

Mesolithic hazelnut roasting – Experiments and their implications on subsistence and consumption strategies

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Abstract

Hazelnuts (*Corylus avellana*) are considered as a staple in Mesolithic subsistence, decisive for early Holocene land use strategies. According to pollen analyses, ethnographic and historic accounts hazelnuts provided high return harvests. Roasting structures potentially served for the processing of nuts into large scale staples and therefore had an important economic role. As yet, the related nut technologies remain poorly understood and could not be replicated successfully. By controlled experiments we provide detailed data on the roasting process, its efforts and implications. Roasting in hot sand proved as a most efficient technology, capable of processing large amounts of nuts loss-free in a short time. These data help to quantitatively substantiate early Holocene nut economy and related land use strategies. Experiments on cracking and grinding of roasted nuts and analyses of resulting use wear supply references for future investigations in nut processing sites and their equipment. A significant improvement of flavour and processability were the most important advantages of roasting. However, shelf life could not be prolonged by roasting, neither for ripe nor for green nuts. Based on these results we discuss, if nuts served as a fat storage or were roasted for immediate consumption during feasting.

1. Introduction

Hazelnuts are a very valuable food source, known to have been used intensively at least since the early Mesolithic. They are immensely rich in fats (60%) and proteins (12%) and contain essential minerals (Ca, Mg, P, K), vitamins (E and B), antioxidants and unsaturated fats (USDA 2018). In addition, hazelnuts are characterised by very high return rates, a long shelf life, a good predictability and an easy and rapid processing (cf. Bischoff et al. 2014; Holst 2014, 220ff). These qualities distinguish hazelnuts as one of the most important food resources for hunter-gatherers and farmers as well.

On early Mesolithic sites hazelnuts occur regularly and in sometimes large amounts (e.g. Bishop et al. 2014; Bokelmann 1981; Holst 2010; Jacomet & Vandonpe 2022; Mellars 1976; Mithen et al. 2001; Regnell 2012; Zvelebil 1994). The intensive exploitation, the skilled processing to large scale staples and maybe management of hazel plants was even claimed as a hallmark of the early Mesolithic (Holst 2010). Especially in northwestern Europe hazelnuts have been harvested and processed in large amounts. Examples for sites with large nut quantities are the sites of Duvensee (D) (extrapolated 28800–33600 nuts at site Wohnplatz 5, Holst 2010; 2014), Howick (GB) (~ 200000 nuts, cf. Cotton 2007), Staosnaig (GB) (> 30-40000 nuts, cf. Mithen et al. 2001) or Holmegaard I and IV (DK) (extrapolated 86400–165200 nuts, cf. Holst 2014, Table 80). According to pollen analyses, hazel stocks could regionally have formed woods (Firbas 1949) with high potential crop yields, that might have exceeded available manpower (Holst 2010). Quantifications of labour input for nut harvesting and processing resulted in large return rates that prove the efficiency of the early Mesolithic nut economy (cf. Holst 2010). Hazelnuts seem to have formed a staple food, that could regionally have provided more than 44% of the energy demand (Holst 2010; 2014) and by this will have determined the hunter-gatherer settlement behaviour and land use strategies. Accordingly, hazelnut availability regionally obviously determined settlement history as for Lake Duvensee, that was regularly frequented over more than 2400 years in the early Holocene during

the harvesting season in early autumn. The abandonment of the lakeshore coincides with the decline in hazel in the early Atlantic. Similarly, albeit earlier, for the Scheldt basin (B) a settlement decline was observed in the mid boreal, coinciding with the decline of hazel pollen, charred nutshells and processing structures on settlement sites (Crombé et al. 2023).

Hazelnut remains discovered on Mesolithic sites are usually charred nut shells, frequently found in spatial relationship to settlement structures (pits or sand layers), that are interpreted as roasting hearths (e.g. Bokelmann 1981; Bokelmann et al. 1981; Crombé et al. 2005; Holst 2014; Kind et al. 2012; Perry 1999). The sites of Duvensee provide the best preserved and documented examples of roasting hearths. They basically consist of sand layers, mixed with thousands of hazelnut shells and charcoal, that have either been placed on bark mats (site Wohnplatz 8) (Fig. 1) or are just spread on the pure ground, slightly sunken in a shallow depression (site Wohnplatz 6) (Fig. 2). The layers of white sand are preserved up to a depth of 20cm and size of nearly 5m² and have central brown, organic rich lenses (Bokelmann 1981; Bokelmann et al. 1981; Holst 2010; 2014).

Hence, the processing of hazelnuts, their roasting, cracking and potentially also grinding were essential for Mesolithic subsistence. While the roasting structures have been described in detail, the parameters of their modes of operation remain speculative. There are still only few reliable data on roasting techniques and the effects and reasons for roasting. Reconstructions so far are based on ethnographic examples that have rarely been successfully tested experimentally:

Nutroasting in pits, where the nuts are covered by sand and heated from a fire above proved to result in high loss rates by charring in an experiment (Bokelmann 181. 183). This was confirmed by a replication of the same experimental setting with varying pit sizes and roasting durations (1.5-3.5h) (Mithen et al. 2001; Score & Mithen 2000). Again, this resulted in high loss rates of around 25% by accidental burning, suggesting that nuts would need to have been roasted without direct contact with flames. Still, instead of rejecting the experimental arrangement as an inefficient and unnecessary waste of valuable foods, the high loss rates are regarded as given, leading to the assumption of regular high losses during roasting (e.g. Crombé et al. 2023, 5; Holguin et al. 2022).

Roasting without a direct contact to fire on an air-dried clay plate, heated by a fire from below proved as very efficient, fast and loss-free technique (Lage 2004). The nuts have been roasted for only 5–10 minutes at about 300°C. Yet, the archaeological evidence for clay plates remains difficult, although small lumps of clay have been recorded during the Duvensee excavations (Lage 2004). Furthermore, the clay plate implies additional effort, difficult transportation and restrictions in terms of the nut amounts that can be roasted at a time. Anyway, the roasting without direct contact to fire or glowing charcoal is a promising reconstruction. Based on ethnographic observations on the processing of Mongongo nuts in southern Africa (Yellen 1977) it was assumed, that nuts might have been roasted in a layer of sand, heated by glowing charcoals (Bokelmann et al. 1985, 19; Holst 2010), but this was not confirmed by experimental data so far.

More recent controlled experiments have focussed on the charring process and provide valuable results on the taphonomy of charred nutshells (Bishop et al. 2019; Holguin et al. 2022; Lopez Duriga 2015). According to this, hazel nutshells char at a minimum temperature of 300°C, applied for at least 30min (Holguin et al. 2022, Fig. 3). While these experiments produced reference data on the taphonomic processes at roasting hearths, it remains unclear how the roasting of whole nuts for consumption worked. Knowledge on the effort needed to roast nuts in terms of working time and energy would be important for high-resolution reconstructions of Mesolithic land use strategies.

And what is the reason for roasting? In contrast to other plant resources like acorns (Ayerdi et al 2016; Barlow & Heck 2002) or roots (Bishop 2023; Kubiak-Martens 2016) nuts are well digestible without roasting, they don't have to be processed or cooked to remove indigestible ingredients. Several reasons are discussed as benefits from roasting: prolonged shelf life, better digestibility, improvement of taste, improvement of further processing (cf. Bishop 2014, 37 with further references). The chemical composition and nutritional value of hazelnuts are not substantially affected by roasting (Amaral et al. 2006), while the amount of proteins decreases a bit by roasting due to the increase in fat concentration (USDA, cited after Brufau et al. 2006, 25). It was assumed, that roasted nuts have a prolonged shelf life, but according to studies from food technology this is not the case. Rather, by heating the oils transpire to the surface, get exposed to air, oxidize and go rancid (e.g. Brufau et al. 2006; Shafifei et al. 2020). Instead, the shelf life of nuts is dependent mostly on the temperature and humidity of the storage conditions: Hazelnuts can be stored up to at least one year at room temperature without roasting or even up to 24 months under cool and dry conditions (e.g. Howes 1948; Shahidi & John 2010), while roasted kernels might only be held for 6 months (Shahidi & John 2010, 281). Of course, roasting destroys potential carcinogenic fungi or other contaminants, but considering a long shelf life of unroasted nuts without getting mould, this would probably have been not of importance.

According to archaeological experiments with different types of nut caches, roasted nuts seem to sprout less frequently than air dried nuts (Cunningham 2010, 22), while the overall success of storage in pits under damp conditions remained as low as for unroasted nuts (~ 50% loss).

As animal competitors can cause fatal crop failures for human nut gatherers after own observations (R.H.) (cf. also observations in McComb 2009, 227: 14 ripe hazelnuts could be harvested out of 970 green nuts), it was assumed that the nuts might have been harvested while still unripe. This was also observed on Indian people in Oregon, who air-dried the green nuts and stored them in pits and sacks (Kuhnlein & Turner 1991, 140; Simms 1987; McComb 2009, 229). Green, unripe hazelnuts might be poorly digestible and have a short shelf life that could be improved by roasting. Furthermore, green nuts are not tasty, their kernels shrink soon and they are not easy to process because of the tightly connected husks (cf. Bishop et al. 2014, 36f with further references). Until now, experimental data on the shelf life of green nuts in comparison to green roasted nuts are missing.

Hazelnuts are regularly roasted in modern food industry to improve their taste, colour and texture. Thereby the right roasting temperature and modulation are important parameters to develop the typical

nut flavour (e.g. Alasalvar 2012; Donno et al. 2013, 390f with further references; Saklar et al. 2001). Industrially roasted hazelnuts are heated to 100–160°C for 10–60 minutes (Donno et al. 2013, 391). Factors as the improvement of flavour are usually not taken into consideration when discussing stone age subsistence. On the one hand, these parameters are hard to prove nor quantify archaeologically, and on the other hand such unnecessary indulgence is usually not conceded to hunter-gatherers who are often considered as permanently struggling to survive.

As far as the further processing of nuts is concerned, according to ethnographic and historical accounts, after cracking they might have been grinded or smashed, baked as bread, cooked as mash or soup or pressed to oil (summarized in Bishop 2013, 37; Holst 2014). Cracking of roasted nuts was observed to be much easier and faster (e.g. Score & Mithen 2000, 511; Talalay et al. 1984, 351), as the shells get brittle and the husk is removed. This means, roasting reduces work load and transport weight by 50% (Holst 2010; 2014). This is a decisive advantage, as the ecological potential of hazelnuts in the early Holocene must have exceeded available manpower necessary to harvest and process this resource by far (Holst 2010, 2878). As yet, evidence on nut cracking tools remains scarce and uncertain for Mesolithic sites. Macrolithic tools have been put forward as nutcracking stones due to their spatial correlation to nut remains and to ethnographic examples (e.g. Holst 2014; 2021; Roda Gilabert et al. 2012; Score & Mithen 2000, 511f). Even though experiments on the cracking of (unroasted) hazelnuts resulted in the formation of characteristic use wear patterns (Cristiani & Zupancich 2020; Roda Gilabert et al. 2012), these have not been recorded on archaeological find material from Mesolithic nut processing sites so far.

The aim of this paper is to address the roasting of hazelnuts and its implications on nut quality, processing and shelf life through controlled experimentation. First of all, we want to set the record straight, that roasting was expensive in terms of loss rates. Instead we want to assess, if roasting facilities as known from Duvensee were capable to process nuts quickly and efficient. Therefore, we conducted an open-air roasting experiment with heated sand, where we quantitatively assessed the effectiveness of roasting in terms of effort, temperature, duration and loss rates. In doing so, we tried to keep the effort for roasting as low as possible while achieving optimal yields by avoiding high loss rates. This seems appropriate as roasting is not a necessary requirement for the consumption of nuts. Furthermore, we tested the effects of roasting on nut quality, processability and shelf life of nuts. In detail, the following research questions will be addressed:

- how does roasting work in hot sand (technique, duration, temperature)?
- how efficient is it in terms of the effort needed (raw materials, working time), the capability and the success rate (% of successfully roasted nuts versus charred nuts)?
- does roasting improve shelf life of a) ripe or b) green hazelnuts?
- do green roasted and green unroasted nuts differ in quality during storage?

- what are the effects of roasting on nut quality (flavour, texture) of a) ripe or b) green hazelnuts? do improvements of quality retain during storage?
- how could roasting be recognized in the archaeological record/ how does a roasting structure look like after abandonment?
- does roasting improve the processing of nuts (cracking and grinding)?
- does the processing (cracking and grinding) of roasted nuts lead to characteristic use wear traces?

By an improved knowledge of roasting and processing techniques, their effects and efficiency we hope to substantiate the understanding of early Mesolithic nut economy as one of the most important subsistence strategies of the early Holocene.

2. Material and methods

2.1. Nut gathering and storage

Hazelnuts have been harvested in the German Middle Rhine valley and on the first hills of the neighbouring low mountain range. Green, unripe as well as ripe nuts have been harvested. Green nuts have been picked from the shrub in the mid of August. Few nuts could be collected from the ground but proved as sterile. 1/3 was gathered in the mountain range, 2/3 in the Rhine valley, whereat these were significantly riper and of a different, more rounded variety. The green nuts were nearly all attached to their husks. Some husks were still closed. Obviously worm-eaten nuts with holes were sorted out for not to bias the number of failed roasting attempts. For organizational reasons, part of the unripe nuts was put in a freezer to avoid getting mould before the roasting experiments that were conducted during the harvesting time of ripe nuts. A sample of unshelled green nuts has been stored without freezing. Another sample was roasted at 180°C for 15 minutes in the oven as a reference for immediately roasted green nuts without freezing prior to roasting. All samples contain an equal mix of nuts in different stages of ripeness (green with closed husk, light green with open husk, light green with brownish parts without husks). The roasted and unroasted samples of green nuts have been stored over 5 months at room temperature in open baskets for observations on shelf life.

In early September ripe hazelnuts have been harvested at the same spots. The nuts have been partly picked from the shrub, but mostly collected from the ground. Most of the husks fell off during harvest, the remainder were easily removed by hand. Again, nuts with worm-holes were sorted out.

Samples of roasted nuts from each roasting trial (see 2.2.) were stored unshelled in paper bags at room temperature for observations on shelf life and changes of nut qualities. The nut quality was regularly controlled every second day by visual inspection and tasting of single kernels for the first two weeks. Thereafter, they were controlled every second week by visual inspection for as long as 4 months. After 4

months single kernels from the different samples were controlled for mould fungi under the stereomicroscope.

2.2. Roasting experiments

Altogether, six roasting trials were conducted, each with a sample of 50 hazelnuts (**Table 1**).

Table 1: Roasting experiments, descriptions of parameters and results of single trials.

No.	n nuts	status	duration heating of sand (min)	temperature		duration roasting (min)	roasting results			taste	other observations	
				on surface	beneath surface		charred	unroasted	burst			roasted
1	50	ripe	15	293°C	133/100°C	4	0	50	0	0	only slightly roasted	nuts very hot, but not roasted, sand not yet heated properly temperature constantly high inside sand; shelling very easy without force, partly without hammer stone, as some shells cracked by roasting; kemels friable
2	50	ripe	35	245°C	230°C	2:30	2	0	1	47	very aromatic, tasty, sweet	
3	50	green with husk	15	408	350°C/ 170°C at bottom	2:30	0	0	2	50	buttery, like boiled potatoes or chestnuts, not very tasty but more flavourful than unroasted	easy shelling, especially as husk is removed by heat
4	50	ripe	15		352°C	1:30	0	0	0	50	very aromatic, sweet	temperature inside sand constantly high, even though fire was removed, therefore roasting duration very short; nutshells blackened outside
5	50	ripe			290°C	1:00	0	0	0	50	very aromatic, sweet	temperature inside sand constantly high, even though fire was removed, therefore very roasting duration very short
6	50	ripe			218°C	2:00	0	0	0	50	very aromatic, sweet	temperature inside drops slowly after removal of

Nuts have been counted instead of weighted to make sure not to overlook nuts when raking them out of the hot sand after roasting. For roasting, ripe hazelnuts were used and green nuts for the 3rd roasting attempt. The controlled open-air experiment on hazelnut roasting replicates the roasting technique in heated sand, as postulated for the hearth structures of Duvensee (Bokelmann 1981; Bokelmann et al. 1981; Holst 2010; 2014) (Fig. 1; 2): a more or less rectangular and slightly deepened surface of about 1m² was prepared by cutting of sods (Fig. 3a). A layer of fine white sand (around 25–30 l) was spread evenly on this earthen surface (Fig. 3b), up to a depth of approximately 8cm. In close proximity a camp fire was lit in a metal fire pit and burned for around 30min, until enough embers were produced. About 1l of embers and burning wood were shovelled in one part of the sand surface (Fig. 3c). The temperature of the sand surface above (trials 1–3) and inside (trials 2–6) the cluster of buried embers was controlled with a digital temperature probe (PCE instruments, T311 K-Type) (cf. Table 1; Fig. 3e-g) with a flexible high temperature sensor (TF-104A). After 15min the sand was assessed as hot enough for roasting (cf. Table 1): the surface was heated from initially 13,2°C to 293°C, while the temperature inside the sand in a

depth of approximately 7cm was 133°C. Then, the first sample of hazelnuts was buried in the hot sand (trial 1). Temperature was observed to drop quite quickly inside the sand to 100°C after burying the nuts. After 4 minutes the nuts were raked out with a metal kitchen spatula (Fig. 3i). In the Mesolithic, for example a wooden plank or fork could have been on use. The nuts proved to be hot, but not properly roasted. To raise the sand temperature, a campfire was built directly on the sand surface and allowed to smoulder here for another 35 minutes (Fig. 3d), until the sand reached a temperature of 230°C inside. Then the fire was raked to the side and the 2nd sample of nuts was buried in the hot sand (Fig. 3f), that holds a constantly high temperature of over 230°C during roasting. Because of the high temperature, nuts were already raked out after 2:30 minutes in the 2nd trial. In the following, roasting duration was tentatively adapted to the sand temperature and adjusted for each roasting trial according to the observations on the preceding roasting event. For the 3rd roasting trial burning wood was again shovelled from the external camp fire on the sand surface and burned here for 15min. Embers and charcoal were raked away when a sufficient sand temperature was reached (Fig. 3g). Nuts were buried at a temperature of 350°C inside (Fig. 3h). After the fourth roasting trial the sand layer held a more or less constant temperature, that dropped only slowly so that the last three nut loads could be roasted without additional fresh heat supply. Now, very short roasting durations of just one to two minutes were sufficient (Table 1).

2.3. Nut cracking and grinding

Immediately after roasting nuts were cracked open while still hot to control for nut quality by tasting and visual inspection (Fig. 4; 5). This was done on sandstone slabs (Fig. 5), using either a fist-sized boulder or a wooden plank as hammers. The use of a wooden plank seems appropriate as planks in varying sizes have been detected at the roasting hearth of Duvensee, Wohnplatz 6 (Fig. 2).

As a reference for the study of use wear, roasted hazelnuts have been cracked within another experiment. A thick quartzite slab served as anvil and a rolled-off fist-sized sandstone as hammer (Fig. 6a, b). Afterwards, the stone surfaces have been scanned for use wear like percussion marks and crushed grains by visual inspection and with the help of a stereomicroscope (Zeiss SteREO Discovery.V8, 0.63×/0.116 objective with 10× oculars). Potential use wear traces and residues were documented under a 3D Digital microscope (Zeiss Smartzoom5) at magnifications of 34x to 335x using the 1.6x/0.1 objective.

To produce a maximum of possible use wear and to take also multiple and unskilled handling of the nutcracking stones into account, two more hammerstones have been analysed (Fig. 7a, b). The granite and sandstone boulders have been used during a public nut roasting event by unexperienced participants, mostly children, to cracked 1kg of roasted hazelnuts.

Further processing of the shelled nuts grinding was experimentally tested. To evaluate potential differences in the processability and in the formation of use wear, the experiment has been conducted with unroasted hazelnuts and has been replicated with a sample of nuts that has been roasted in the oven for 15min at 150°C. For grinding, sandstone slabs have been used as active and passive tools (Fig.

8). The active, hand-held stone was used on its upper surface of the grinding of roasted nuts and on its lower surface for unroasted nuts. The stones were used by a combined grinding and pestling motion for one hour. The stones' surfaces have been documented before and after use under the 3D Digital microscope. Micro wear (especially micro-polish) was recorded with the metallographic, reflected light microscope Zeiss AxioScope.A1 with the 10×/0.25, 20×/0.40 and 50×/0.75. Casts of silicone rubbers of the respective utilized areas of the tools were created using Accu trans (Coltène Whaledent) (Schunk et al. 2022) before and after use to facilitate the documentation of micro wear and directly compare the surface characteristics before and after use. The microscopic analyses were conducted at TraCEr (*Laboratory for Traceology and Controlled Experiments*) in MONREPOS (LEIZA), Neuwied.

3. Results

3.1. Roasting

Our roasting experiment indicates that hazelnut roasting in hot sand is a simple, efficient and actually loss free technique. At the beginning it needs some experience to recognize the sufficient heat of the sand. This is why the first attempt failed to produce properly roasted nuts, but only delivered half done nuts, already recognizable by the unchanged colour of their shells. By raising the sand temperature, roasting efficiency and duration were significantly improved. The effort for roasting was very low as it just needs a small camp fire and some sand, without any time- or resource intensive preparation of a complex roasting structure. All in all, the preparation time including heating of the sands equals around 1-1.5h. For the amounts of nuts roasted here, even half of the sand surface would have been sufficient. The small camp fire provided enough embers to heat the sand to high temperatures (inside 218–352°C, sand surface > 400°C), that exceeded those of industrial roasting hearths (100–160°C, cf. Chapter 1) by far. Due to the high temperature roasting took only two minutes. Three minutes of roasting proved to be nearly too much heat intensity as the kernels got a bit brittle, but just two were inedible charred. When the sand was properly heated, roasting even took just one minute (trial 5)! Roasting then is just a short in and out of nuts, like the blanching of vegetables in hot water. Once properly heated, the sand stored heat quite constantly for some time. This means, large amounts of nuts could have been processed in a short period of time, without reheating of the sand. In our experiment we did not use the period of properly heated sand to full capacity but concentrated on the observation of the temperature drop after the 5th roasting trial. The gradual temperature drop could have been compensated by a slight prolongation of the roasting duration (experiment 6). Even 25 minutes after the last roasting trial the sand reached a temperature of 177°C inside; after another 35 minutes it dropped to 132°C, still sufficient to roast.

After each roasting trial the nuts had to be raked out of the hot sand quickly, what was probably the most “elaborate” step of nut roasting, as you have to hurry up to prevent losses from too long heat supply. Furthermore, it is easy to overlook nuts or to burn oneself.

Charred or burst kernels almost never occurred (Table 1), unroasted only in the first attempt. Instead, in the roasting trials 2–6, nuts were perfectly roasted. Only three single nutshells were charred by

accidental direct contact to embers. Interestingly, these kernels proved to be neither charred, nor unenjoyable, but crunchy and aromatic (Fig. 4). Generally, the nutshells were darker after roasting and greyish by ash. The green nutshells (trial 3) became darker as well, more brownish and the husks dried out and shrivelled (Fig. 4). Single nuts burst during roasting (like popcorn), mostly green nuts, what happened also during roasting in the oven.

Roasting in our experiment was much less gentle than in modern nut industry, where roasting temperatures are considerably lower with longer roasting durations. However, that has obviously not affected nut quality: flavour improved a lot by roasting, just not to compare to unroasted nuts. Roasted nuts developed a typical, very pleasant nutty taste. When cracking the nuts, an intensive, sweetish, flavoursome aroma spreads. Furthermore, the texture has changed and nuts are pleasantly crispy, except for experiment 1. The green, still unripe nut kernels in trial 2 also improved their flavour. Before roasting the taste of the white soft kernels was weakly unpleasant, unripe, giving a furry feeling. By roasting, the green kernels developed a soft, buttery texture and a flavour reminding on jacket potatoes, just less sweet.

3.2. Nut processing

Nut cracking was significantly facilitated by roasting, as was observed in previous experiments (Score & Mithen 2000, 511; Talalay et al. 1984, 351). Some shells had heat related fissures and were opened even without tools (trial 2, Table 1). Where husks enclosed the nuts (trial 3) these got lost during roasting or more often shrunk, so that they just fell off during cracking the nuts open. For cracking, just a careful strike was needed to open the brittle shells and several could be opened at once (Fig. 5). During careful cracking, the hammer actually did not touch the basis upon which the nuts rested. The application of stronger power of impact led to the undesired smashing of the kernels. Furthermore, the stone on stone percussion can lead to the loosening of stone particles that unpleasantly contaminat the nut kernels. The risk of applying too much force was minimized by the use of a wooden plank, that proved as a very efficient and easy to handle alternative to a hammer stone (Fig. 5). This happened just rarely and unintentionally and did not lead to visible traces on the stone surface. During experimental cracking, already after short use a fatty spot accumulated in the centre of the underlying stone and on the stone hammer (Fig. 6a, b). Use wear traces could not be observed on the anvil involved in nut cracking (Fig. 6c). On the hammerstone a single crushed grain was observed under the microscope (Fig. 6d).

Even on the two stone hammers extensively used during the public nut roasting event, only few use wear traces developed (Fig. 7). Single crushed quartz grains have been observed, distributed loosely in very low densities over the stones' surfaces, due to the non-uniform handling of the stones. These percussion marks were not visible to the naked eye. Especially for the granite hammer stone (Fig. 7a, c), they may hardly be distinguished from crushed grains of naturally rolled-off surfaces, as to be observed on stones from secondary deposits like moraines. Remains of the nutkernels and shells deposited as characteristic fatty yellow to whitish residues on the surfaces involved in nut cracking (Fig. 6; 7d, e).

According to these observations, the development of pits on nut cracking stones as observed ethnographically for nutcracking stones of Mongongo/ Mangetti, Marula or Quandong (cf. Holst 2021, 708ff. with further references) seems to be unlikely for stones involved in the processing of roasted hazelnuts, unless other technics for nut cracking have been employed (e.g. the intentional modification by drilling of a pit to hold the nuts during cracking). Similar large stones, some with potentially pitted surfaces, have been documented for the nut processing sites of Duvensee (Holst 2021).

The use wear resulting from grinding of nut kernels will be presented elsewhere in detail (Holst et al., under review). Here we just summarize the results with a focus on the differences of roasted versus unroasted hazelnuts. Both, unroasted as well as roasted nuts proved difficult to grind or pound with small stones, as they require the application of quite some force. This is especially true for unroasted nuts that are harder and tougher. Roasted kernels are more brittle and drier and demand less pressure for grinding (cf. also observations in Score & Mithen 2000, 511). Even though grinding proved to be quite time consuming and exhausting, it resulted in only 200g of nut flour per hour, because the fatty nut mush quickly clogged the rough grinding surface (Fig. 8e, f). Nut mush was removed several times by hand. Still, part of the nuts could only be smashed into larger particles (Fig. 8e). The stone surfaces quickly got dark from fat (Fig. 8) which soaked deeply under the stone surfaces and could hardly be removed. Already after short use smooth plateaus formed on the high parts of the active upper stone by the stone on stone contact (Fig. 8b, d). These plateaus developed more pronounced and extensively for unroasted nuts, because grinding required more effort for roasted nut kernels (Fig. 8d-f). Microscopic analyses under low magnification show strongly levelled grains, often with pits, notches or striations, for unroasted nuts also crashed grains (Fig. 9). Levelled grain edges of surfaces used for grinding unroasted nuts are mostly sharp-edged while more rounded for roasted nuts. Under high magnification extensive polish is visible (Fig. 9d-e, i-j). It is flat, clearly limited, partly striated and often has a greasy shine. Its texture is smooth and sometimes appears a bit fluid. The polish induced by grinding of roasted nuts was observed to be in some parts slightly domed but in general equals that of unroasted nuts. These use wear characteristics are of course also dependent on the grinding tools, the force applied and the direction of motion. Even though differences between roasted and unroasted nuts have been experienced during grinding and have been observed microscopically, they still remain gradual and can probably not be differentiated on archaeological tools. Anyway, the experiments clearly substantiated an improved processability of roasted nuts, that was probably one of the main reasons for roasting, of course crucial when cracking and grinding very large amounts of nuts.

3.3. Shelf life

Even though observations on shelf life were not comprehensive, as they did not involve the testing of different storage methods or include large amounts of nuts, they still show important results on the implications of roasting. We compared changes in nut quality between roasted and unroasted green nuts after storage. It turned out that unroasted unshelled green nuts post-ripened during storage. The shells coloured light brown, the husks shrunk and also the kernels changed colour and texture by drying, now resembling ripe kernels (Fig. 10b). The same is true for the development of taste, that is comparable to

ripe nuts now and no more unripe. Green roasted kernels on the contrary shrunk and got quite hard. They are smaller than kernels of unroasted green nuts (Fig. 10c, d). Interestingly, by drying they also improved in taste, now tasting nutty. Mould fungi could not be detected, neither on roasted, nor on unroasted green kernels or shells. According to this, hazelnuts could also have been stored for quite a while when harvested in an unripe state. The quality of the nut kernels in terms of size, texture and taste, was actually better for unroasted green nuts.

As to be expected, ripe nuts did not get mouldy when stored for some months, independent of their treatment. This was validated microscopically on a control sample. Interestingly, the great improvement in flavour by roasting was weakened soon. Already one day after roasting we stated a gradual loss in aroma. After 4 months, the roasted nuts were still crunchy and tasty, but just not comparable to freshly roasted nuts.

4. Conclusion

The experiments on hazelnut roasting and related activities make a large-scale processing of hazelnuts possible and likely. Roasting proved as a very efficient, quick and easy to handle technique, requiring low expenditures of material, energy, manpower and time. Instead, roasting facilities consisting just of heated sand, are capable to accumulate high temperatures for quite a long time, sufficient to roast large nut amounts in a few minutes only. In contrary to former experiments on hazelnut roasting, there are no losses by charring. Archaeologically, such roasting features will be visible only under most favourable conditions and hardly ever on a sandy substrate. It was not within the scope of the experimental setup to test for the maximum capacities of a Mesolithic roasting feature. But considering the small experimental samples roasted (50 nuts), that filled just a small part of the total sand surface, it can be carefully estimated that at least 200-300 nuts could have been roasted at once, to give a conservative estimate. Finished after ~ 2 minutes and raked out in approximately another 5 minutes (depending on the available hands) more than 1000 nuts could have been roasted in an hour, including a renewed heating of the sand if necessary. Based on experiments it was assumed that one person could have harvested around 1400 nuts per hour and cracked 500 nuts per hour (Holst 2010, 2876), corresponding to 950 processed nut kernels per hour. Now, roasting time can be added to this quantification of the labour input necessary to process hazelnuts in a tasty, energy rich fat stock, corresponding to ø 970 cracked, roasted kernels per hour. During a seasonal stay in Duvensee a stock of ~30.000 nuts could have been harvested and processed as quantified on nutshells detected at "Wohnplatz 5". According to our experiments, maximal 30 hours would have been necessary to roast these nuts, corresponding to about 5-8 days, which is in accordance to the settlement durations suggested for Duvensee (Holst 2014, 232f). Also, it has to be considered, that our roasting experiment worked on a small-scale, while the sand surface of the roasting structures in Duvensee were more extensive and besides, several roasting features were run at a time (Fig 1; 2).

Interesting observations have been made on potential reasons for roasting: a prolongation of shelf life was probably not intended as even green, unroasted nuts not got rancid or mouldy during storage time.

Instead, the significantly improved processability of roasted nuts, for cracking as well as grinding and above all, the improvement in flavour are considered as decisive factors for roasting. Even though the quality of green nuts was clearly improved, roasting was probably not a prerequisite to consume or store green nuts. Instead, unroasted green nuts proved to have an even better quality. We consider the preferred harvest of green nuts as unlikely because of the large differences in nut quality compared to ripe nuts. If green nuts have been harvested they have rather been air-dried than roasted.

Our results not only have implications for the understanding of Mesolithic land use and quantifications of subsistence strategies but also for the understanding of the tool kit involved in nut processing. Roasting made the nutshells so brittle, that cracking just required a careful strike, potentially with a softer, ductile hammer, as for example a wooden tool or maybe antler. If stone hammers have been used for nut cracking, the formation of use wear is expected to be very low or even nonexistent. This is probably the reason why even systematic and high-resolution use wear analyses on ground stone tools from the sites of Duvensee so far failed to unequivocally classify nut cracking tools or assign use wear patterns to nut processing (Holst, forthcoming). The experimental grinding of nuts on the other hand immediately produced significant use wear, visible already with the naked eye. Use wear related to grinding was not observed on the ground stone tools from Duvensee (cf. Holst 2014) nor other nut processing sites so far, speaking against a further processing of the nuts at these sites. In our experiments, use wear developed gradually different for unroasted and roasted nut kernels, albeit these differences will probably not be detectable in archaeological material based on the reference provided here. Further experiments and quantitative use wear analyses will help to substantiate the differences of use wear development between roasted and unroasted nut kernels.

Furthermore, roasting converts hazelnuts into a delicate goody, especially when immediately consumed. So far, a large-scale storage of hazelnuts is mostly assumed. Taken together, our observations could alternatively also speak in favour of a direct consumption of the nuts instead of the investment in storage. This in turn sheds a different light on subsistence and land utilisation strategies! Considering the high amounts of hazelnuts harvested and processed per season, we can assume a larger group size consuming nuts at specialized nut processing sites like Duvensee. Then, in terms of energy, hazelnut economy was not only a high-return strategy (Holst 2010) but at the same time an immediate return strategy (cf. Woodburn 1982). An assumption, that contrasts previous notions of Mesolithic economy. This is not to reject or underestimate Mesolithic subsistence as not anticipatory from hand to mouth-living. But to put forward, that times of larger social clustering, maybe feasting and plentiful indulgence could have been afforded and probably had social importance.

Declarations

The authors have no competing interests to declare that are relevant to the content of this article.

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Author Contribution

Conceptualization: D.H., R.H., W.H.; experiments: R.H., W.H., D.H.; use wear analyses: D.H.; original draft: D.H.; figures and tables: D.H.; fotos: D.H., R.H., W.H.; review and editing: W.H., R.H., D.H.

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Figures

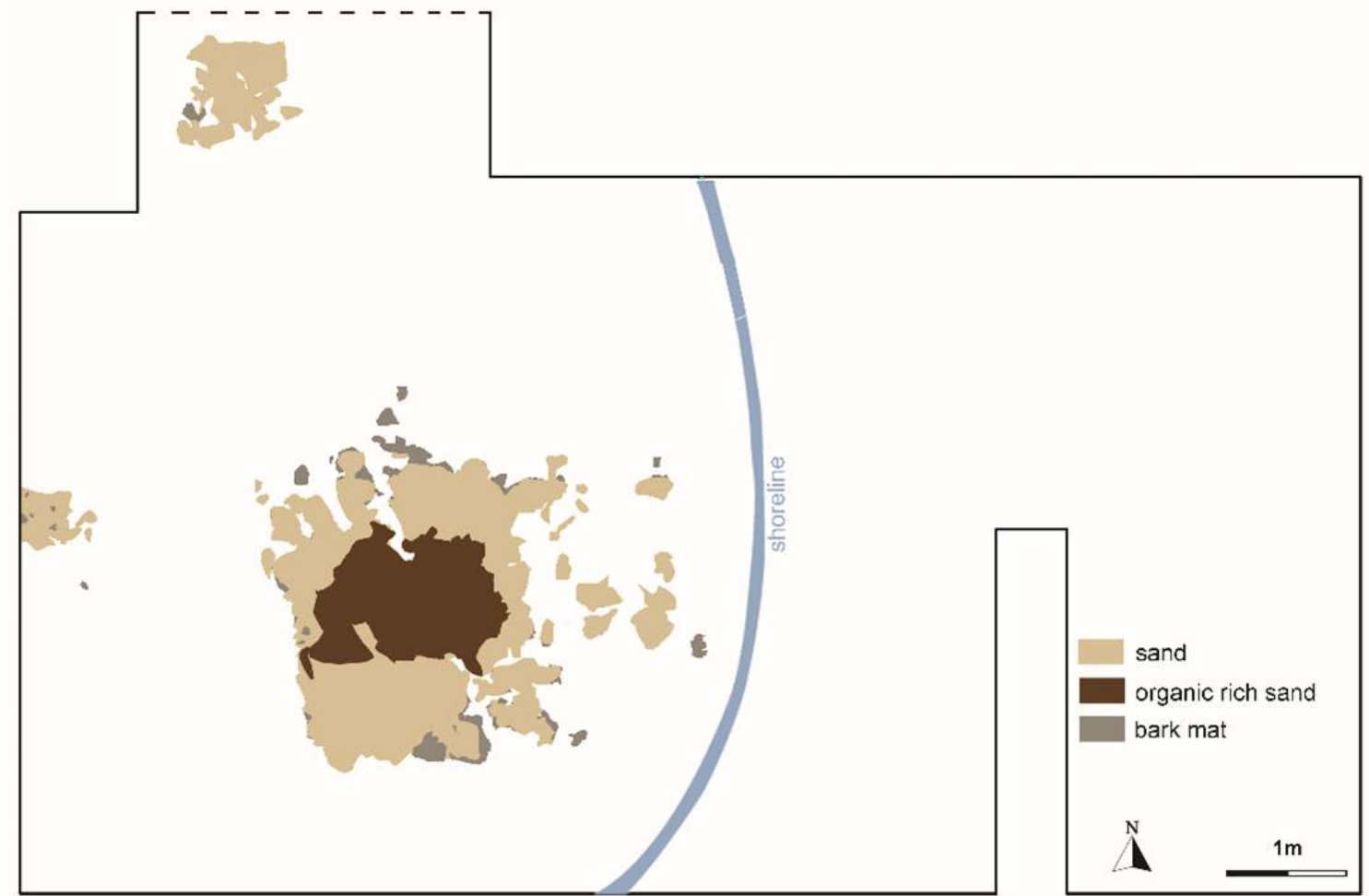


Figure 1

Duvensee, Wohnplatz 8. Roasting structures of sand, mixed with charcoal and nutshells, based on a barkmats.

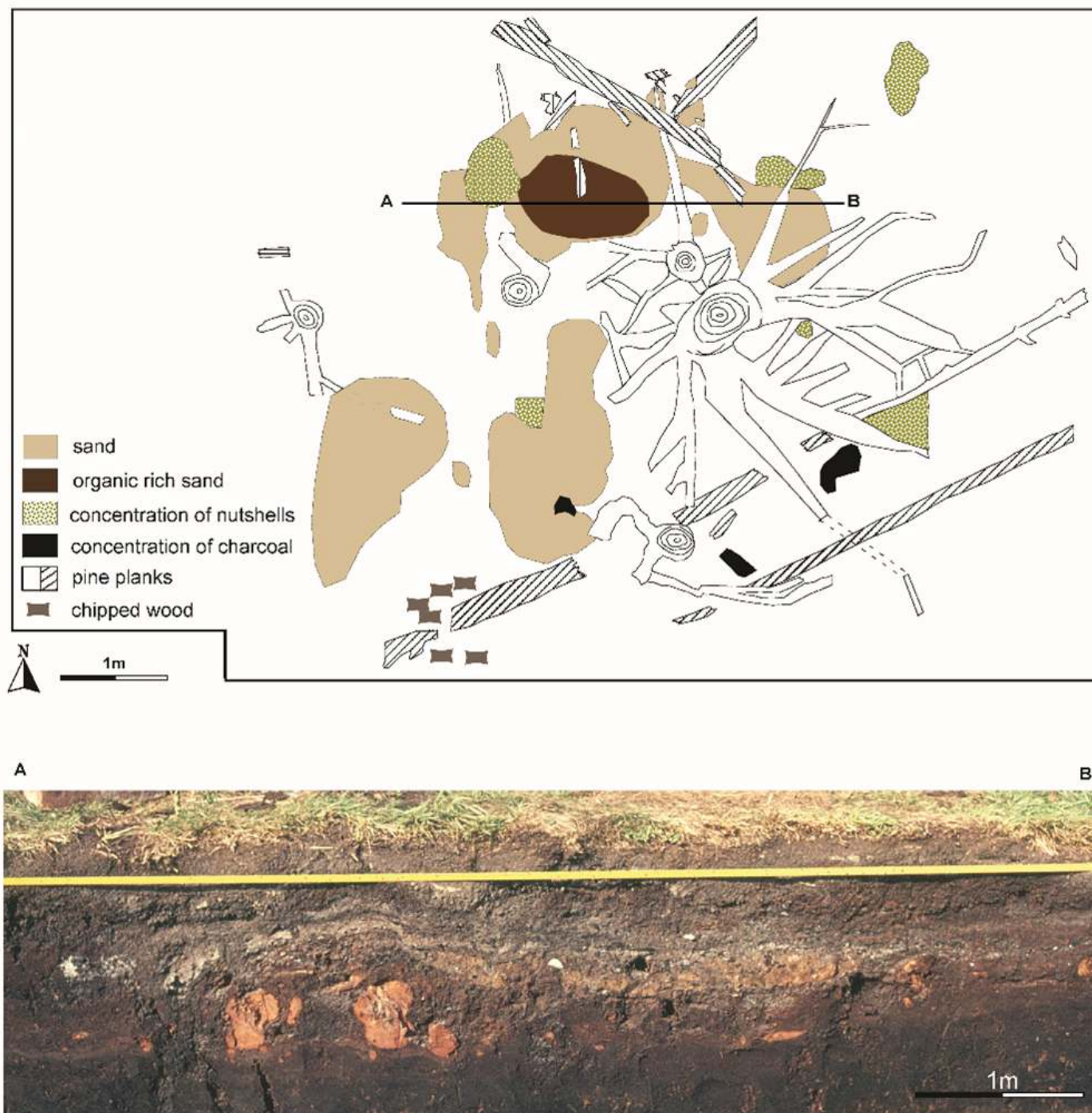


Figure 2

Duvensee, Wohnplatz 6. Roasting structures, consisting of sand with charcoal and nutshells. Below, section through central roasting structure.



Figure 3

Hazelnut roasting experiment. a: preparation of underground for roasting by cutting of sods; b: earthen surface filled up with sand and external fire place in metal fire pit; c: embers and burning wood was shovelled on sand surface; d: new fire lit directly on sand surface; e: sand heating was controlled by temperature probe, embers were cleared away after reaching sufficient roasting temperature; f: ripe hazelnuts were buried in hot sand; g: temperature control for experiment 3; h: green hazelnuts buried in hot sand; i: nuts were raked out after roasting.



Figure 4

Roasted nuts, some impressions before (1st row) and after cracking.



Figure 5

Cracking of roasted nuts with hammer stone and with wooden hammer immediately after roasting.

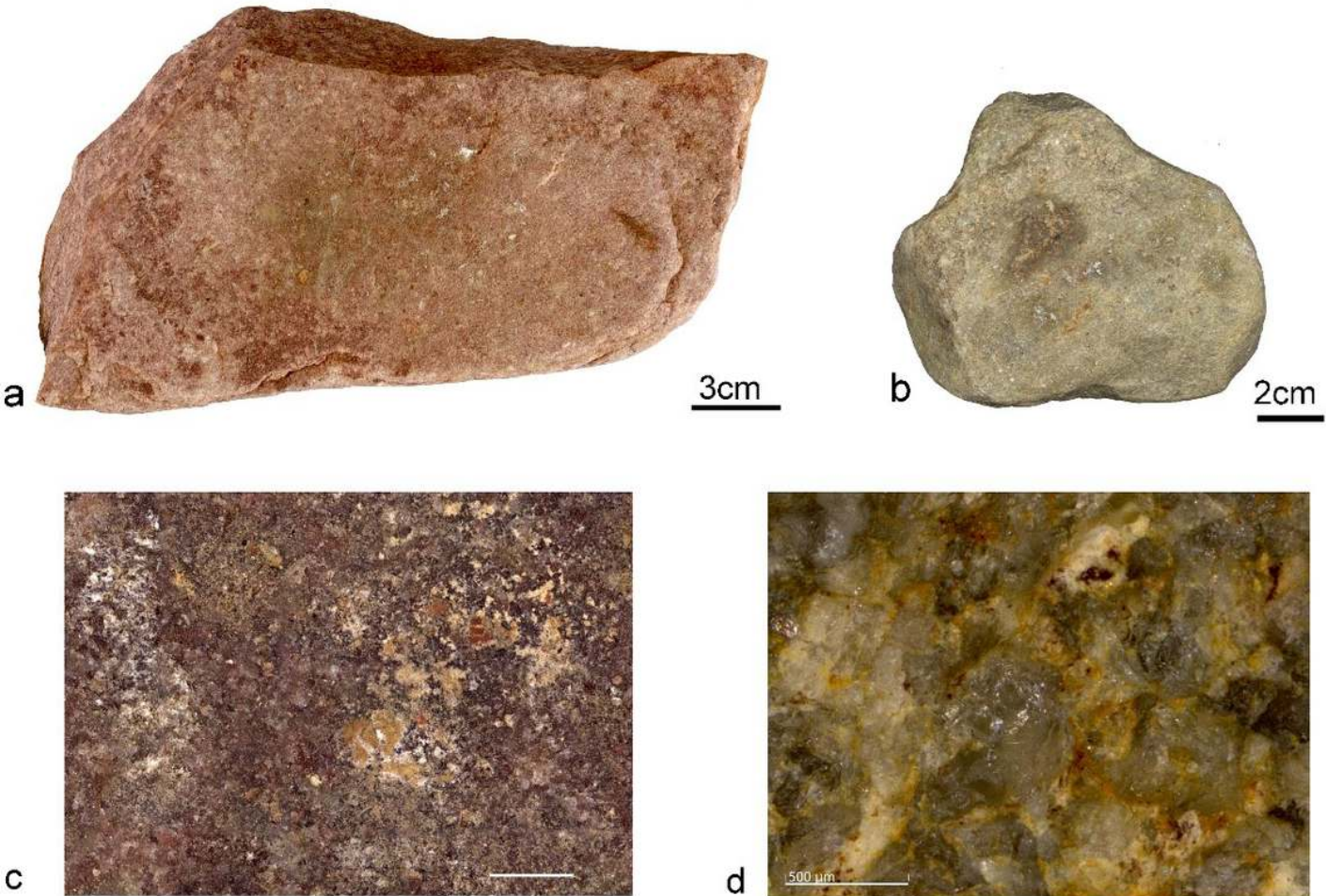


Figure 6

Anvil (a) and hammerstone (b) used for experimental cracking of roasted nuts and examples of microscopic documentation after use with residues on anvil (c) and a single crushed grain on hammerstone (d).

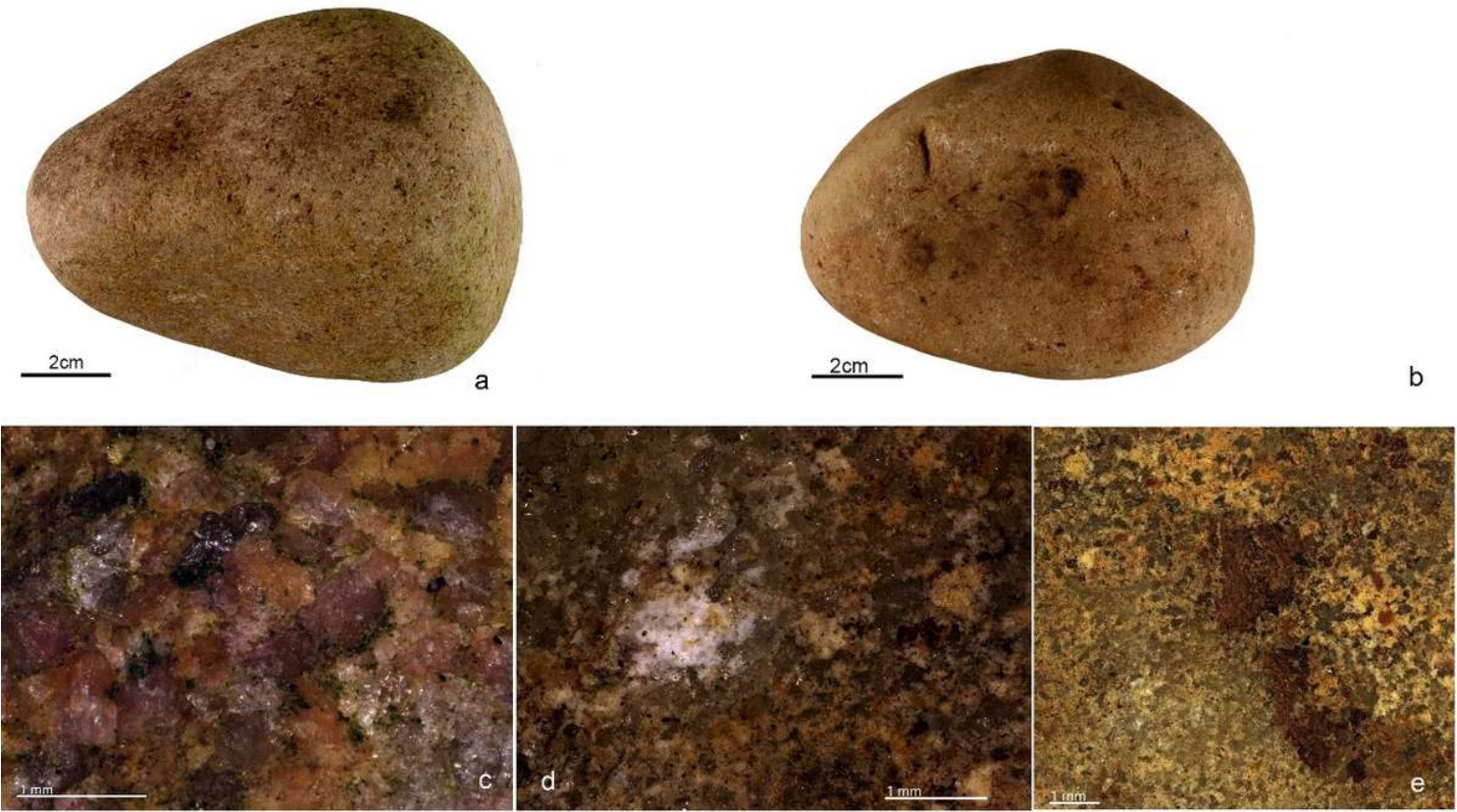


Figure 7

Hammer stones used for cracking 1kg of roasted hazelnuts by various participants of a hazelnut roasting event and resulting use wear. a, c: granite with single crushed grains; b, d, e: sandstone with single crushed grains and yellow residue.

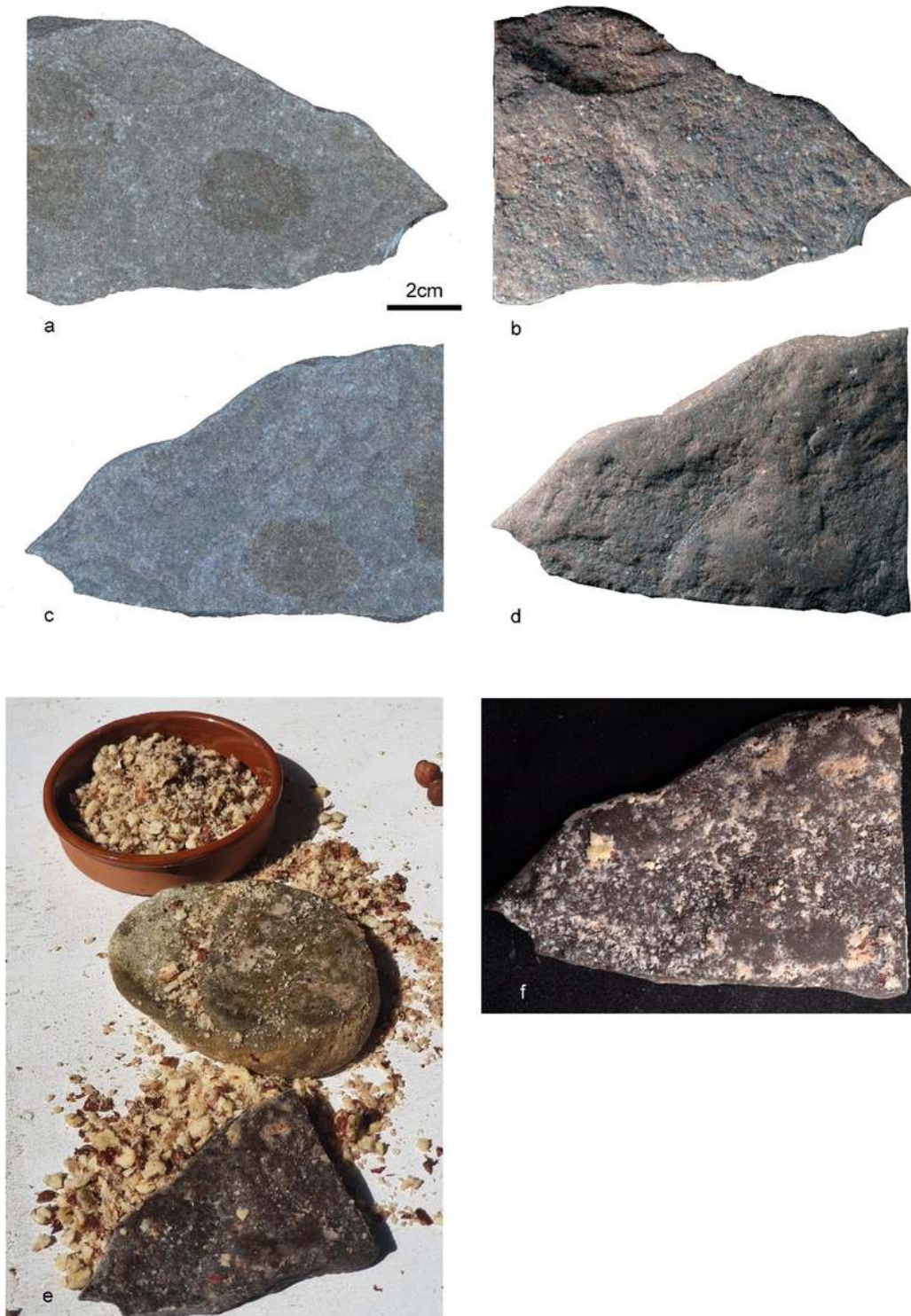


Figure 8

Sandstone slab used for grinding of roasted and unroasted nuts (a, c: stone surfaces before use, dark spots result from casts; b, f: after grinding of roasted nuts, cleaned and uncleaned; d: after grinding of unroasted nuts, cleaned; e: grinding of unroasted nuts).

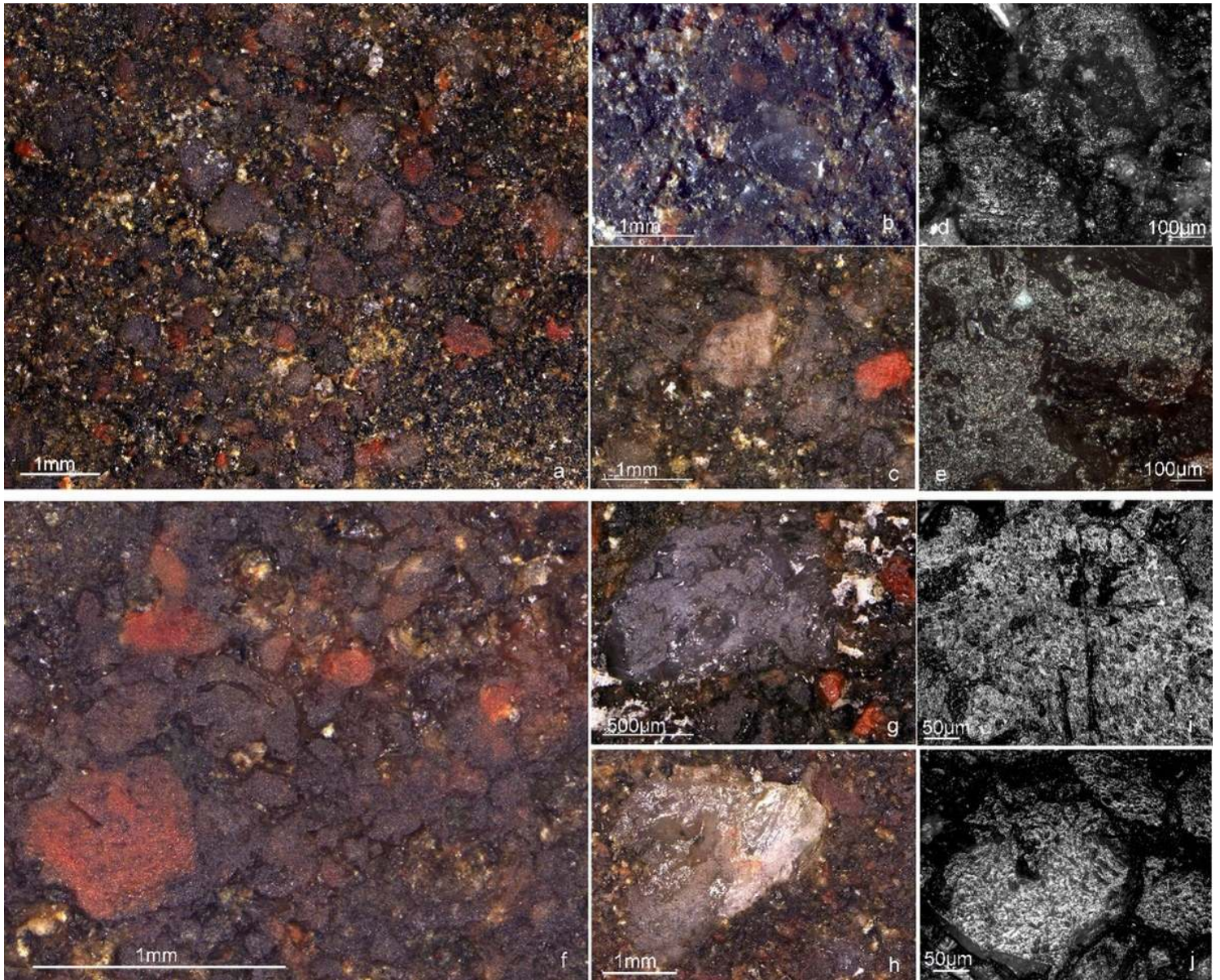


Figure 9

Use wear resulting from experimental grinding of roasted (a-e) and unroasted hazelnuts (f-j).



Figure 10

Green nuts before and after storage (a: green nuts after harvesting; b: green nuts unroasted after storage for 5 months; c: unroasted nuts, shelled after storage; d: roasted nuts, shelled after storage, c and d in same scale).