Multistep food plant processing at Grotta Paglicci (Southern Italy) around 32,600 cal B.P.

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Residue analyses on a grinding tool recovered at Grotta Paglicci sublayer 23A [32,614 ± 429 calibrated (cal) B.P.], Southern Italy, have demonstrated that early modern humans collected and processed various plants. The recording of starch grains attributable to *Avena* (oat) caryopses expands our information about the food plants used for producing flour in Europe during the Paleolithic and about the origins of a food tradition persisting up to the present in the Mediterranean basin. The quantitative distribution of the starch grains on the surface of the grinding stone furnished information about the tool handling, confirming its use as a pestle-grinder, as suggested by the wear-trace analysis. The particular state of preservation of the starch grains suggests the use of a thermal treatment before grinding, possibly to accelerate drying of the plants, making the following process easier and faster. The study clearly indicates that the exploitation of plant resources was very important for hunter–gatherer populations, to the point that the Early Gravettian inhabitants of Paglicci were able to process food plants and already possessed a wealth of knowledge that was to become widespread after the dawn of agriculture.

starch grains | *Avena* | pestle-grinder | flour | Early Gravettian

Over the last few decades, a renewed interest in ancient diets has led to particular attention being paid to the plant residues recovered from tool surfaces and dental calculus in Paleolithic sites (e.g., refs. 1–6). The data that we have collected have expanded our knowledge of the lifestyle of ancestral humans, indicating their familiarity with a wide variety of edible plants and their capacity for complex, multistep food processing. Moreover, they corroborated the hypothesis that the "natural diet" of our ancestors may not have been quite as simple and basic as previously assumed.

Starch and phytolith analyses were successfully used to analyze grinding tools and dental calculus, enriching the list of the Paleolithic food plants with taxa that are very difficult to detect by other methods. Indeed, traditional carpological studies have generally furnished lists of edible plants restricted to those that comprise easily preservable portions or that were charred.

Starch analysis on grinding stones from Bilancino in Italy, Kostenki 16 in Russia, and Pavlov VI in the Czech Republic (2, 3, 7) illustrated plant exploitation in the Mid-Upper Paleolithic and demonstrated that the ability to process plants to obtain flour was already diffused across Europe during this period.

In this study, residue analysis on a grinding tool from Grotta Paglicci, an important Paleolithic site in southeastern Italy, supplied new data about plant gathering and multistep processing for obtaining flour since the Early Gravettian.

The Site

Grotta Paglicci [Rignano Garganico, Apulia, N 41.6539722, E 15.6151666, 143 m above sea level (a.s.l.)] is located on the eastern slope of the Vallone di Settepenne, a valley excavated in the karst formation overlooking the Candelaro River plain, at the foot of the Gargano promontory, a mountainous peninsula jutting into the Adriatic sea on the southeastern coast of Italy, characterized by a Mediterranean climate (*Supporting Information* and Fig. S1).

Excavations at Paglicci have been carried out for over 40 y, first by the Museo Civico di Storia Naturale di Verona and, since 1971, by the University of Siena, in collaboration with the Soprintendenza Archeologia della Puglia. The stratigraphic sequence of the cave (12 m) (Fig. S2) yielded a large quantity of Paleolithic artifacts, examples of portable art, burials, and human and animal remains. Wall paintings of horses and hands were discovered in the innermost part of the cave. These parietal paintings are the only Paleolithic ones known in Italy (8). The retrieved materials mostly date to the Upper Paleolithic, namely to the Aurignacian, with marginally backed bladelets, and to the entire Gravettian and Epigravettian chronology (9, 10).

The faunal association, along with the results of the isotopic analyses from faunal remains, indicate a climate colder than the present one (*Supporting Information*).

Plant remains consist of charcoal fragments mostly belonging to *Juniperus*, *Pistacia*, and *Prunus*, occurring in almost all of the Aurignacian and the Gravettian levels. Deciduous *Quercus* was often recorded. *Pinus* spp., *Salix*/*Populus*, *Acer*, *Rhamnus*, and *Fraxinus* sporadically occurred (11).

The Paglicci Pestle-Grinder

The tool (Fig. 1) was found in June 1989 in sublayer 23A (square 36H) (*Supporting Information* and Fig. S2). This sublayer was radiocarbon dated 28,100 ± 400 B.P. [UtC-1414: 32,614 ± 429 calibrated (cal) B.P.] (12, 13).

On the basis of the functional analysis, this item has been interpreted as a pestle-grinder; evidence of the grinding function was found mainly on side 2 (13). Since its retrieval, this artifact has been stored in a plastic bag. It is an elongated cobble of fine, not completely cemented calcareous sandstone bearing

Significance

The Early Gravettian inhabitants of Grotta Paglicci (sublayer 23 A) are currently the most ancient hunter–gatherers able to process plants to obtain flour. They also developed targeted technologies for complex processing of the plant portions before grinding. The present study testifies for the first time, to our knowledge, the performance of a thermal pretreatment that could have been crucial in a period characterized by a climate colder than the current one. The starch record on the Paglicci grinding stone is currently the most ancient evidence of the processing of *Avena* (oat).

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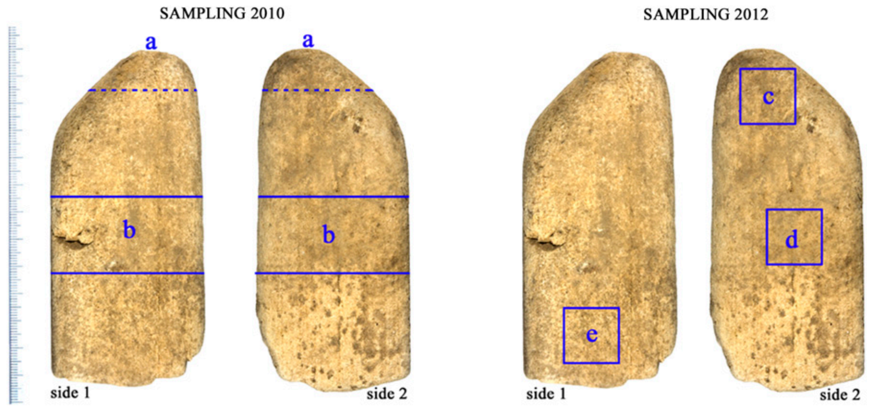

Fig. 1. The Paglicci pestle-grinder with the sampling areas. The dashed line indicates the area that became wet during the sampling on the apex.

longitudinal fissures, fractured at one end, slender and rounded at the other end, with a flat subquadrangular section. It measures 11.8 × 5.5 × 3.7 cm and weighs 443 g.

The stone, not previously washed, was subjected to two successive samplings (Fig. 1). The first one was carried out in 2010 on the apical area [sample P23A(a)] and on the medial band area [P23A(b)]. In 2012, following a new procedure, three further samples were collected: P23A(c) on side 2, close to the apex; P23A(d) from the previously washed medial band area on side 2; and P23A(e) from an unwashed, presumably unused area on side 1, near to the fractured end of the stone.

Residue Analysis

Residue analyses revealed the presence of numerous starch grains concentrated on the apex [samples P23A(a)], close to the apex [P23A(c)], and on the medial band of the tool [sample P23A(b)]. More specifically, 250 starch grains per cm^2 were calculated in sample P23A(c). In sample P23A(d), which was collected from side 2 after washing, and in sample P23A(e), from an unused area on side 1, 25 grains per cm^2 and 40 grains per cm^2 were, respectively, detected.

Most of the grains (over 60%) showed more or less pronounced fissures radiating from the center of the grains, possibly referable to the grinding process; numerous grains revealed a faded or very faded extinction cross with a very wide center. Gelatinized, swollen grains (about 4% of the total grains) were observed in samples P23A(a), P23A(b), and P23A(c) (*Supporting Information*, Fig. S3, and Table S1).

Excluding the swollen grains, five different starch morphotypes were recorded, in addition to the rather numerous spherical–ovoid small grains (≤5 μm in size), which were not taken into consideration in view of the lack of any diagnostic feature for identification and because they are very common in plants. The morphotypes proved to be unevenly distributed in the examined samples (Fig. 2).

Morphotype I (Fig. 3). Morphotype I consisted of polyhedral starch grains, irregular in shape, with the main axis ranging from 7.5 to 24 μm, exceptionally 30 μm (mean value 18.9; mode 17.5); facets irregularly concave; closed centric hilum with radiating fissures nearly always present; extinction cross slightly distorted by the facets. The size of the grains was smaller in sample P23A(a) (Fig. 4). The grains generally show a good state of preservation. Their morphology was consistent with the grains of *Avena* sp. (oat), particularly *Avena barbata*, although some of the grains of the Paglicci grinding tool exceeded the dimensional range of the modern *Avena* species (*Supporting Information*, Fig. S4, and Table S2).

Morphotype II (Fig. 3). Morphotype II consisted of irregularly subspherical, rounded in outline, and faceted starch grains with rounded vertices, measuring 3–30 μm (mean value 15.4; mode 17.5); centric hilum generally surrounded by radiating fissures; extinction cross bilaterally symmetrical or asymmetrical. The size of the grains was significantly smaller in sample P23A(a) (Fig. 4). Most of the grains were severely affected by damage attributable to the grinding process. The grains displayed a morphology very similar to that occurring in numerous Poaceae, for instance in Panicoideae and Polygonaceae.

Morphotype III (Fig. 3). Morphotype III consisted of starch grains elongated, irregularly ovoid, main axis measuring 25–30 μm; hilum eccentric, closed, sometimes with a longitudinal fissure. The grains were more or less damaged. They occurred in sample P23A(b) and P 23A(c). The particular shape was strongly reminiscent of the morphology of the *Quercus* (oak) starch grains (*Supporting Information*, Fig. S5, and Table S3).

Morphotype IV (Fig. 3). Morphotype IV consisted of spherical and subspherical to ovoid starch grains with centric closed hilum, the main axis or diameter measuring 5–20 μm (mean value 9.5; mode 7.5). Spherical grains were prevalent in samples P23A(b) and P23A(c), subspherical and ovoid in P23A(a). The size of the grains was smaller in sample P23A(a), not exceeding 15 μm (Fig. 4). Many of these grains were more or less severely damaged. These grains did not display diagnostic characteristics and may be attributed to a large number of plants.

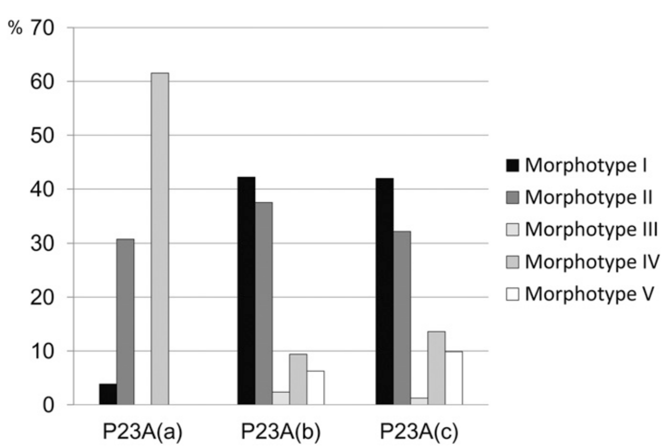

Fig. 2. Percentage distribution of the starch morphotypes on the grinding stone areas.

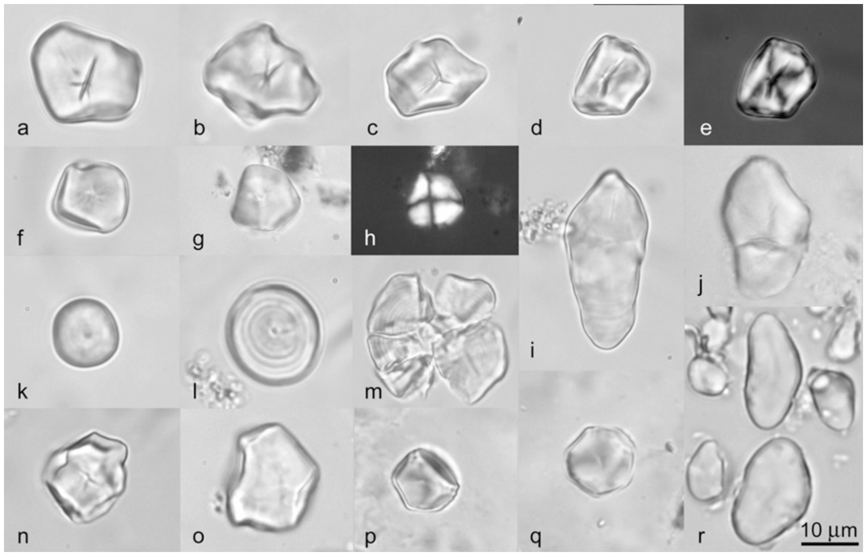

Fig. 3. Starch grains from the Paglicci pestle-grinder (*A–M*) and from modern plants (*N–R*). Shown are (*A–D*) morphotype I, (*E*) morphotype I under polarized light, (*F* and *G*) morphotype II, (*H*) morphotype II under polarized light, (*I* and *J*) morphotype III, (*K*) morphotype IV, (*L*) morphotype V, (*M*) a crushed starch grain, (*N* and *O*) *Avena barbata*, (*P* and *Q*) millet (Panicoideae), and (*R*) *Quercus cerris*. (Scale bar: 10 µm.)

Morphotype V (Fig. 3). Morphotype V consisted of lenticular starch grains, almost perfectly rounded in plain view, 12.5–22.5 µm in diameter, with clearly evident circular, centric hilum and easily visible lamellae. Extinction cross was sometimes faded and with wide center. Most of the grains revealed cracking and broken edges. These grains occurred exclusively in samples P23A(b) and P 23A(c). Similar grains can be observed in the flour of numerous modern plants: they could reflect the appearance acquired by spherical–subspherical grains after grinding.

Starch grains with different morphologies occasionally occurred (2.3% of the total observed grains), the main axis measuring 6–24 µm. The grains recorded in sample P23A(a) were smaller than those in samples P23A(b) and P23A(c).

Two months after sample preparation, a reassessment of samples P23A(a) and P23A(b) revealed that most of the grains had increased remarkably in size, appearing gelatinized and swollen. Very frequently, they showed an evident central star-like mark, much less frequently a circular one. They did not display birefringence under polarized light and were slightly colored with Lugol solution (Fig. 5). Afterward, new observations showed that their size had further increased.

Residue analysis revealed the occurrence, together with starch grains, of phytoliths, pollen grains, diatoms, and tissue fragments (*Supporting Information* and Fig. S6). In particular, very small quantities of phytoliths were recorded, mostly fragmented and not diagnostic. In any case, the scarcity of these remains makes it impossible to determine whether they originated from the grinding tool or from the soil where the artifact was buried.

Discussion

Residue analysis revealed the presence of a large number of grains on the Paglicci tool, providing new information on the food plants that were selected and processed and the procedures used for producing flour.

The Paglicci Tool and Its Use. The size distribution of the starch grains on the pestle-grinder surface showed interesting differences between the apex and the side: the grain size did not exceed 20 µm on the apex [sample P23A(a)] whereas it reached 30 µm on the sides [sample P23A(b) and -(c)] (Figs. 1 and 4). This size distribution could be determined by the different use of the same tool for percussion (apex) and for grinding (sides): percussion possibly favored the detachment of the larger grains whereas the smaller ones were trapped between the lithic clasts.

The presence of very few grains in sample P23A(d), collected from an already washed area on side 2, suggests that washing with running water removed a large number of the starch grains from the tool. Finally, rare grains occurred in sample P23A(e), which was collected from an unwashed area in proximity of the fractured end, where use-wear traces were not observed. These results point to a significant correspondence between the presence of use-wear traces and the abundance of residue. As a

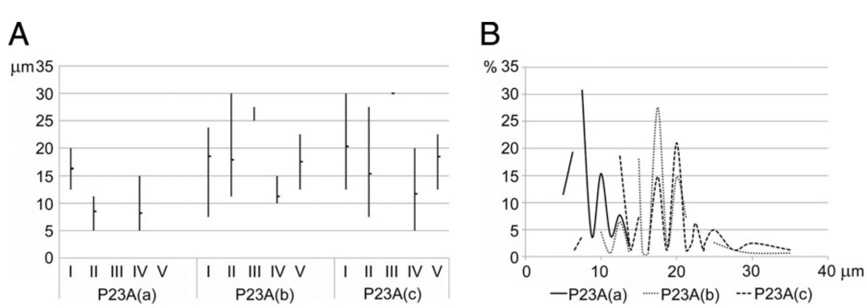

Fig. 4. Starch grain distribution on the Paglicci pestle-grinder surface. (*A*) Dimensional range (min-max) of the morphotypes in the samples. (*B*) Percentage distribution of the grain sizes in each of the sampled surface areas of the Paglicci pestle-grinder.

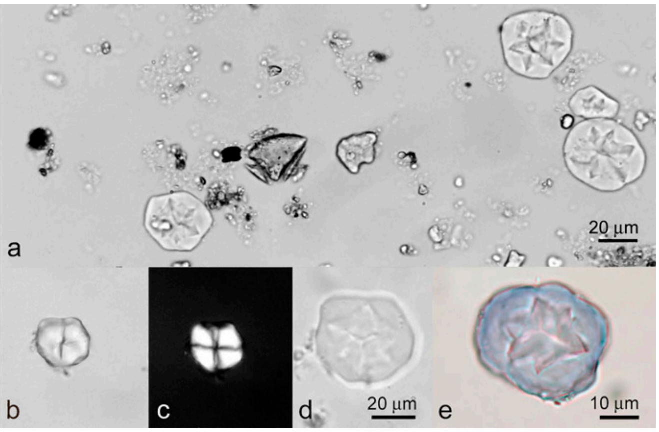

Fig. 5. Sample P23A(b). (*A*) Swollen starch grains. (*B*) A starch grain under a light microscope. (*C*) The same grain under a polarizing light microscope. (*D*) The same grain after swelling, at the same magnification. (*E*) Swollen starch grain colored with Lugol solution.

whole, the distribution of the starch grains on the tool surface supports the hypothesis that the Paglicci grinding tool was used as a pestle-grinder (13), with scarce residue in correspondence with the handle.

The scarcity of phytoliths (*Supporting information*) suggests that the Paglicci tool was not used for dehusking cereals, as was assumed in the case of the Paleolithic grinding stones from Shizitan, China (5).

Plant Exploitation for Flour Production. Starch grains attributable to grasses are dominant on the Paglicci grinding tool, indicating that plants belonging to the Poaceae family were widely collected and processed in the site. The angular grains (morphotype I) are consistent with the morphology of the *Avena* starch; their dimensional range proved broader than that of the modern *Avena*. It is possible that they increased in size as a result of the grinding process. Indeed, grinding and milling were proven to provoke damage to the starch grains and increase in size (5), thus altering the metric parameters. The *Avena* genus includes several species with Mediterranean distribution (14, 15) and the well-known Middle-Eastern cereal *Avena sativa*. Starch grains of *A. barbata* and/or *Avena sterilis* were found at Ohalo II (23,000 B.P.), Israel; the authors noted that the archaeological *Avena* grains were larger in size than the modern ones (16), as observed in Paglicci samples, too. Possible *Avena* starch grains were also recovered from dental calculus in the middle Holocene site of Tell al-Raqā'i, Syria, where caryopses of *Avena* spp. were also found (17). *Avena* caryopsis contains elevated quantities of valuable nutrients, such as soluble fibers, proteins, unsaturated fatty acids, vitamins, minerals, and phytochemicals (18).

Morphotype II, or part of it, can also be attributed to Poaceae. The grains displayed features similar to those of several genera belonging to the subfamily Panicoideae (19) but which also occur in plants of other taxonomic groups, both within the Poaceae family and not.

A small number of large, irregularly ovoid starch grains (morphotype III) were very similar to those observed in *Quercus*. At Paglicci, the presence of deciduous *Quercus* is testified by the recovery of charcoal (11). In the Mediterranean basin, acorn consumption was indicated in Morocco, between 15,000 and 13,700 cal B.P (20); acorn flour has been recorded in Qingshui River valley, China, since the beginning of the Holocene, when broadleaf trees began to spread in that region (21). Therefore, the Paglicci record could represent the most ancient documented use of acorns after processing, marking the beginning of a very long tradition that has not yet completely died out in the Mediterranean basin and in Italy, surviving in the production of bread for village festivities (22).

Pregrinding Thermal Processing. A challenging result in studying the Paglicci grinding tool was the record of swollen or partially swollen, gelatinized grains: i.e., grains featuring the physicochemical changes that normally occur after thermal treatments (23–25). This evidence suggests that a thermal treatment was performed on the plant material before grinding.

Indeed, thermal processing is proven to destabilize the crystalline structure of the starch grains, which lose the birefringence and acquire the capacity to absorb water: i.e., gelatinize and swell irreversibly (26, 27). Studying changes in starch grain morphology after cooking, Henry et al. (23) observed that the grains can assume the same morphology as a result of different thermal procedures: for example, boiling for a long period or baking.

Immediately after the laboratory treatment, the number of swollen grains was small, but, shortly afterward, most of the Paglicci grains began swelling and jelling. This phenomenon was possibly related to the permanence of the grains in the water/glycerol solution: indeed, glycerol is an efficient plasticizing agent that has a crucial influence on starch-based materials (28) and possibly enhanced the swelling of the grains that were previously subjected to thermal processing. Furthermore, observations carried out on starch grains from other ancient grinding stones indicated that the use of water/glycerol solution alone was not sufficient to cause jelling and swelling: indeed, the phenomenon was not observed in the Bilancino starch grains, which were subjected to the same laboratory procedure (3), after a prolonged permanence in the water/glycerol solution. Moreover, behavior identical to that of the Paglicci grains was observed in modern starch grains only after thermal treatments. This process proved not to be affected by the laboratory procedures for preparing the samples, irrespective of whether it included the use of zinc chloride for the heavy liquid separation (*Supporting Information* and Table S1).

Jelling starts at the hilum of the grain (29), where a large circular depression appears a few minutes after the thermal treatment (23). Instead of the circular depression, which was displayed by very few Paglicci grains, a star-like hollow was often present, rather similar to that observed in partially gelatinized modern starch grains by Barton (30). However, the Paglicci grains generally reveal a greater number of vertices; their arrangement recalls the distribution of the fissures radiating from the center of the grains, possibly due to the grinding process or to the thermal treatment in the absence of external water (23). Changes in morphological properties and increased swellability of the starch grains in cold water were observed in experimental thermal treatments of chestnut and acorn flour (31, 32). Swollen and gelatinized grains were also recorded in Middle Paleolithic dental calculus, demonstrating consumption of cooked plant food (33), but, at Paglicci, the thermal treatment of plant materials must have been performed in a previous step, before grinding.

Considering that, in the Middle-Upper Paleolithic, the climate was colder than at present, thermal treatments to accelerate the drying of the plant portions to be ground may have been crucial. Indeed, drying facilitates the seed/fruit grinding, making this process easier and faster, as was also proven by experiments in the laboratory (*Supporting Information*). In northern Europe, heating methods were used for centuries to prepare the freshly cut cereal grains for grinding in a very short time (34).

As regards oats, the caryopses are soft and contain a considerable amount of storage lipids, which makes milling difficult (18). The milling process is favored by thermal treatment, which also prevents the oxidation of the lipids and develops the specific flavor absent from oats collected from the fields (18, 35). The heat treatment could have also provoked the flaking off of the outer covering of the caryopsis, making dehusking unnecessary.

Heat treatment of acorns facilitates both their preservation and grinding and also results in an improvement of the flavor due to the reduction of the tannin content (36).

Conclusions

This research demonstrates a specific skill in processing plant foods during the Early Gravettian, casting light on complex human behavior.

The sampling method, which was adopted here for the first time, to our knowledge, on a pestle-grinder, has furnished additional elements for the functional study of these kinds of artifacts, in terms of more precise indications about the quantity and dimensions of the starch grains in relation to the use traces.

The production of flour requires multistep processing and manipulation before cooking, depending on the different parts of the plants used. Grinding requires a previous drying of the plant portion to be processed, and drying may be accelerated by means of heat treatment. The present analysis indicates that the inhabitants of Grotta Paglicci (sublayer 23A) were the most ancient population to use a method that involves at least four subsequent steps in preparing plants for consumption. The examination performed on the Paglicci pestle-grinder provides direct evidence of heating and grinding. Although there is no direct evidence of the following steps, namely the mixing of the flour with water and the cooking, these processes can be plausibly hypothesized because the rehydration is necessary for cooking and the cooking is necessary to make the starch digestible. The thermal pretreatment could have been an additional crucial step in a period that was characterized by a climate colder than the current one.

The majority of the starch grains recovered on the Paglicci pestle-grinder indicate a preference for Poaceae. The collection from the wild of grass caryopses, as opposed to underground organs, and the subsequent processing phases of heating, grinding, and preparing for cooking were undoubtedly time-consuming activities. These observations demonstrate that, from at least the Early Gravettian, economic activities connected with the exploitation of vegetable resources for nutritional purposes had assumed an important role in the subsistence strategies of these peoples.

It is significant that the plant most represented on the pestle-grinder is an *Avena* species. This finding is currently the most ancient evidence of the processing of *Avena*, a genus that includes *A. sativa*, a cereal that was to be a successful crop long after. In the absence of spontaneous forms of other cereals that were later domesticated in the Near East and that feature a better ratio of time investment/energy yield, oats could have represented an interesting nutritional source for the diet of European Gravettian groups.

In conclusion, this research clearly reveals that the early modern humans of Paglicci already had a wealth of well-developed knowledge that included a multistep technology and organizational ability in processing food plants, long before the Neolithic.

Methods

In 2010, sampling for residue analysis was performed according to Revedin et al. (3), using a light jet of distilled water directed on two areas (a and b) of the cobble, selected based on the occurrence of use-wear traces (Fig. 1). The sampling on the apex (a) was performed by precisely directing the jet of water at the apex of the tool: the dashed line in Fig. 1 indicates the unwrapped area that became wet even though not directly struck by the jet of water. Sample b involved a central band of the artifact, where both sides were directly struck by the jet of water. In 2012, further samplings (c, d, and e) were carried out according to a procedure (Fig. 1) previously tested on experimental grinding tools: the stone was wrapped in a PVC plastic film, leaving a selected square area 2 × 2 cm free for collecting samples. This procedure was refined with the aim of obtaining a quantitative evaluation of the residues and their distribution on the tool's surface, to acquire information regarding the motion of the artifact during grinding. Moreover, the wrapping preserves a large part of the grinding stone surface for further analyses. The number of plant residues per cm^2 was calculated in 30 μl of each sample (1 ml). The three areas sampled using the new method were chosen in relation to the position and type of the use traces: sample c, located on side 2 close to the apex, already involved in the previous sampling (a) in proximity with the traces of percussion; sample d, located in the center of side 2, at the point corresponding to the use traces (striation) and the previous sampling (b); and sample e, located on side 1, in proximity with the base of the tool, in an area without any use traces.

Samples P23A(a) and P23A(b) were then subjected to heavy liquid separation, using zinc chloride, and mounted in a water–glycerol 50% (vol/vol) solution. Samples P23A(c)–P23A(e) were directly mounted in water. Analyses were carried out under a light microscope, as is, or after iodine/potassium iodide (Lugol) staining (37), and a polarizing microscope, operating at ×400 magnification. Overall, about 1,000 starch grains were observed. All of the grains were measured; mean value and mode are reported for the morphotypes exceeding the number 50. Identification was performed with the aid of literature (19, 23) and modern reference collections of the Department of Biology in Florence and the Herbarium Centrale Italicum. The modern material was selected on the basis of the available data on the ancient vegetation at Paglicci (11) and the plants currently common in comparable environmental contexts (*Fagus*, *Castanea*, *Quercus* spp., *Pistacia terebinthus*, *Festuca* spp., *Stipa* spp., *Ammophila arenaria*, *Dasypyrum villosum*, *Rumex acetosa, Glyceria maxima*, *Phragmites australis*, *Nymphaea*, *Nuphar*, and *Typha*).

ANTHROPOLOGY

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