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Reviewed Article:

Pit Preserve from Ida – on the Problem of Charred Seeds from Prehistoric Pits

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The whys and hows of surviving plant macro-remains from the beginnings of agriculture onwards is a central question in the understanding of early sedentary economies. The vast majority of archaeological macro-remains consists of cereal grains, often described as charred. The research presented here repeats charring experiments with a variety of modern seed samples and complements the results with additional data from the literature. Whereas previous charring experiments have required further experimentation to explain the survival of charred macro-remains, the results presented here suggest an alternative explanation: a cold carbonisation involving fermentation and humification as opposed to a hot charring process. Additional fermentation experiments show the positive effects of this process in order to create seeds close to those from prehistoric pits. The biochemical and economic outlines of the fermentation technique are described and thus reintroduced into archaeology. Earth pit fermentation was documented by ethnological fieldwork in many parts of the world, whereas such data is not available for Europe. Analytical methods to verify one or the other conservation model are discussed.

> “ Dagegen haben wir die Säuerungsgrube gehabt, auch wenn unser Faß mit dem „Kraut“ aus dem Boden heraus stieg! Und in der Grube wurde einmal Kraut gesäuert aus mancherlei Pflanzen, bis der Kohl über alle anderen siegte,…
>
> Accordingly we have had fermentation pits until they were elevated as barrels of „sauerkraut“ above ground! And the pits contained sauerkraut of a multitude of plants before cabbage overcame them all,… (translated by the author)
>
> Ida Hahn 1935, p.273

Introduction

A wild seed propagator and gardener (such as myself) relies on years of close human-plant interaction. The adaptability of domesticated and many wild plants to human economy and behaviour has always thrilled me. When I first read archaeological reports of frequent and large amounts of prehistoric charred seeds that were dumped in the ground I was bemused. It contrasted starkly with the care and sensitivity I use in the processes of seed harvest, drying and selection. So I started reading more and also charring seeds myself.

Charred remains from domesticated plants (mainly cereals and pulses) are, besides charcoal, the most widespread botanical traces from early agriculture onwards. The term *charred* describes a conservation process initiated by fire (Zohary and Hopf, 2000, p.4) that was dominantly used from the early years of archaeobotany on (Wittmack, 1886; Netolitzky, 1900). The conservation of prehistoric seeds by a cold carbonisation has been described as being present at many European archaeological sites (Neuweiler, 1905, p.27). Nevertheless, contemporary research focuses on charring. Seeds classified as non-charred remains occur only as constantly desiccated matter in arid regions or waterlogged on sites such as Alpine lakeside dwellings (Pfahlbausiedlungen), peatbogs and wells. Most of the charred plant remains discovered come from subterranean structures, such as pits that occur outside or inside houses. They are often excavated in high densities and good condition from the Early Neolithic onwards (Forrer, 1903). Fully conserved pits often show a tapered opening, a well-worked (pearhaped) body and an inner coat of clay. Following the spread of farming, they were dug in the preferred loess all through Europe. Due to their small size (less than half m³) they are classified as household level. These pits are sometimes empty and sometimes contain hoards of almost pure grain. (Zohary and Hopf, 2000, p. 5).

Buschan (1895, pp. 247- 268) offers a striking summary of compact pitfills and ceramic vessels containing burnt grain from the Neolithic to the Bronze Age. Recent fieldwork reports of numerous similar pits. Additionally, modern excavation standards include detailed crosssections, which mostly show an even and compact layer of the grain in the lower part of the pit. Two site reports may illustrate these features. The first pit was found in Linearbandkeramik Werl ,Westfalen, Germany (Kempken and Oehmen, 2011, Schamuhn and Zerl 2012), where 16 kg of dehusked emmer (*Triticum dicoccum* L.) with no signs of *in situ* firing were placed as a layer in the bottom part.

In Plate, Mecklenburg Vorpommern, Germany (Heise and Schacht, 2014) two pits from the Early Bronze Age were documented. One pit revealed 600 g of naked barley (*Hordeum vulgare f. nudum*),

the other one contained three kilograms of pure dehusked emmer (*Triticum dicoccum*) both in compact layers at the pit bottom.

All the finds were not mixed with the dark soil above which, in the author's opinion, accounts for a careful deposition. Instead, both field reports assume dumping of accidentally burnt grain in a waste pit. This view is prevalent and adopted by most archaeologists since decades (Knörzer, 1967: Fröhlich, 2002).

Alternative opinions and viewpoints are scarcely published; Chondrogianni-Metoki, (2015, §. Refuse or deposition) argued that: '*Rubbish' and 'dirt', however, are not categories common to all cultures... It is believed that the gathering of refuse from daily activities should be removed as a hypothesis for interpreting Neolithic pit.* A similar opinion was debated in experimental archaeology by Reynolds (1979).

There is, however, another widespread pit type which is associated with cereals even more. These pits are larger (mostly several m³ in volume) and occur grouped, such as those in Stillfried, Austria (Griebl and Hellerschmid, 2013) and Bohemia (Koutecky, 1990). They are not regular parts of all settlements but occur inside or away from urban centres in more permeable soils (Biederer, 2017). A considerable increase in pit volume is documented from the Early Bronze Age on in Western and Central Europe indicating a shift from one type to the other one (Prats, Antolin and Alonso, 2020).

Even though hardly any of the large pits contained prehistoric grain they are classified as cereal storage systems for trade, supply or surplus harvest. This is proven by historical documentation. Until the beginning of the 20th century the practice of dry grain storage below ground was documented in Hungary, Slovakia, Austria, Romania and the Near East (Biederer, 2017, pp. 74-77).

In arid or continental climates well-drained locations are detectable, where even deep pits are not exposed to precipitation or groundwater. But still then, there is a high risk of storage failure and a regular ratio of wasted grain accompanied by lowered germination caused by condensation and superficial processes within one year (Biederer, 2020; Reynolds, 1979). The percentage of the regularly wasted fraction can be reduced by the use of straw insulation or by increased pit volume.

But the testified lower germination rate makes earth pits unlikely for seed storage units. For the Early Neolithic during the Holocene climatic optimum (Atlantikum) with its humid warm climate, above-ground storage in dome repositories and longhouses is hypothesised instead (Hopf, 1975; Coudart, 2019, p.317).

The vast absence of prehistoric cereal grain from these large pits might be explained by the permeable ground, which may offer aerobic conditions, followed by disintegration.

The dominance of cereal remains in the smaller pits has been explained by the antimicrobial effect of carbonisation, which inhibits decay. Why were large pits not used for dumped waste in the same way as small ones?

Following the idea that only charred seeds were able to survive, it seems reasonable to exclude any terrestrial excavated non-charred seed from documentation in site reports. In the remaining documented cases a secondary pollution with recent material is always presumed as for *Polygonum spp*. seeds in Linearbandkeramik Gwoździec, Poland (Czekay-Zastawny *et al*., 2020).

Nevertheless non-charred plant remains in European terrestrial excavations are scarce but evident (Willerding, 1975, Gleser and Marinova, 2018). Either this evidence is taken for modern pollution or it must be taken into prehistoric account.

To the present day, a prehistoric seed is classified as charred not by analytics, but by plausibility.

Zohary and Hopf (2000) claim that the dark brown to black, coal-like colour of the prevalent material and the heat-related deformation (swelling, combined with shrinking in length) of some kernels confirm firing (2000), but Märkle and Rösch (2008) have questioned the testimonial value of the dark colour.

This confusing situation led to a number of modern heating experiments which were designed to elucidate charring conditions and seed survivability.

Survey of Literature on Experimental Charring

Various experiments have been carried out within the last decades by two different scientific disciplines:

- Archaeobotany focuses on examining conditions that result in determinable remains with expected survivability (Boardman and Jones, 1990: Schneider and Raunjak, 1994, Gustafsson, 1999; Charles *et al*., 2015: Heiss *et al.,* 2020). Survivability, however, is difficult to model and open to biased interpretations.
- Biochemistry (pyrolysis research) investigates the general process of charring, independently from anatomical changes or survivability (Braatbaart *et. al.,* 2007; Braatbaart, 2008).

There is a general acceptance of temperature as a ruling factor. Temperatures between 200-400°C are suspected to induce a transformation process, in which carbon substitutes most organic compounds and may still retain much of the given anatomical structure. When heating is not suddenly stopped at this point it is followed by oxidation of all carbon.

There is no current consensus about factors such as exposure time (Märkle and Rösch, 2008) or the quantity of heating. This is the speed in which a certain temperature is applied. Braatbaart *et al*. (2007) divide into high heating rates HHR >100°C/min and low heating rates LHR < 10 °C/min.

Little debated is the availability of oxygen during the heating process. An abundance of oxygen causes carbon to volatilize as carbon dioxide (CO2) completely, but oxygen free heating cannot be assumed under household conditions.

Throughout the published investigations laboratory experiments in muffle ovens are predominant. Gustafsson (1999) burnt a model of a prehistoric house and focused on hearth experiments to show the effects on cereal and weed seeds. This led him to consider more natural conditions in charring experiments. Gustafsson also introduced soaking and mechanical treatments like floatation and sieving into discussions on survivability, which were added to by Tutusaus (2012).

Great variability in the effects of heating of different seed types is confirmed by all available literature. Even different cereals act differently in heat.

The numerous coexisting factors make it difficult to relate to the diversity of published data.

A suitable condition that creates definite high carbonisation with persistent anatomical criteria has not been described for any species. At about 250°C the botanical determination of the seeds is severely affected. However, carbonisation that has reduced proteins and polysaccharids to a minimum (excluding microbial and other damage) is not present before 310°C.

This is illustrated by the available data concerning einkorn wheat (*Triticum monococcum* L.) and emmer (*T. dicoccum* Schrank) (See Table 1). These two domesticates are regarded as the most heat-resistant cereals, as the damage caused by heating on other grains may start at even lower temperatures.

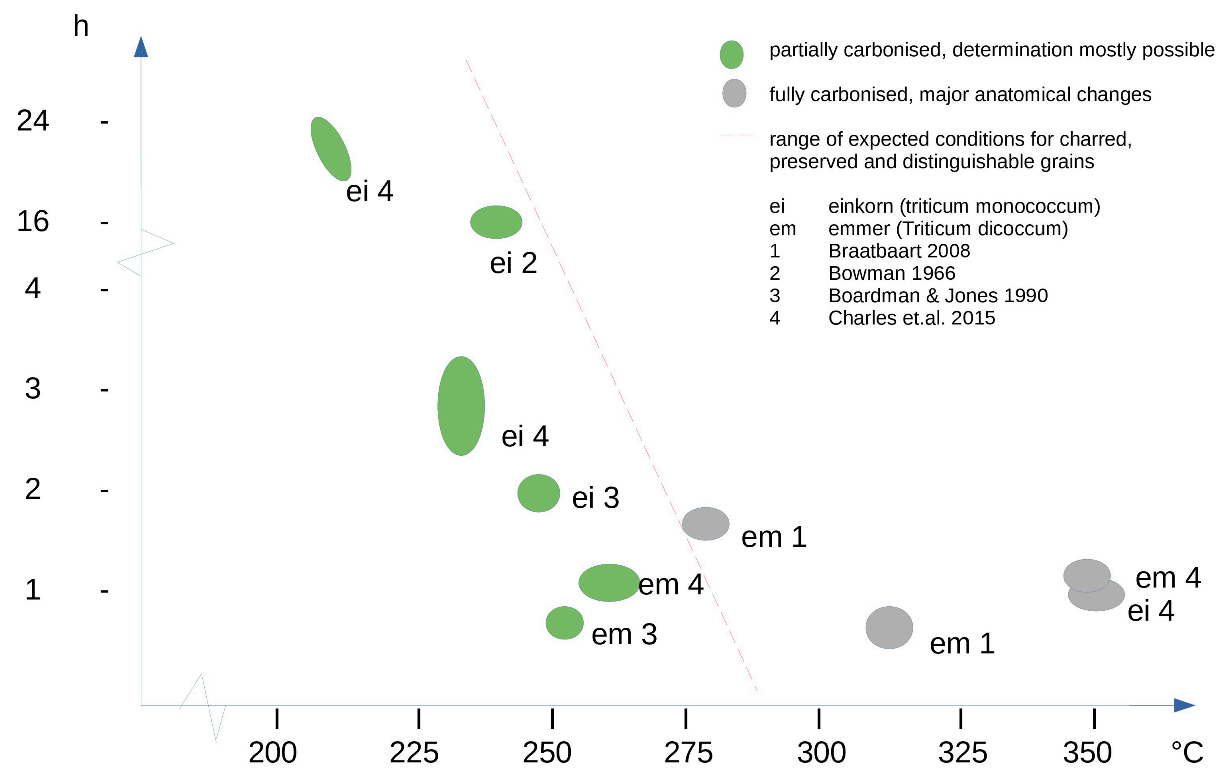

TABLE 1. PERFORMANCE OF EINKORN (*T. MONOCOCCUM)* AND EMMER (*T. DICOCCUM)* IN RECENT CHARRING EXPERIMENTS ACCORDING TO CITED LITERATURE.

Changes to the seed surface during heating, such as epidermal blisters have been noted (Braatbaart, 2008; Märkle and Rösch, 2008; Charles *et.al,* 2015), as has damage such as puffing, and cracks with protrusions on grains which have been heated at temperatures even below 300°C (Braatbaart, 2008; Stika, 1996). Even at low heating rates (LHR) the cracking of epidermal layers is accompanied by black protrusions of endospermic material which sometimes causes undefined clumps of grain (Tutusaus, 2012).

Braatbaart (2008, p. 161) has stated:

"It is interesting to note that no literature was found where grains recovered from archaeological sites are described showing protrusions, while in these carbonisation experiments in a preheated oven protrusions were rather common. "

Experimental charring under laboratory conditions has not successfully recreated carbonised cereal remains like those on prehistoric sites. Instead, it has created poor quality remains with features not observed in ancient contexts. The established hypothesis, that cracked, popped, fragmented or not fully charred grains are underrepresented because of their total decomposition currently has no experimental evidence. This has inspired the research presented here.

Material and Methods

The experiments recorded here are based on simple setups and kitchen techniques that are easy to reproduce domestically as well as under laboratory conditions.

All tested seeds were home grown during 2020 and consisted of local weeds and traditional cultivars belonging to species frequently reported from Neolithic sites.

Seeds of nine domesticates, two of them in different form, acorns of *Quercus robur* L. and seeds of four widespread weeds underwent a heat application. This was done for two groups, one in dry conditions and the other one germinated and redryed (See Table 2).

species dormant	species germinated	major protrusions % of all seeds	cracks and blisters % of all seeds	firmness charred	firmness after soaking	size change	pericarp separated %
Hordeum vulgare L. f. nudum		10	65	ft	c	>>	40
	Hordeum vulgare nudum	0	15	fn k	fn	>	10
Hordeum vulgare f. vulgare		0	75	ft	ft	>>	30
	Hordeum vulgare vulgare	0	25	fn k	fn	>	0
Triticum aestivum L..		5	25	fn	c	>	<10
	Triticum aestivum	0	0	fn	fn	>	0
Triticum dicoccum L.		0	20	fn	ft	>	15
Secale cereale L.		0	15	fn	fn	>	<10
	Secale cereale	0	0	k	fn	=	0
Pisum sativum L. f. arvense		0	50	k	fn	>	75

	Pisum sativum arvense	0	5	k	fn	=	90
Pisum sativum L. f. sativum		0	35	k	fn	>	70
	Pisum sativum sativum	0	0	k	fn	=	80
Papaver somniferum L.		0	0	fn	ft	=	?
Vicia faba L.		0	0	k+	c	=	90
	Vicia faba	0	0	k	k fn	>	90
Vicia sativa L.		0	20	k+	fn	>	90
	Vicia sativa	0	0	k	fn	=	90
Galium aparine L.		0	0	k+	k fn	=	20
Persicaria lapathifolium (L.) Del.		50	30	fn c	c	>>	-
	Persicaria lapathifolium	40	20	ft	fn	>	-
Fallopia convolvulus (L.) Á.L.		20	30	ft	c	>	75
Chenopodium album L.		20	40	ft	ft	>	10
	Chenopodium album	40	30	ft	ft	>	10
Vitis vinifera L.		0	0	fn k	fn	=	0
Quercus robur L.		0	0	fn k	fn	=	
	Quercus robur	0	0	fn k	fn	=	

TABLE 2. RESULTS OF CHARRING EXPERIMENTS 2020/2021.
C = CRUMBLES EASILY, FT = CRACKS UNDER FINGERTIP, FN = CRACKS UNDER FINGERNAIL, K = CRACKS UNDER KNIFE, K+ = CRACKS WITH PRESSURE ON KNIFE, = SEED SIZE STABLE, > SEED SIZE SLIGHTLY EXTENDED, >> SEED SIZE ~ DOUBLED

After slow cooling, all seed samples were soaked in cold water. The water treatment simulates the earth pit condition in a modest way as well as the floatation and sieving process during excavation.

The firmness and structure of the seeds were documented after charring and after the soaking procedure.

For the larger seeds (acorns, cereals, pulses) 20 kernels were selected, while the smaller seeds (poppy seed, lamb´s quarters, bedstraw) numbered between fifty and eighty. The effect of soaking has only been documented for the seeds that properly survived heating. Therefore the amount of investigated seeds in the second step (soaking) was reduced (which leads to the use of relative counts in Table 2).

Heat from a woodfire hearth was applied to shallow steel pans containing the seeds. The pans were covered with lids to provide a homogenous temperature. They were regularly shaken and agitated to turn the seeds. The procedure's end was defined by the change of seed colour to dark brown/ black. Because of seed size, surface and material the heating time varied considerably (3 min for *Papaver somniferum* L., 45 min for *Vicia faba* L.)

Naturally dark seeds (*Chenopodium album* L.*, Persicaria lapathifolium* (L.) Delarbre, *Papaver somniferum*) were heated until the first smoke rose, which marked the point of carbonisation in most of the other seeds. The hearth plates were kept slightly below gray heat (400 °C) so that the effective temperature in the panels was estimated between 250 °C and 350 °C, depending on seed size, shape and surface.

Additionally seeds of five domesticates (rye, *Secale cereale* L., wheat, *Triticum aestivum* L., medlar, *Mespilus germanicus* L., peas, *Pisum sativum* L. and grapevine *Vitis vinifera* L.) were fermented and stored as wet preserve in jars. After different periods the processes of transformation were documented and survivability issues were considered (see 5. Lactic acid fermentation experiments).

Results of Charring

A homogenous charring of all the kernels required special attention and was not imaginable as an accident. Complete data of the charring results is given in Table 2

Cereals

- Dry hulled and naked barley seeds (*Hordeum vulgare* L., *Hordeum vulgare* L. *f. nudum*) almost doubled their lateral circumference in the heating process, producing egg-shaped deformation with the typical ventral fold completely stretched. Popping occurred more often in naked barley but cracks, blisters and protrusions marked both formae dominantly (See Figure 1). The hulls kept a brown tint even on fully carbonised kernels. The endosperm structure of mildly charred seeds developed to a dense porous brown sponge resembling a popcorn consistency. The loss of firmness in heating was dramatic, with the popped and cracked seeds easy to pulverise between two fingers. The epidermis of barley seeds separated in blisters as transparent golden-coloured membranes. Sherds of this membrane were not detectable in the crumbled mash. The loss of weight was not measured but was evident. The soaking process of the carbonised seeds took several minutes before they sank. After soaking, all seeds crumbled easily when rolled between fingers, even those with intact pericarp. Fragments of the husks stayed detectable in the crumbled mash.

- Samples of hulled and naked barley were sprouted to the point of two to three radicles (about 3 days at 15°C). At this stage, the endosperm is soft and partly dissolved. It can be squeezed between fingers. The aleuron layer more than doubled its thickness but wrinkled in the following drying process. Before carbonising the samples were dried thoroughly. The resulting charred remains were less swollen and showed no cracks after heat application. In firmness, they exceeded those from the first test. They broke over a fingernail lengthwise or crosswise mostly in two halves. The hollow interior showed glasslike black ridges. Similar descriptions are found in sprouted barley charring experiments (Stika, 1996). Presumably the weakness of carbonised pericarp in the first test is due to interior pressure caused by gas expressed from the endosperm (as in popcorn).

The results given for barley are equally valid for wheat (*Triticum aestivum* L.), emmer wheat (*Triticum dicoccum* L.) and rye (*Secale cereale* L.) but in a reduced mode as expansion of the heated grain is lower than in barley. Wheat shows more swelling than emmer and rye, leaving the rye grains slightly harder. Cracks, blisters and protrusions were found reduced in number and expansion. The ventral fold was found opened or cracked but never stretched completely.

The increase in firmness of sprouted charred grain compared to just charred was less distinct than in barley.

Pulses

Fava bean (*Vicia faba* L.), both peas (*Pisum sativum* L. ssp*. arvense,* ssp. *sativum)* and common vetch (*Vicia sativa* L.) show great differences in size and form. Forage pea (*Pisum sativum* ssp. *arvense*) and common vetch (*Vicia sativa*) are nearly spheroidal.

Garden pea (*Pisum sativum* ssp. *sativum*) and fava bean (*Vicia faba*) do not roll and carbonise irregularly, the dents last.

The endosperm of all pulses is rich in proteins, which causes a nitrous smell during the procedure. The endosperm is very hard before heating and still hard afterwards (pressure on knife).

However, after 12 hours of soaking, the carbonised seed sank, both sprouted and dormant. This produced a disintegrating endosperm, which was at its most fragile in fava bean. Common vetch was found most durable, due to the thick testa, peas were intermediate. The garden pea with reduced testa acted similar to the fava bean.

The testa of all investigated pulses is not connated. It is sometimes shed even in the harvesting process, although more readily when heated, but sherds of it are durable at a minimum size. In the mash of black endosperm they are still detectable.

Tutusaus (2012) reported similar results for lentils (*Lens culinaris* Medik).

Poppy seed (*Papaver somniferum L.*)

Poppy is a domesticate of Mediterranean origin.

There was little difference between heated and non-heated poppy seeds. Only the colour changed to deep black and the comb-like seed structure was less elevated. The carbonized seeds could be cracked under fingernail pressure, whereas the soaked seeds were pulverized between fingertips.

This differs from the results in Märkle and Rösch (2008) where poppy seeds were mostly destroyed at 350°C. This might be due to a lower temperature in the presented case or different exposure times.

Whether charred or charred and soaked, poppy seeds long-term survival is rather improbable.

No sprouting was tested.

Grape seeds (*Vitis vinifera* L.)

The differences in firmness between pre– and post heating and even after soaking were minimal for grapevine seeds. No size change was observed, only the obligatory turning to carbon black. This might be due to the high lignine content of the pericarp that encloses a folded seed capable of buffering expansion during the heating process.

Acorns (*Quercus robur* L.)

Acorn finds are not solely related to agriculture as they occur on Palaeolithic sites. The use of acorns in historic human diet is often linked to times of famine and hardship. The high content of nutrients is protected by endospermic tannin. Various techniques to lower the bitter taste are recorded, including watering, sprouting and roasting. The charring experiments in acorns yielded very similar anatomical features and firmness in sprouted, non-sprouted and soaked samples.

It is still questionable whether the large and dense endosperm can be thoroughly charred to a durable condition.

Weeds

Unlike arable domesticates, weeds show great diversity in germination. The investigated sprouted weed samples always consisted of all stages from dormancy to full germination. That qualifies the information drawn from the sprouted samples.

Knotweeds (*Persicaria lapathifolia* (L.) Delarbre, *Fallopia convolvulus* (L.) Á.Löve)

Both species are closely related and accompany agriculture from neolithic times on. In Bronze Age excavations *Persicaria lapathifolia* is often found as a dominant grain in deposits, and as such it is suspected of domestication (Kirleis, 2002; Kroll, 2003).

The seed of *Persicaria lapathifolia* is biconcave to trigonal, the seed of *Fallopia convolvulus* is strictly trigonal winged on three edges. Both have a hard and shiny testa which allows a long dormancy in the ground.

Even though the seeds were dry, the gas emitted from the endosperm destroyed 40 % of the *P. lapathifolia* seeds and 20 % of *Fallopia convolvulus* completely by rupture. The testa of the latter is less sturdy and shows cracks early in heating. Sherds of its testa were easier to break after charring and crumbled after soaking. The non-cracked seeds of both were swollen just before bursting, showing protrusions at the cracks regularly. The typical form was changed to spheroidal (See Figure 2). *F. convolvulus* kept linear traces, where previously the winged edges had been. The charred remains were far from taxonomical identification.

Germination of knotweeds starts with the breaking of the top section of the testa, giving way to the sprout. When seeds are dried at this stage, the testa closes accurately fitting and cuts off the sprout. Thus germination evidence for knotweeds is more difficult to detect than for cereals.

Cracking and rupturing rates in sprouted *P. lapathifolia* were slightly reduced but still, most seeds lacked determination features after the procedure.

The typical outline of the experimental charred seeds differs to charred Bronze Age seeds (Kirleis, 2002). More similarities to the Bronze Age remains are evident in non-charred germinated seeds (See Figure 3).

Interestingly high numbers of rupture, testa sherds and indetermination are not recorded in archaeobotanical data for this species.

Lamb´s quarters (*Chenopodium album* L.)

Together with poppy seed, lamb´s quarters was the smallest seed investigated. *Ch. album* is an annual weed and after cereals the most widespread and frequent component in macro remain reports from the Neolithic period on (Elburg et al., 2012).

Heating produced a high percentage of destruction by cracking, whilst protrusions marked nearly all the rest. During the process a characteristic popping was audible.

Germination rate was low and firmness tests with these tiny seeds are not comparable to the cereal and pulses samples. Most of the carbonised sprouted seeds just pulverized between fingertips.

The regular appearance of *Ch. album* as a weed in prehistoric cereal finds cannot be explained by a single charring process of those mixed samples. The cereal charring conditions would have destroyed the weed completely.

Bedstraw, Cleavers (*Galium aparine* L.)

Bedstraw - another of the most familiar early weeds – generates epidermal hooks on the hollow follicle seed. They are the first to be burnt in the heating process. All archaeobotanical reported seed remains of this species are found in this uncoated state. But mechanical treatment causes the same effect.

The seed size of this species did not change at all in the heating process. Tensions of the endosperm were completely compensated by the hollow seed, as the swollen endosperm inside indicated.

Bedstraw seeds – despite their hollow open form - are very hard. The charred remains still maintained much of this firmness.

Summary of experimental charring

The presented charring experiments yield a high variability in seed condition and firmness depending on species and sample treatment. Regarding cereals, this variability conforms to the results of Boardman and Jones (1990) and Gustafsson (1999).

Corresponding to Charles *et al*. (2015) and Tutusaus (2012), the main groups (cereals and pulses) revealed some very fragile seed conditions in which dramatic anatomical changes were evident. This fragile condition is also documented in Gustafsson (1999), who lost much of his charred material from the house burning experiment in the process of watering and sieving. Site reports with frequent deformations as mentioned are exceptional. Buschan (1895, p.255) cites a clump of charred matrix that must have consisted of wheat grains from Bronze Age Lobositz/Lovosice (Czechia). And a still more definite case of charred grain was unearthed inside a destroyed Vinča dome repository from 4600 BC Selevac (Serbia). Here a vast mash of distorted and pulverised charred grain contained a minor proportion of reliable emmer grains and achenes (Hopf, 1975).

Charring experiments with sprouted cereals were previously carried out by Stika (1996) to confirm malting. Much of his results are confirmed by the presented results. Additionally, it was possible to compare non-sprouted to sprouted seeds in which the latter showed better conditions for long-term preservation.

The soaking of the charred remains considerably reduced firmness in most species.

The good conservation of charred barley, fava bean, knotweeds and Lamb´s quarters seeds as reported from Neolithic sites is particularly conspicuous. The experimentally achieved thermic deformation of the named species, testified by Charles *et al.* (2015) and Stika (1996), is not documented in archaeobotany.

Analytics

At present, there is no standard to verify *charred* as a conservation process in archaeobotany.

The following methods are recommended for verification and as a standardized procedure:

- Microscopy is universally used for the determination of macro-remains. Besides this, it proves germination by identification of missing embryo and separated scutella[1] . Furthermore, cross-sections of seeds show different endospermic structures according to conservation methods, specific temperature applied and other factors.
- Vitrinit reflexion analytics is used in organic petrography to detect heat impact. Reflectance of light is positively correlated to the temperature involved in the process of carbonisation. This effect was suggested for analytics in pyrolysis research of recently charred macro-remains (Braatbaart *et al.*, 2007). Applied to archaeological plant remains it may help to detect firing events. Recently charred barley and wheat from the presented experiments were investigated at TU Bergakademie Freiberg /Germany[2] and showed: ‚*…definite signs of thermic impact. The average reflectance of the wheat sample was 0.396 in oil, whereas the value for the barley sample was even higher showing 0.694 in oil, corresponding to temperatures of 326°C for wheat and 390°C for barley. Average reflectance of recent non-treated plant material is about 0,2 to 0,25 in oil. However, due to the porosity and thin-walled nature of the samples examined, the number of measuring points required in accordance with the standard was not achievable. Rather, only individual values could be obtained. Thus, a reduced representativeness and statistical reliability of the measurements can be assumed, even if an initial estimate of the reflectivity is given based on the measured data.'* (Gerschel, pers.comm, 2022; Gerschel, 2016, p. 246 ff.)

Lactic Acid Fermentation experiments

Introducing processes and agents

Lactic acid fermentation is a natural process used globally by humans in food preparation and storage even before sedentism (Vinderola *et al.*, 2017) and in compost reprocessing. It is not entirely separable from alcoholic fermentation in early food processing (Rosenstock and Scheibner, 2017).

Ida Hahn (1935), drew attention to the relevance of this technology in ethnology and archaeology.

She concluded the fermentation of grains, as of any raw food, is a cultural heritage from hunter-gatherer economies and described Neolithic grain-filled pits as fermentation pits (Hahn, 1935, p. 260).

Comparable to cooking, lactic acid fermentation works as a process of external digestion, reducing the effort of chewing and stomachic energy.

This transformation is performed by several heterotrophic bacteria, known as lactic acid bacteria (referred to subsequently in this paper as LAB) under merely anaerobic conditions, turning saccharides and carbohydrates as starch into lactic acid, in lesser quantities into methane and alcohol. Lactic acid is the metabolic product of this process. It is a simple organic acid, solid below 17°C and less exposed to evaporation than water (Lumitos AG, 2021). Its antimicrobial properties cannot be solely explained by lowering the pH value, but rather by the occurrence of bacteriocine metabolites as phenolic compounds (Scheinemann *et al.,* 2015). Even at pH values above 5, most of the investigated decaying bacteria and fungae vanished. This is underlined by the use of lactic acid salts as registered food preservatives.

One case of fermented food from historical earth pits in the South Pacific was found to remain edible even after 300 years (Steinkrauss, 2009). Current examples of fermentation involving lactic acid, besides the well-known Sauerkraut and its versions, are sourdough, olive fermentation, kimchi (Korean pickles), wine and fruit processing, composting and contemporary biogas reactors.

This study focuses on examples of cereal treatment. LAB fermentation of sourdough usually begins with a starter culture of flour and water. Grinding is essential to make the starch available to the bacteria. Whole grains are protected by the seedcoat (aleuron) and create a great chance of failure in fermentation. An appropriate way to start safe fermentation without milling is germination. In this process, starch is transformed into saccharides and the swollen embryo breaks the seedcoat. The permeable pericarp offers immediate growth of the LAB.

According to Hahn (1935, p. 272) and Neuweiler (1905 p.28) a loss of the embryo is frequently reported from prehistoric cereal finds. This indicates germination as claimed for macro-remains by Stika (1996).

The positive effects of lactic acid on long-term conservation of food only mark a first step in the life of several thousand-year-old pits. Many climatic and terrestrial changes such as flooding, erosion, vegetation, drought and ice affected their further condition and transformation. These impacts on the superficial layer of the earth are investigated in soil science and related studies.

In soil science, lactic acid is not regarded as of great importance. It occurs impermanently in the decomposing process of organic compounds, for example in the aerobic topsoil. Enduring presence only occurs under anaerobic conditions as in buried topsoil. The acidity of such organic matter (pH value) lowers its decomposition rate but again is only persistent in anaerobic conditions (Scheffer and Schachtschabel, 1992, pp. 54-61). The term *buried humous topsoil* is a good description of the black pitfill that indicates most prehistoric pits. Very slow decomposition rates are suspected.

Composting experiments reveal the low mass loss and higher persistence of structural material such as lignin for LAB-induced decomposition. Among the metabolites, a high number of aromatic carbohydrates such as polyphenols can be traced (Hildebrand, 1979). Their ability to transform further organic matter into permanent humids and so enhance humus concentration is documented (Gao *et. al.,* 2016).

Permanent humids are characterized by extremely large and diversified molecules, chemical stability and their dark colour (Scheffer and Schachtschabel, 1992, p. 54).

Especially the process of generating humids draws attention to lactic acid fermentation in recent discharge treatment investigations (Golling, 2008; Andreev, 2017).

From this perspective, dark humid compounds colouring persisting organic structures in mere anaerobic conditions is typical for lactic acid-induced humification also named cold carbonisation

Experiments

Three samples with various LAB fermented ingredients were stored and controlled over a fix timespan (See Table 3). In all samples the initial phase was carried out at 18°C for two weeks as used in many sauerkraut recipes. At this time the release of gas ended and the jars were stored in the dark at 12 to 15 °C.

sample	basic ingredients	further ingredients	Control after 6 weeks	Control after 13 weeks	Control after 14 months
1	wheat, sprouted	*(Persicaria lapathifolia L.)*	seeds fully preserved;	seeds fully preserved;	Seed outside preserved;
	rye, sprouted	knotweed, sprouted	liquid milky, dimmish	grains close to surface tanned	more grains darkened,
	water, salt (NaCl 2%)			liquid cloudy beige	endosperm mostly dissolved,
					liquid of intensified tan
2	wheat, soaked 24 h		seeds fully preserved;	seeds fully preserved;	seeds fully preserved, edible;
	fava beans, soaked 24 h		liquid dimmish	liquid dimmish	endosperm partially preserved
	water, salt (NaCl 2%)				liquid dimmish
3	wheat, sprouted	after two weeks: wet compost soil	seeds fully preserved	cereals, grape seeds	stages of white mould and rotting; cereals detectable, although

	rye, sprouted	grape seeds *(Vitis vinifera L.)*		and cores darkened,	shrivelled and blackened, endosperm dissolved,
		medlar cores *(Mespilus germanicus L.)*		outside preserved	grape seeds and medlar cores blackened, preserved

TABLE 3. STORAGE EXPERIMENTS WITH LAB FERMENTED SAMPLES 2021/2022

The first sample consisted of just cereal grains covered with salted water. The grains remained preserved and distinguishable over 14 months. Within this time a change in seed colour emerged in the top layer of the jar. The colour resembled charred cereal grains and was permanent after rinsing and slightly brightened after drying (See Figures 4 and 5).

Cross-sections of seeds showed a dissolved endosperm. The white liquid drained from the interior and left the bran empty. In the drying process, the seed coat was completely preserved and the inner liquid evaporated so that only a white inner coating remained.

A second sample consisted of 24-hour soaked wheat and fava beans. The preservation of this sample was even better, retaining colour and edibility with a typical sour taste. The cross-section of the wheat grains showed a solid endosperm which showed a sponge like consistency when dried. Whether the fava beans or the non-sprouted state of the ingredients result in the optimum preservation needs more testing.

To a third sample of sprouted and fermented wheat and rye grapeseeds, cores of medlar (*Mespilus germanicus* L.) and wet compost were added, allowing fermentation to continue. This sample was not fully anaerobic due to pores in the compost section. After six weeks at 12°C, no change in seed colour was observed. But after 13 weeks some wheat and rye grains placed just beneath the surface darkened remarkably in the bran.

After 14 months the cereal grains all showed similar dark colouring, some were flattened and shrivelled by a white mould attack but still bearing typical features. The grapevine pits and the medlar-cores showed a remarkable coal-black all through the seed coat without any further transformation.

Cross-sections of all agents revealed the same partly dissolved endosperm as with the first sample.

In all samples, the fermented grains were preserved and distinguishable over documented time. Depending on sprouting duration and fermentation conditions the endosperm of cereals was facing transformations starting with porous material and slight weight loss continuing with white dissolved endosperm culminating in total disappearance. The superficial colour of some grain types was affected after months due to complex biochemical transformations that did not damage the superficial structure of any of the investigated seeds. The evolving dark colour is interpreted here as initial humification.

Similar changes in colour are known to anybody familiar with the making of sauerkraut. When the barrel is not properly covered or stored under warm conditions for too long the uppermost layer is wasted by tinting, disintegration and mould.

Domestic approach to fermentation

In the modern economy, the knowledge of food preservation by fermentation is declining. Cookbooks rarely present more than recipes. some basics may help to approximate the process.

- The concentration of lactic acid in the preserve depends on the number of available saccharides and suitable carbohydrates, temperature, hindering and beneficial additives and the efficiency of the bacteria.
- Raw plant material with low content of saccharides might be preserved by adding fruit juice, malt, or sugar (as in ensilage for animal feed). The germination of cereals transforms starch into saccharides of smaller size which are effective in the preservation of additional foodstuffs such as leaves, stalks, and tubers.
- Inhibiting LAB fermentation might be desirable as regards taste or prevent further nutritional loss. Many pulses act as fermentation inhibitors. That is why cereal samples with weed vetch pollution (*Vicia* L. spp.) yield only poor sourdough. On the other hand, a skilful combination of cereals and pulses may be beneficial to the result.
- Added salt (NaCl, K2CO3 and others) increases fermentation and lactic acid content. LAB are halotolerant up to 5,5%. Without added salt, only a few plants leaves (such as cabbage) ferment to a durable preserve (Schöneck, 1981).
- LAB also converts malic and citric acids and even tannins into mild lactic acid as in red wine processing (malolactic fermentation), LAB fermented European cornel (*Cornus mas*), crab apples (*Malus sylvestris* Mill., *Malus domesticus* Borkh.) and Acorns (*Quercus* spp). Authors recipes are available on demand.
- Further disintegrating metabolism such as mould on the surface is inhibited by phytochemicals from plants such as wormwood (*Artemisia absinthium* L.), mugwort (*Artemisia vulgaris* L.), horseradish (*Armoracia rusticana* G.Gaertn et.al), milfoil (*Achillea millefolium* L.) and tannin- and terpene-containing leaves of trees and shrubs such as olive (*Olea europaea* L.), grapevine (*Vitis vinifera*), juniper (*Juniperus* L. spp.) cherry tree (*Prunus avium* L.) and others. These plant's purposes were exploited throughout many parts of Europe.

Discussion

Site reports

Once the possibility of prehistoric seeds conserved by fermentation is accepted, the uniformity of the current interpretation is opened to a variety of processes associated with food preparation. The knowledge of these technologies connects prehistoric pits to ethnological documented practice and domestic routine. The following site reports will illustrate that:

- Popovtschak, Heiss and Thaneiser (2017) published about Hanfthal, a small settlement dating to circa 200 BC Lower Austria. Two pits with high concentrations of *Panicum milleaceum* L., *Hordeum vulgare* and *Triticum* spp. as well as a bronze saucepan with similar content were classified as dumps of charred food. Many of the seeds lacked embryo and scutellum. On the other hand, a high number of separate scutellae was documented. Lack of embryo and separate scutellae indicate germination. To char germinated grain a thorough drying is inevitable. But even then the scutellae would be burnt first, followed by the small *Panicum* seeds and barley and wheat last. Only in a fermentation pit, all ingredients are preserved in one step without any fire. The outline of the Hanfthal pits was rather uneven, which is not beneficial for a long-term conservation. These pits may represent shallow processing pits that were not emptied. Whether the final destination of the fermented grain was a preserve or a beer remains uncertain. The author supposes that finds of equally charred seeds of different sizing or grouping (cereals, sprouted cereals, pulses, weeds, chaff, glumes) are not likely to be the result of the same charring process and require a very distracted prehistoric worker.
- High concentrations of cereals along with halves of crab apples (Malus sylvestris) were reported from a Schussenried culture pit (circa 4000 BC), at Baden Württemberg, Germany (Piening, 1992). Even though not all grain was completely charred it was preserved. This combination was interpreted as accidental waste from a drying process. Nevertheless, the precise charring of such mixture by chance seems a sheer singularity. A similar pit content was reported from another Schussenried culture pit in nearby Hochdorf Baden Württemberg, Germany (Piening, 1992). There it was interpreted as a drying rack which had been burnt down. Moisture content, size and harvest time offer hardly any reason for drying or firing of apples and cereals at the same time. But if this mixture is taken as a lactic acid fermentation to lower tannic acid in crab apples no unlikeliness remains. In an allegedly ancient Russian recipe, called pickled apples in rye, this mixture survives to the present day (Fitze, 2018).
- A similar case of side-by-side conservation of fleshy plant tissue and dry seeds is reported from a Mesolithic pit in Scotland, where tubers of figwort (*Ficaria verna* Huds.) and acorns (*Quercus* spp.) were found blackened and interpreted as charred (Bishop, Church and Rowley-Conwy, 2014). The idea of mixed fermentation again is less unlikely than hunter/gatherer communities dumping waste of burnt tubers and seeds of very different size, harvest time and consistency in pits.
- The botanical macro-remains from Neolithic wells in Saxony/ Germany are unique in quantity and quality. More than 640.000 remains of almost 200 taxa were documented (Elburg *et al.,* 2012). The log-constructed wells of several metres in depth do not remind

one of fermentation pits. In backfilling them large amounts of organic matter, foodstuffs, other plants and artefacts were used for as yet unknown reasons. It is irritating that most of the cereal and pulse grains were found charred, whereas the vast majority (> 98%) of all weeds, other domesticates and chaff/glume remains were reported uncharred. Why are uncharred cereals and pulses absent in aquatic conditions that would have conserved them properly? Was the fermentation of cereals a basic principle in this economy and processed grain was transferred from the fermentation pits to the wells?

- Modelling the genesis of aquatic conservation of charred seeds in lakeside dwellings (*Pfahlbausiedlungen*) faces difficulties because of charred seeds' floatability in water. The experimental soaking to the point of sinking lasted several minutes to several hours. During this time the seeds are exposed to drift and wind, especially in troubled water of supposed house burning. Notwithstanding this, charred remains are a regular part of clustered cultural layers at the bottom of the seas (Neuweiler, 1905). Still more interesting is the observation of Hosch (2004) from Neolithic Bodensee (Switzerland), where the ratio of charred to uncharred seeds was more than ten times wider for cereals than for all other seed types. This observation corresponds to the results from the Saxon wells mentioned above (Elburg *et al.,* 2012). Why was the charred grain of barley and wheat so frequent compared to all other charred domesticates? A selection for fermentation purposes is reasonable, a selection in a charring process is not.

DNA extracted from charred seeds

Much of what is known about the genesis of domesticated grain plants is based on ancient DNA (aDNA) analysis from charred and desiccated prehistoric remains (Nistelberger *et.al.,* 2016). Detections in charred cereals were repeatedly successful (Ciftci *et al.*, 2019) and in charred pulses (Jovanovič *et al.*, 2011).

On the contrary, different experiments with historical and recently charred material of domestic plants showed the impossibility of detecting DNA from them (Fuller, 2018; Lundström et al., 2018; Lempiäinen-Avci et al., 2020).

The suggested analytics to prove charring are recommended in this discussion.

Fermentation pits and ethnology

Whereas archaeologists still discover new prehistoric pits, the practice of pit fermentation in current indigenous communities has declined or been lost (Atchley and Cox, 1985, Macintyre and Dobson 2018). Substantial ethnological documentation is limited to the late nineteenth-century and early twentieth-century research. Such food pits were common knowledge among hunter/gatherers and isolated pre-metallurgic tethered communities throughout tropical and temperate regions on all continents except Europe (Schweinfurth, 1875; Hambruch, 1915; Hahn 1935).

Most of the documented communities only incorporated small groups. According to this the documented pit size was mostly defined as household level, which is well below 1m³.

In most field studies the food from these pits was not found integrated into everyday use. A long-lasting pit preserve from birth to adulthood or to the marriage of a child was frequently reported (Hambruch, 1915). Archaeological indications highlight seasonal and special occasions connected to feasting on preserved foodstuffs (Barnard *et al.,* 2001, Hamilakis and Sherratt, 2012).

The source plants of the preserved food were often not part of the daily diet, and in many cases were toxic when eaten raw (Hahn, 1935; Guerra-Doce, 2015). That is true for many tropical plants which are not even registered as domesticates. The fermentation process is essential for many of them to let them nourish the community. In temperate Europe, digestability is found increased by fermentation in most of the cabbage family (*Brassicaceae* Burnett), buttercup family (*Ranunculaceae* Juss.), onion family (*Liliaceae* Juss.), nightshade family (*Solanaceae* Juss.) and many mushrooms as indicated by inherited fermentation recipes.

Pits and burials

Sometimes prehistoric pits are used for burials. Karamitrou-Mentessidi *et al.* (2012) report on a Neolithic child burial amidst grain in Greece. Similar cases from Linearbandkeramik pits are reported. This might express more than a gift for the dead. If a fermentation pit is created in relation to the birth of a child, it is strongly bound to its fate and well-being as reported by ethnology.

Whether this correlates to a more abundant practice from the Bronze Age documented from excavations throughout Central Europe in Urnfield cultures (Hofmann, 2008; Griebl and Hellerschmid, 2013, Hellerschmid, 2015, Landesdenkmalamt Sachsen-Anhalt, 2015), Únětice/Aunjetitz and Knovíz cultures (Koutecký, 1990) is not answered yet. During this time burials or deposition of animal and human corpses in larger dry storage pits (see section 1 of this paper) were rather common but mostly lack the presence of grain.

The full depth of the pit

Even though no analytics on prehistoric macro-remains have been carried out yet the necessity to do so might be enforced by the perspective of the presented material.

It has become clear that the dominance of cereals in prehistoric macro-remains must not be taken for the dominance of a cereal-based diet in general. The practice of pit fermentation which may have caused the survivability of many prehistoric seeds is ethnologically and archaeologically described as an occasional food source. Additionally, in most documented cases pit stratigraphy limits grain to a defined layer in the bottom part of the pit. The major portion of the pits is filled with black humous material. This section is normally classified as refilled topsoil (Knörzer, 1967). How settlements could provide abundant amounts of such material is not to be dicussed here, but the humous content derives from decomposed organic material. Leaves, stalks and tubers are plant parts which decompose best.

This might indicate the full recipe of prehistoric fermentation pits. Large amounts of vegetables could have been fermented with the help of a layer of cereals (See Figure 6). This 'mother of fermentation' provided the food for the LAB to conserve the pit content and meanwhile was best for survivability. Even though clean and dehusked cereal layers of a single cultivar are reported from some pits, cereal mixtures, husked emmer, spelt and sorghum were found common as well. After the extraction of starch from the endosperm the husked grains might not have been valued as food itself.

I hope to have revived the interest in the hypothesis of mixed fermentation in prehistoric European earth pits and in its "…*multitude of plants*" still unknown (Hahn, 1935, p.273).

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1 part of the seed's epidermis that is shed during germination

2 The mean reflectance value (R0) was measured using the LEICA DM 4000 P research microscope coupled with the spectrometer system of A.S. & Co. GmbH. The system represents a permanently mounted unit consisting of a Carl Zeiss AG photospectrometer and a control unit for the directly mounted photomultiplier measuring head (CZ-CCD sensor). In addition, the microscope has a variable field diaphragm to shield the measuring spot from diffuse ambient light. The measurement is controlled by the SpectraVision software. This includes the independent optimization of the instrument combination to the prevailing brightness conditions or intensity values of the specimen, as well as the independent compensation of the system's own dark current combined with a digital suppression of the electronic noise. The calibration of the system was carried out using suitable reflection reference materials of Klein and Becker GmbH & Co. KG. According to ISO 7404-5:2009-10, 100 vitrinite particles randomly selected and uniformly distributed over the section should be measured to form an arithmetic mean (ISO 7404-5:2009-10, Methods for the petrographic analysis of bituminous coals and anthracite – Part 5: Method of determining microscopically the reflectance of vitrinite).

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Gallery Image

FIG 1. COMMON FEATURES (SWELLING, LOSS OF VENTRAL FOLD, CRACKS, PROTRUSIONS) OF NAKED BARLEY (H. VULGARE F. NUDUM) IN RECENT CHARRING. PHOTO BY LUTZ ZWIEBEL

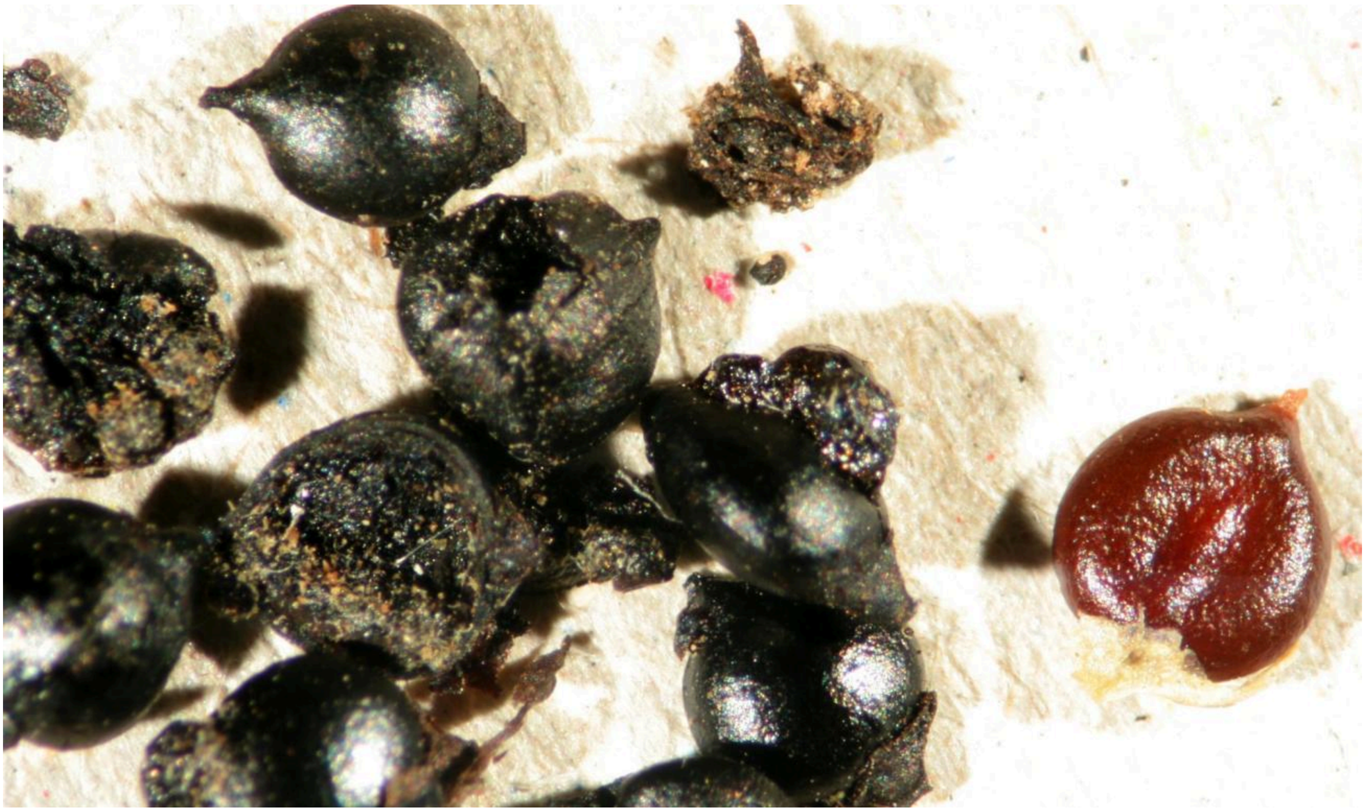

FIG 2. RECENT KNOTWEED SEEDS (PERSICARIA LAPATHIFOLIA SSP. PALLIDA) CHARRED (LEFT) AND NON-CHARRED (RIGHT). PHOTO BY LUTZ ZWIEBEL

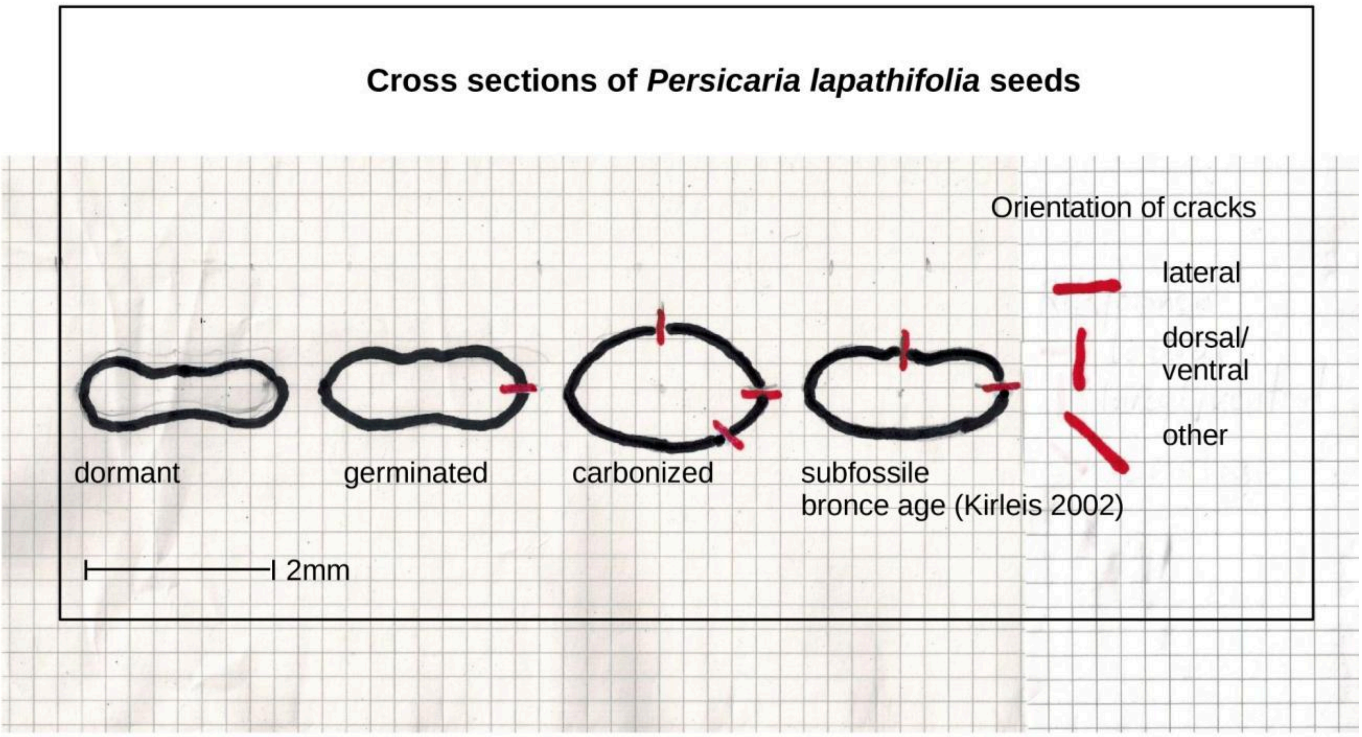

FIG 3. OUTLINES OF DIFFERENTLY TREATED KNOTWEED SEEDS (PERSICARIA LAPATHIFOLIA). PHOTO BY LUTZ ZWIEBEL

FIG 4. NAKED BARLEY (H. VULGARE F. NUDUM) DORMANT (LEFT), LAB FERMENTED AND PARTIALLY HUMIFIED AFTER 14 MONTHS (RIGHT). PHOTO BY LUTZ ZWIEBEL

FIG 5. SUPERFICIAL SIMILARITIES BETWEEN CHARRED GRAINS (ABOVE) AND COLD CARBONISED /HUMIFIED, 14 MONTHS AGED GRAINS (BELOW) OF RYE (SECALE CEREALE) AND WHEAT (TRITICUM AESTIVUM). PHOTO BY LUTZ ZWIEBEL

FIG 6. MODERN MIXED FERMENTATION SETUP USING SPROUTED WHEAT, RED BEETS, APPLES AND LEAVES OF DANDELION, NETTLES, LAMB´S QUARTERS, TURKISH WARTY CABBAGE, GRAPEVINE AND OTHERS. PHOTO BY LUTZ ZWIEBEL