earlier), and cotton (by 5500 BP) (Dillehay et al., 2007). Manioc and other unidentified tubers and fruits were also recovered. The early presence west of the Andes of peanut and manioc, originating in eastern South America, and quinoa, from the southern highlands, has documented the extent of networks of communication and exchange among early agriculturalists. Study of starch recovered from the dental calculus of 39 teeth from the same contexts as the dated macroremains led to the identification of starch from bean and paca seeds (tree fruit), squash flesh, and peanut (Piperno and Dillehay,

2008). Starch from these four taxa was commonly recovered; rarer types identified included possible manioc and tree fruits. Irrigation technology, vital to the later development and expansion of agriculture in desert coast Peru, was also documented early in the Ñanchoc valley, in the form of small-scale gravity canals (Dillehay et al., 2005). Paleobotanical and archaeological evidences from this small valley combine to indicate how early effective farming emerged in western Peru, and took on a regional identity (Dillehay, 2011).

The Iceman and His Environment

In September 1991, a well-preserved corpse of a man was discovered frozen in the Alps at 3214 m elevation. Eventually dated to more than 5000 years ago, studies of 'Ötzi,' the Tyrolean Iceman, and his tools and clothing have provided a snapshot of life in the Alps during the Neolithic. Detailed paleobotanical studies played a central role in understanding Ötzi's life and death and his natural environment. For example, study of pollen sequences from bogs and peat deposits demonstrated that the alpine grasslands of the region were used as pastures since the beginning of the Neolithic (Bortenschlager, 2000). Forests were also cleared to increase pasturage. Ötzi was likely involved in an early form of transhumance, moving his flocks seasonally to higher elevation pastures. Wooden objects found with Ötzi were identified through dendrological analysis. Ötzi's bow and the handle of his ax, for example, were made of yew, while arrow shafts were made of wayfaring tree (Oeggl and Schoch, 2000). His pack frame was made of hazel and larch. A birch-bark container was filled with maple leaves and charcoal fragments, and probably served as a storage container for cold embers. The majority of wood species belonged to the montane region, and technological analysis suggested that Ötzi selected species based on the requirements of each object.

Study by Oeggl et al. (2007) of a sequence of gut samples revealed what Ötzi ate during the last hours of his life, and what kinds of environments he traveled through. Pollen, plant macroremains, whipworm eggs, and muscle fibers were recovered. Pollen can become incorporated into food residue in the gut in a variety of ways, for example, through food consumption, drinking water, and breathing. Only frequently occurring pollen was interpreted as associated with food consumption. Ötzi's last meals included meat, wheat, bracken, chenopod, and plants in the primrose and legume families. At least three different meals were identified. Abundant charcoal particles suggested that Ötzi's meals were prepared over an open fire. Background pollen from the gut series indicated that Ötzi traveled from the subalpine region down to the valley bottom, and then back up to the alpine region, where he died from an arrow wound.

Study of macroremains recovered from the location of Ötzi's discovery, a rocky hollow, provide further insights into the Iceman, his life, and his environment (Heiss and Oeggl, 2009). Materials studied included Ötzi's clothing and equipment, some of which was made of plant material, such as a grass cape/mat and grass shoe insulating material. Plant remains were also recovered from Ötzi's clothing and equipment and from wet-sieving or floating sediments from

the bottom of the hollow. In all, over 40 000 plant macroremains have been studied, from at least 66 species, representing environments from the valley bottom to the snow line. However, only Ötzi's equipment, clothing, and the cultivated plants found in association with him, hulled barley, einkorn, millet, opium poppy, and flax, can be unambiguously considered the result of human rather than natural deposition through long-distance transport.

Ritual and Feasting

Beyond their roles in diet and economy, foods (and drinks) play important roles in social relationships, both public and private. In the Andes, for example, maize beer (*chicha*) is an important part of cultural identity, and plays a central role in ceremonies. Documenting when this role emerged was one goal of paleobotanical research at Formative sites on the Taraco Peninsula, Bolivia (Logan et al., 2012). Phytolith and starch grain analyses were used to investigate maize processing and its consumption in both ceremonial and domestic contexts. Charred maize remains were lacking at sites, and no maize microfossils were recovered from cooking pot residues. The only evidence for maize processing came from phytolith or starch residues on grinding stones from a ceremonial space, on teeth of a sacrificed individual, and in other ceremonial contexts, such as burials and sunken courts. The evidence supported a ceremonial role for maize, probably in liquid rather than cooked form.

Study of macroremains, starch, and phytoliths from a buried ceremonial room at the Buena Vista site provides insights into ritual feasting during the preceramic period in coastal Peru (Duncan et al., 2009). The ceremonial room, a small temple of the Kotosh tradition, was intentionally buried, and food remains were part of the ritual entombment. Macroremains recovered from the room, well preserved by the desert conditions of the coast, were dominated by nonedible parts of food plants and broken gourd and squash serving vessels. These were not food offerings, but the refuse from feasting associated with the ritual burial of the temple (Duncan et al., 2009). Ritual entombment of buildings has been documented in the region, but not the association of feasting with temple burial. Study of starch residues from the gourd and squash artifacts recovered starch from manioc, potato, chili pepper, arrowroot, and algaroba. Starch and phytoliths recovered from artifacts and sediments led to identification of foods (and drinks) not present as macroremains.

There is a long tradition of studying plant food offerings from cremation cemeteries of the Iron Age and Roman Empire (Rottoli and Castiglioni, 2011). Since all offerings were subject to burning during the funerary rites, chances of preservation are high, and preservation is less selective, in comparison to macroremains preservation at contemporary habitation sites, for example. In their review of plant food offerings from Roman cremation sites in northern Italy, Rottoli and Castiglioni (2011) found that while cereals, legumes, cultivated and gathered fruits, vegetables, and prepared foods, such as bread, were often all present, fruit remains were especially common. This abundance contrasted markedly to abundance of fruits preserved at habitation sites. Presence of

grapes and hazelnuts in Roman cremations indicated continuity of local, Iron Age, traditions, to which offerings of other fruits, such as fig, date palm, olive, and pine nut became increasingly common. Another legacy of more ancient customs was indicated by isolated offerings of wild fruits such as acorn, strawberry, and rose. No evidence of consumption of foods was found, i.e., no remains of meals or preparation waste. Fruits, seeds, and prepared foods were offered in their entirety. Studies of plant food offerings provide insights into the Romanization of new territories and document the growth of trade, including new and exotic fruits, in Roman times.

See also: Environmental Archaeology; Zooarchaeology.

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