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Distinguishing ripe spelt from processed green spelt (*Grünkern*) grains: Methodological aspects and the case of early La Tène Hochdorf (Vaihingen a.d. Enz, Germany)

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ABSTRACT

The practice of harvesting green grains is known worldwide and, although it implies a higher investment of labour than collecting them ripe, it presents some advantages such as the possibility to extend the harvest time or to secure one year's crop yield in case of, for instance, bad weather close to ripening. However, the presence of green-harvested cereals in archaeobotanical assemblages has so far never been studied. No previous work has been carried out on how charring affects the size of grains with different degrees of maturity or of immature grains that underwent different processing activities prior to charring. The main aim of the present study was to observe kernel morphology of modern ripe and unripe spelt (*Triticum spelta* L.) grains and apply the results to the archaeobotanical remains retrieved at the early La Tène site of Hochdorf (Vaihingen a. d. Enz, Germany), where an archaeobotanical assemblage of charred spelt grains, apparently in different stages of maturity, was found. In order to discriminate these two maturity stages within one cereal species, modern specimens of ripe spelt and *Grünkern* have been charred and compared. The results of this experiment have allowed us to confirm the coexistence of spelt grains in different degrees of maturity in the early La Tène Hochdorf assemblage. Similarly, ethnographical information on modern *Grünkern* production provided information on the details of the processing of unripe spelt and the human choices to produce it.

1. Introduction

Drying, parching and roasting were in the past and still are common and widespread methods of processing cereals and pulses. Either as part of dehusking, as a preservation method, or before cooking or preparing them for consumption, many examples of this practice can be found worldwide (Peña-Chocarro, 1999) (see Fig. 1). Harvesting and parching of unripe cereals is also well known, as in the case for instance of wild rice (Anderson, 1978); naked wheat: *freekeh* (Al-Azm, 2009); or spelt wheat (in Slovakia, Markus, 1989 and in Germany, Miedaner and Longin, 2016). The harvesting of green grains offers significant advantages for the communities that practice it. In the first place, it is a means to secure parts of the harvest in regions with short and wet summers. Secondly, it starts the harvest time one month earlier than usual when stored supplies from the previous year are about to run out. Thirdly, green grains may have different nutritional characteristics such as a higher content of proteins (Anderson, 1976; Takruri et al., 1989; Huebner et al., 1990). In addition, parching and roasting alters taste and appearance, which is to say that the organoleptic properties of the grains are modified. This may change their consideration, rendering an emergency food into a culturally appreciated one and leading to new culinary preferences.

The parching of green cereals has been approached from different points of view, such as ethnography (e.g. Schwenkenbecher, 1949; Anderson, 1978; Peña-Chocarro, 1999; Cappers, 2018), food technology (Anderson et al., 1979; Bayram, 2008) or archaeology (Hubbard and Al-Azm, 1990; Al-Azm, 2009). However, it has not been identified in archaeological material before now. This paper represents a first attempt towards a methodology for the distinction between ripe and unripe spelt grains that could be applied to archaeobotanical assemblages. For this

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purpose, a charring protocol was designed to prepare the comparative materials for the present paper (Berihuete-Azorín et al., 2019). By observing morphological differences between ripe and unripe spelt and their changes upon charring, this new methodological tool is capable of identifying unripe spelt grains in archaeological deposits for the first time. The main objective was to document which morphological criteria of spelt grains is able to distinguish between unripe spelt (from here on *Grünkern*) and ripe spelt, and to apply these criteria to the archaeobotanical material recovered at the early La Tène site of Hochdorf. The possibility of identifying this practice archaeologically may help to interpret aspects of past labour organization and its social implications.

The detailed ethnographic observation of current practices helps to understand past preparations based on unripe cereal grains. For this reason, our study included the ethnographic recording of modern unripe spelt processing in the Bauland region, Baden-Württemberg, Germany. The current production of *Grünkern*, a special food made of spelt harvested while still unripe and then artificially dried to ensure preservation, provides the opportunity to observe the operative chain and obtain comparative material for each productive step.

1.1. Current ethnobotany of Grünkern production

Grünkern is traditionally produced in the Bauland region in the north-east of Baden-Württemberg (Germany) (Fig. 2). In this region, weather and soil conditions are suitable for growing spelt. Bauland and Schwäbische Alb are the main regions where spelt is currently cultivated in Europe. The Bauland region is even popularly known as the "homeland of *Grünkern*", for whose production a protected variety of spelt is grown: the "Bauländer Spelz". *Grünkern* has been produced there at least from the 17th century onwards (first written reference cited in Nüske, 1977). A series of small museums scattered across the region give details of its production, such as special tools or work organization. These museums are the Museum in der Grünkerndarre (Walldürn-Altheim), the Odenwälder Freilandmuseum (Walldürn-Gottersdorf), the Tauberländer Dorfmuseum (Weikersheim) and the Heimatverein (Boxberg). Moreover, some farmers are still producing *Grünkern* under almost preindustrial conditions.

In order to obtain the material for the experimentation and to understand the different processing stages involved in *Grünkern* production, we collaborated with Mr. Armin Mechler, a farmer from Walldürn-Altheim. Mr. Mechler's family has cultivated spelt for decades, including for the production of *Grünkern*; having participated in this process since his childhood, he is an inexhaustible source of information. We accompanied him for a full agricultural year during the main tasks involved in spelt cultivation and *Grünkern* production. For further information about the details related to spelt kiln drying, we collaborated with Mr. Jürgen Stäzler, from Rosenberg-Sindolsheim (Fig. 2), who has performed this activity in a traditional roasting installation for decades. We gained valuable ethnobotanical information on the processing of green cereals from both of them.

Because the ethnobotanical record concerning cereal cultivation and processing in Germany is poor, it is especially important to preserve the details of traditional *Grünkern* production. Historically, *Grünkern* production was performed on a small scale with a series of specific tools, buildings, practices and devices, before it became intensified and industrialized during World War II and in the second half of the 20th century. Large special kilns were built from the second half of the 19th century onwards, aimed exclusively at the production of *Grünkern*. Other special tools were used. Spelt harvested for *Grünkern* was reaped by a sickle at a low height, and the thin straw bunch was tied in a bundle, the *Hämpfele*. The *Reffe* was a wooden box with a rake. The bundles of cereal culms with the ears attached were passed through the rake, so that the ears broke off from the culms and fell into the box while the straw remained in the hand (Fig. 4a). The ears then were dried in the special kilns.

At present, production is mechanized and the unripe spelt grains are no longer parched in traditional kilns, but in much larger installations, shared by several farmers or directly in industrial dryers. Notwithstanding, the knowledge of traditional *Grünkern* production is shown and preserved thanks to small-scale dissemination activities such as the *Grünkernfest* organized by the Odenwälder Freilandmuseum, where Mr. J. Stäzler displays the traditional parching method (s. Fig. 4b) which he has learned from his parents. Other outreach events are the "*Grünkern* Familydays" in Altheim, organized by Armin Mechler, with whom we recorded the different steps in the *Grünkern* production.

1.2. Roasting

Due to the extremely short shelf-life of green harvested crops, unripe spelt must be processed immediately. For instance, in the summer of

Fig. 1. World distribution of crop parching: triangles = unripe crops; dots = ripe crops.

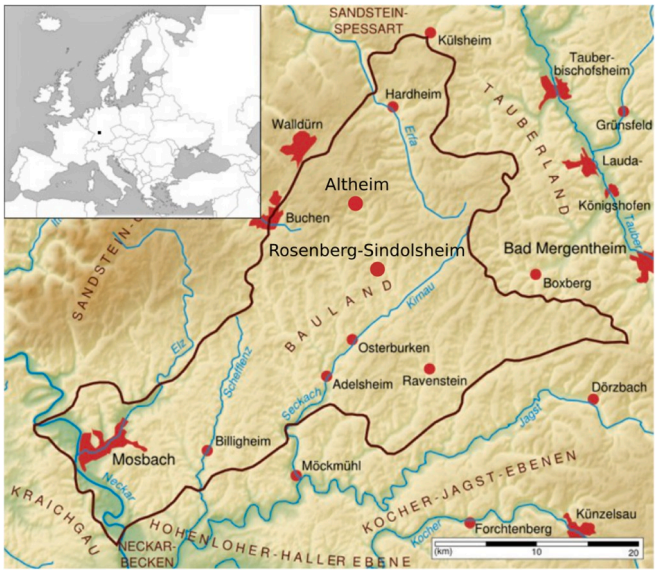


Fig. 2. Map of the "Bauland" region in Germany (Meynen, E. & J. Schmithüsen 1953). (Hrsg.) Handbuch der naturräumlichen Gliederung Deutschlands. 2 Bde. *Bad Godesberg*,https://en.wikipedia.org/wiki/Bauland#/media/File:Karte_Bauland_physisch.png.

2017, the spelt harvested by A. Mechler to produce *Grünkern* had a water content of ca. 42% of the total weight. Without any treatment, those grains would be affected by mould within a few hours and, therefore, they rapidly have to be dried artificially to allow storage and further use without any quality loss. Formerly, the full carts were immediately brought from the fields to the traditional roasting kilns (Fig. 3) where all members of the community (including children and elderly) worked day and night roasting the green cereals. At that time, due to the harvesting technique, the grains were roasted within the whole ears. Currently, mobile harvester-threshers reap the cereals and, in one work step, separate straw and single spikelets, which are then carried to the mechanized kilns. In the Bauland region, these roasting buildings still operate with natural smoke, quite often produced with fires of beech wood. The ownership of these facilities is rather similar to the past ownership of the traditional *Darren*. They are private but used by relatives and neighbours who share the harvesting and roasting tasks.

Thanks to J. Stäzler, we had the opportunity to observe how the roasting of green spelt took place, prior to mechanization. He roasts over one metric ton of unripe green spelt per year in a traditional kiln (Fig. 4b). In the summer of 2017, when we accompanied him, he roasted around 1280 kg.

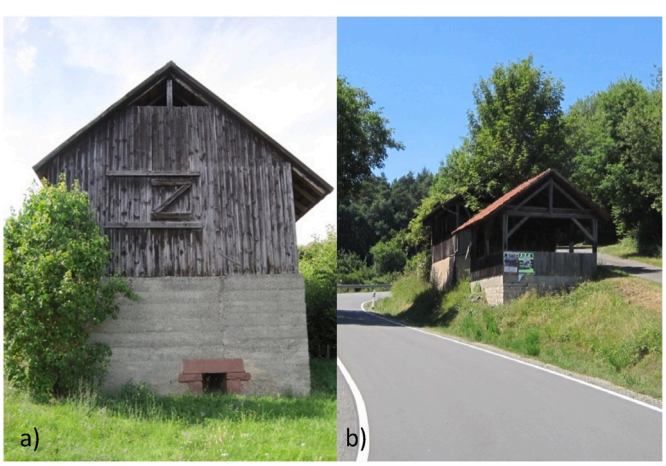


Fig. 3. Traditional *Darre* in a) Altheim and b) Rosenberg-Sindolsheim.

The farmers deliver the grains in spikelets. The kiln is heated with beech and oak wood, species that are locally available and provide good heating properties (as well as a pleasant aroma). When the temperature reaches around 170 °C, the first grain load is deposited. For each load, 13 baskets of ca. 40 l volume are added to each roasting tray (see Fig. 4b). The spikelets are then distributed evenly with the aid of a wooden rake. Around 15 min later, the spikelets are turned and after another 15 min, the fires are fed again. This is an operation which requires a great deal of experience, since the person in charge of the kiln controls the power and temperature only by means of feeding the fire more or less or turning the hulled grains more often when it becomes too hot.

After 4–5 h, when the spikelets have changed their colour from green to a golden hue (Fig. 4c), and 7 of every 10 spikelets are already soft, the hulled grains get packed in fabric sacks with the aid of a special shovel. The sacks will be put together at the side of the *Darre* and roasting will finish inside as the spikelets slowly cool down, before being taken to the mill in the next days or weeks for further processing.

In this case, the kiln-drying operation is carried out by two persons, who are occasionally assisted by friends and family that pass by the *Darre*, bringing food to the workers, having a chat with them or drinking a beer together. People gather at night accompanying the persons in charge of the roasting as a special social event. In the summer of 2017, Jürgen, together with his friend Lutz, roasted around 16 fillings of the *Darre*. The tray of the kiln becomes a measurement unit in this case, and equals around 80 kg.

1.3. Milling

Currently, the roasted spikelets are brought to a modern mechanized mill to dehusk them and to mill them partly, since *Grünkern* is sold whole and/or shredded. Both modalities are highly appreciated and utilized in different recipes.

1.4. Distribution and consumption

At present, *Grünkern* is sold in the whole of Germany, typically at organic markets and small grocery shops, but also in some big supermarkets. However, this broadly distributed *Grünkern* is quite different from the type being discussing here. Current *Fränkischer Grünkern*, with

Fig. 4. a)Demonstration of use of the Reffe; b)Mr. Stäzler roasting in his traditional kiln; c)roasted (left) and fresh (right) unripe spelt spikes.

its certificate of origin, is produced only from one spelt variety (*Bauländer Spelz*) and roasted in a more traditional way, even at the mechanized kilns. The result is a much more intense aroma and a characteristic colour of the grains. Before the 1970s, *Grünkern* was very rarely eaten. However, thanks to the organic food movement, which brought a new appreciation for old foods, historical cereal species, such as spelt, and ancient preparations such as *Grünkern*, new interest was aroused. In fact, many of the *Darren* in Rosenheim were built then, or at least restored and put into use again. It was a prosperous era for some farmers. However, as the organic food movement expanded and production standards were regularized, the farmers were required not only to produce *Grünkern* in a traditional way, but also to cultivate the spelt under the strict regulations of organic agriculture. That marked the end of the golden age of conventional *Grünkern* production, and most of the roasting buildings were abandoned and partly collapsed. The organic cultivation of *Bauländer Spelz* still continues but on a smaller scale than conventional production.

2. Materials and methods

2.1. Experimental charred grains

The material used for our work, sourced by A. Mechler, consists of spelt grains of the *Bauländer Spelz* variety, sowed in October 2016. The fresh unripe grains were harvested on 6th July 2017 and the ready to store *Grünkern* was produced from them the following night and day. The 2017 ripe spelt was harvested three weeks later. After a series of charring experiments (see Berihuete-Azorín et al., 2019), we selected the grains charred in an oxidising atmosphere at 230 °C for 12 h, because they displayed a good balance between the degree of charring and minimal deformation, making them ideal for comparison with the well-preserved grains from the archaeological Hochdorf site. Under these optimized charring conditions, we did not detect any visually obvious differences between the grains charred in the spikelet and the dehusked ones. Shape changes between hulled and naked grains produced by charring are related to the initial degree of moisture, and result in a drop-shaped grain (Jacomet, 2006) when they contain a high degree of humidity before charring.

For morphological characteristics, modern uncharred and charred ripe spelt as well as *Grünkern* grains were observed and photographed under a Wild Photomakroskop M 400 with Zeiss AxioCam Erc5s and processed with Helicon Focus software, while the archaeobotanical finds were photographed under the same Photomakroskop but using an analogue Wild Photoautomat MPS 55. For anatomical aspects and differences, SEM (Zeiss DSM 940) was used after sputter coating with gold/palladium in a Balzers SCD 040. Since no previous work comparing ripe and unripe spelt grains has been published, the grains were observed microscopically, noting differences in size and form of the aleurone layer, as well as differences in the general appearance of the endosperm cells and the quantity/disposition/appearance of starch grains. At the macroscopic level, general appearance, as well as form, size and position of the embryo were observed and recorded. Total length including embryo but without the hairs; length without the hairs and without embryo; breadth; and height (Fig. 5) of 100 ethnographically collected grains were measured (see results in Table S1).

The spelt for *Grünkern* was harvested ca. 3 weeks before the ripe spelt, when the grains were still in the milk-ripe maturity stage. The nutritional values of both spelt and *Grünkern* were analysed at the Core Facility of the University of Hohenheim (Germany).

2.2. Archaeological materials

Between 1978 and 1993, the archaeological excavations in Eberdingen-Hochdorf (close to Vaihingen a. d. Enz, Germany) uncovered an elite grave in a large-sized burial mound (Brestel, 2019) from late Hallstatt Period (late 6th century BC) as well as a settlement (Biel, 2015) dated to the early La Tène Period (5th/4th century BC). During these excavations, archaeobotanical samples were taken from the grave (Körber-Grohne et al., 1985) and from the early La Tène settlement (Stika, 2009). After analysing the settlement samples, Stika proposed that cereal processing had possibly been performed in a special way at the Hochdorf settlement. Within the assemblage of the pit house "1505/1", Stika separated two different morphological groups of spelt grains: normal-looking ones and unripe-looking ones, which were smaller and slenderer than the "normal" spelt grains and their embryo was not as long and well developed as "normal" ones. That led Stika to suggest that the latter could represent grains that were harvested when still unripe. The assemblage is a mixed sample which contains chaff, oil seeds, pulses, gathered wild fruits and weeds, but consisted mainly of cereal grains. While 72% of the grains were determined as spelt, *T. monococcum* grains represent 21% (for a detailed list see Stika, 2009: 262 ff, the relevant sample under the old label of H42 – 1501/1/30; the

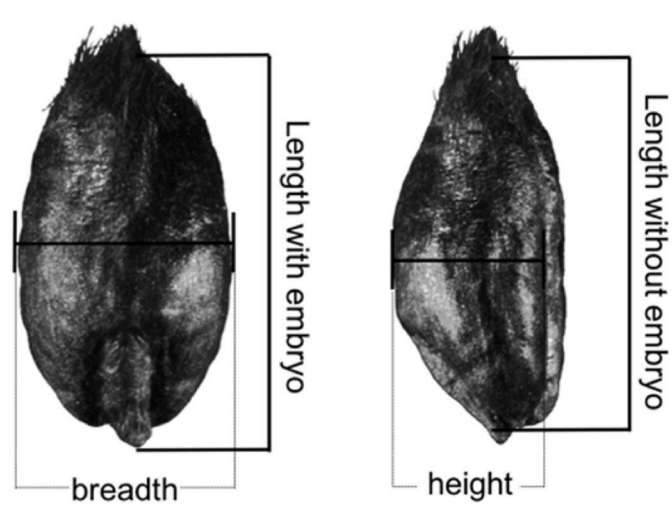


Fig. 5. Diagram showing the different measurements taken for each grain.

new sample number is 1505/1). These two species could have grown together in one field. Spelt grains were a mixture of the abovementioned normal-looking ones, which were dominant in this sample, and slender ones, which were less frequent.

From this assemblage, 50 grains classified as spelt-like and 50 as *Grünkern*-like by Stika (2009) were selected, measured and photographed, and then compared to the experimental material. Since the embryo was missing in many of the archaeological grains, the length of the grains was observed in the lateral view, from top to bottom of the grain, without taking the embryo into account (see Fig. 5).

3. Results

3.1. Experimental material

Grünkern displays a more homogeneous breadth along the whole grain, which gives it a slender appearance. In contrast, the maximum breadth of ripe spelt is clearly visible in its lower half, which grants it a more rounded look. The apex of spelt grains tends to be pointed, whereas in *Grünkern* it is flatter. The differences in size and position of the embryo in the non-charred state are characteristic for most grains. In the case of *Grünkern*, the embryo is shorter and normally does not exceed the perimeter of the grain (see Fig. 6).

Regarding deformation, under the heating treatment applied in our experiments, charring affected ripe spelt and *Grünkern* grains differently. Whereas the first puffed and became much rounder than uncharred ones, the latter maintained more or less their original proportions (Fig. 7).

Regarding the measurements of the experimental charred grains, *Grünkern* grains with embryo are significantly shorter than spelt grains (Graph 1). However, if we take only the length without embryo into account, then it is not possible to discriminate ripe and unripe spelt (Graph 1) by means of the length.

However, the length/breadth ratio is significantly different between the two types of charred grains, with as well as without embryo (Graph 2).

The factor that is determining this difference is the breadth of the grains, which is significantly different between the two maturity stages (Graph 3). In fact, the differences that already exist in non-charred material, as explained above, are exacerbated by charring, since spelt deforms more than *Grünkern*, the latter remaining closer to the corresponding uncharred grains.

When observing the endosperm of the experimental grains under SEM, only very slight differences were noted regarding the general appearance. They are seen above all in the starchy endosperm. In uncharred ripe spelt grains, starch granules appear quite close to each other (Fig. 8a); in fresh, non-parched unripe spelt, starches look rounder and have more empty space around them (Fig. 8b); in uncharred but parched *Grünkern* (Fig. 8c) starch grains appear contracted and are distributed even tighter than in the other two states. However, since most archaeological material (including the materials discussed below) is recovered in a charred state, these observations are not helpful for the remains being studied here, but they show the effects of the drying process on the *Grünkern* starch appearance.

Regarding the changes suffered by the endosperm when charred (12 h at 230 °C), no significant differences can help us to discriminate between ripe and unripe maturity levels in spelt grains. In the case of *Grünkern*, the aleurone layer seems more compact than in ripe spelt (Fig. 9). Moreover, starch granules seem to gelatinize more in ripe spelt

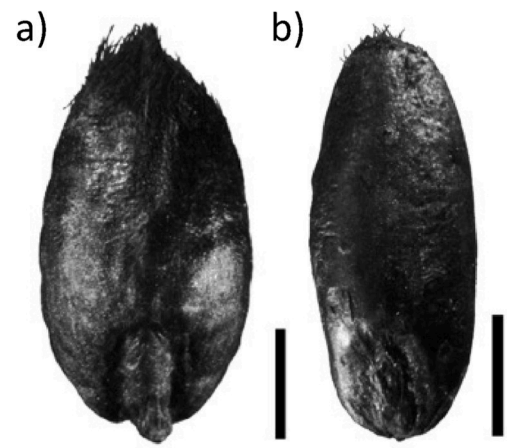
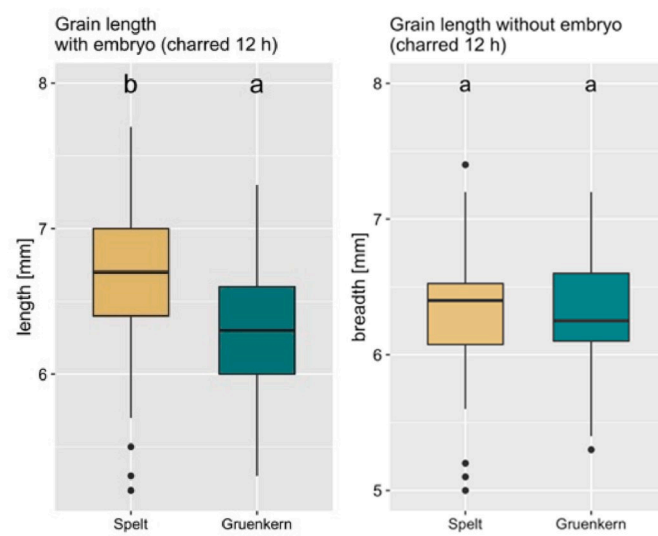


Fig. 7. General grain shape of charred grains (dorsal view): a) ripe spelt; b) *Grünkern* (12 h at 230 °C). Scale = 1 mm.



Graph 1. Comparison of grain length with and without embryo in charred ripe spelt and *Grünkern* (12 h at 230 °C). In the case of the grains with embryo, the letters a and b indicate a significant difference between the means ($p < 0.05$, HSD Tukey post-hoc test).

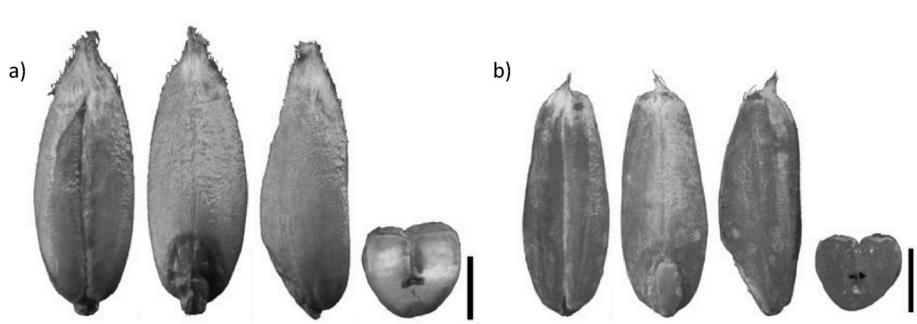


Fig. 6. Ventral, dorsal, lateral and section view of typical grains of ripe spelt (a) and *Grünkern* (b). Scale = 1 mm.

grains than in *Grünkern* grains, likely owing to the higher water content of the former (Fig. 10).

Finally, the differences in the nutritional values of the two types of grains are non-significant for all the measured values, with only slight differences in water content and practically the same quantity of protein, fat and carbohydrates in ripe spelt and *Grünkern* (Table 1).

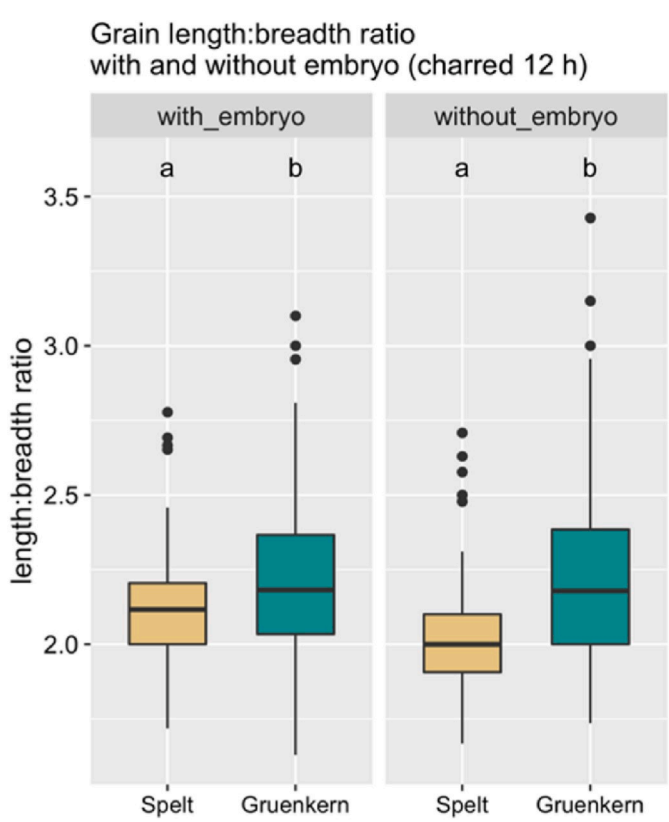
3.2. Archaeological material

The archaeological grains were measured (see results in Table S1) and the data was analysed in the light of the results obtained from the experimental material. As seen in the previous section, the criterion that revealed differences between the two degrees of ripeness is the breadth of the grains. Regarding the archaeological materials, the differences are likewise significant (Graph 4), allowing the two grain types to be discriminated.

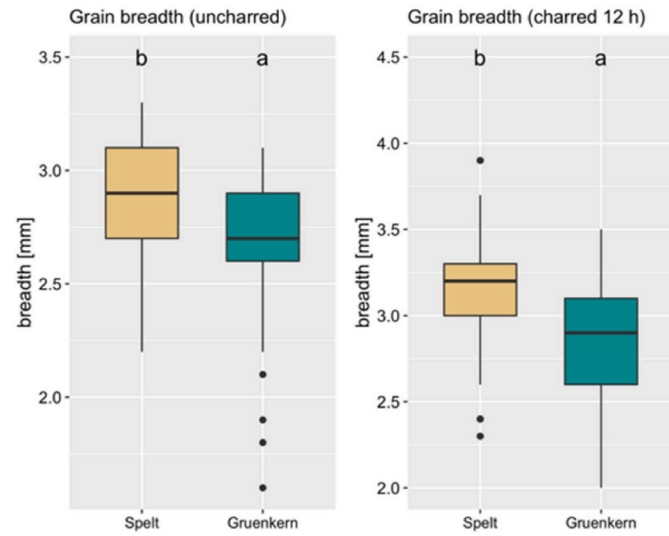
When exploring the endosperm of the archaeological grains under the SEM, the endosperm did not display measurable differences between the two kernel types. The main discriminating factor in the experimental material, the starch granules, was not preserved (Fig. 11).

4. Discussion

Based on the results obtained from the modern ethnographic and experimentally charred material, it is possible to distinguish between uncharred ripe spelt and *Grünkern*, as well as between charred ripe spelt and charred *Grünkern*, when charred under the same regime. The observation by SEM was not able to detect distinct diagnostic features of the endosperm cell anatomy that might help to distinguish ripe spelt from *Grünkern*, especially since the only slight difference applies to the starch granules which were not preserved in the archaeological grains.



Graph 2. Length/breadth ratio with and without embryo for charred ripe spelt and *Grünkern* (12 h at 230 °C). The letters a and b indicate a significant difference between the means ($p < 0.05$, HSD Tukey post-hoc test).



Graph 3. Comparison of grain breadth between uncharred and charred ripe spelt and *Grünkern* (12 h at 230 °C). The letters a and b indicate a significant difference between the means ($p < 0.05$, HSD Tukey post-hoc test).

When the embryo can be measured, charred spelt grains are significantly longer than *Grünkern* ones (see Graph 1). However, in archaeological assemblages, we often find that a considerably proportion of the grains is preserved without the embryo. The differences in length without embryo are no longer significant, and therefore, this criterion would be relevant only for very well preserved grains.

At the beginning of this research, it was hypothesised that the length/breadth ratio might be the determining factor to differentiate between grains of ripe spelt and *Grünkern*. While it is possible to discriminate spelt and *Grünkern* grains using this ratio, since the length, especially without embryo, is almost the same, the crucial factor is the breadth, and thus the sole use of this parameter is enough to separate both stages of maturity in the experimental material. Since we have shown that breadth discriminates ripe from unripe spelt, a similar result would be expected in the two types of archaeological spelt grains from Hochdorf.

Moreover, this decisive parameter enabling differentiation between ripe and unripe grains, the breadth of the kernels, is further enhanced by charring (Graph 3) and, in consequence, it is an adequate criterion to establish the distinction between the two degrees of maturity. According to our experiments, it seems that ripe spelt grains are more susceptible to swelling than *Grünkern* ones are during charring. This characteristic could be due to the kiln drying of the unripe grain during *Grünkern* preparation, a process that probably contributes towards stabilizing the anatomical structures of the grain kernel. As a result, the differences between ripe and unripe spelt are easier to observe in charred than in uncharred grains.

This parameter also discriminates well-preserved archaeological remains. In the histograms of the size allocations within the assemblages (Graph 5), a bimodal distribution can be observed, which is further proven by the significance of the Shapiro Wilk normality test, indicating a non-normal distribution. This means that, although some bias may have been introduced when sorting the grains into the two categories by subjective human appreciation, the coexistence of two types of grains is verified. In spite of overlapping, breadth measurements of the archaeological materials showed differences leading to two distinct groups, one with breadth ranging between 2.2 and 3 mm in the case of *Grünkern*-like grains and another between 2.7 and 3.6 mm in the case of "ripe" spelt (Table S2). The differences could also be observed qualitatively as similarities are seen between the two groups in the archaeological spelt grains and the modern, charred ripe and unripe spelt grains (Fig. 9).

Notwithstanding, it should be pointed out that in order to use this

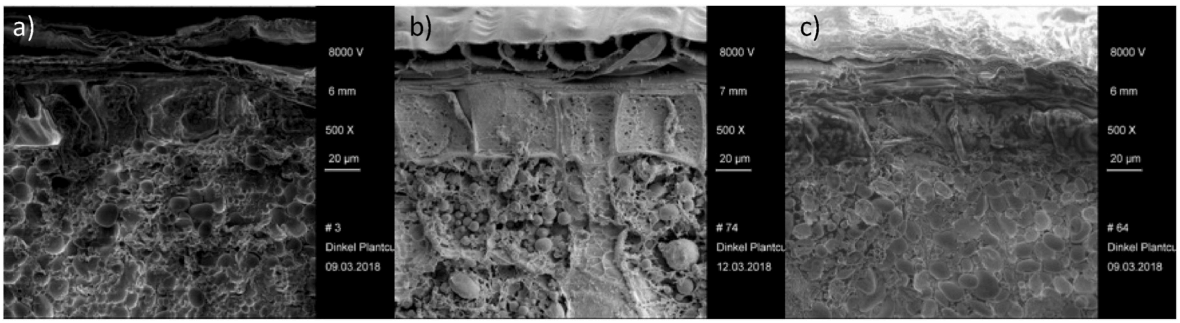


Fig. 8. SEM micrographs of non-charred grain endosperm appearance of a) ripe spelt; b) unripe non-parched (fresh); c) parched *Grünkern*.

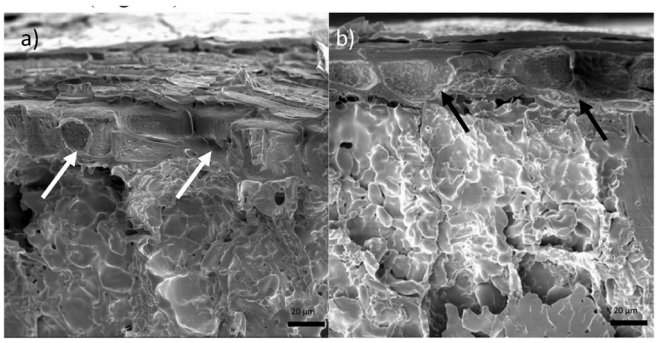


Fig. 9. SEM micrographs (8000 V, 500x) of cross section of charred ripe spelt (a) and charred *Grünkern* (b), with visible aleurone layer and starchy endosperm. Arrows point to the aleurone layer.

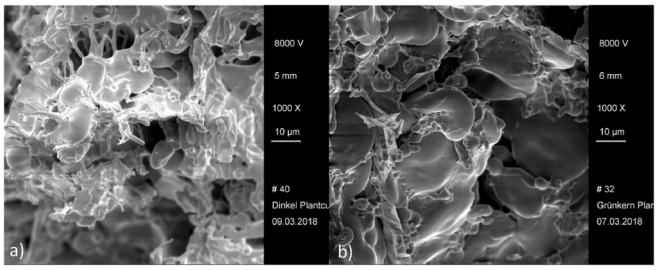


Fig. 10. SEM micrographs of starch granule appearance in charred ripe spelt (a) and charred *Grünkern* (b).

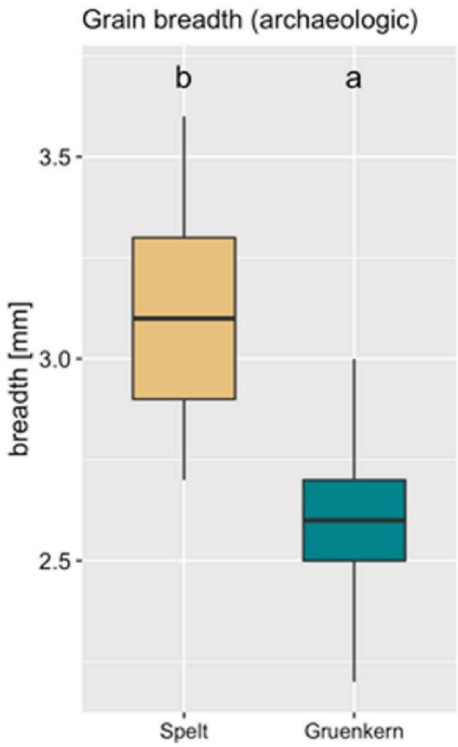
criterion, the grains in a large enough assemblage must display clear features allowing them to be assigned to one category or the other. The main feature is the general shape of the grain for the cases in which the shape and position of the embryo are not observable (Fig. 12).

When dealing with different grain species, the measurements alone are not sufficient to help distinguish the taxa (e.g. spelt and emmer) within archaeological samples (Reed et al., 2019). In spite of recent advances in this matter (e.g. Wallace et al., 2019), it is also still not possible to separate two landraces within one cereal species with measurements alone. Therefore, although the sorting and separation of archaeological grains by a trained researcher, combined with the measurement of the grain size, allows the identification of two sub-populations (ripe spelt and *Grünkern*), as visible in the bimodal pattern of the histograms discussed above, individual grains cannot be classified into any of the sub-populations exclusively based on biometric criteria because of the overlap that exists.

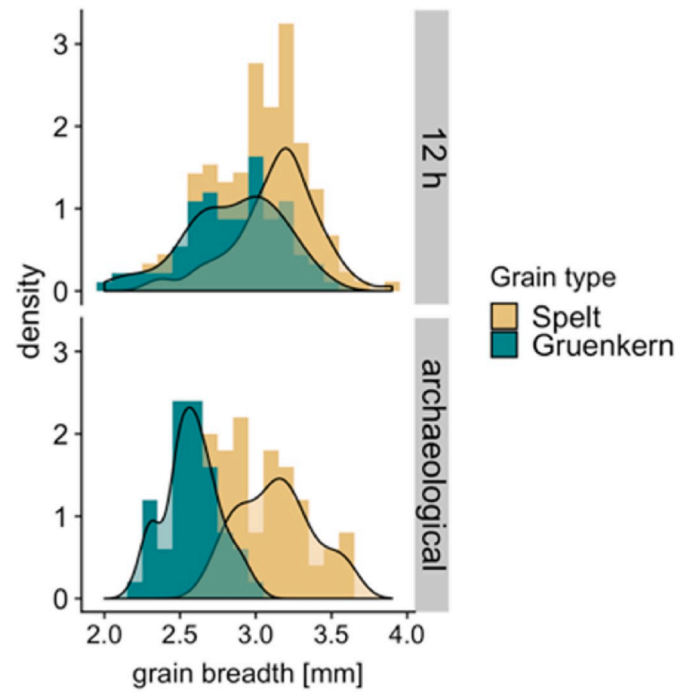
Table 1
Nutritional values of ripe and unripe spelt.

Cereal preparation	Water [%]	Ash [%]	Protein [%]	Fat [%]	Fibre [%]	Carbohydrates [%]
Ripe spelt	10.1	1.8	14.9	3.1	2.0	61.1
Grünkern	9.6	2.0	15.0	2.9	1.9	58.7

Our last point concerns the nutritional values of ripe and unripe spelt, which do not display significant differences. Being aware of differences in the quality of the proteins available in ripe and unripe durum wheat, used for the preparation of another meal based on unripe wheat: *freekeh* (Takruri et al., 1989), we considered possible differences which could have influenced the preference towards one or the other ripeness states. Although other studies have found differences regarding the nutritional components of ripe and unripe spelt (Kraska et al., 2019), these affect mainly the micronutrients. Regarding the values of the macronutrients, the evidence does not support one of the original hypotheses: that the preference of *Grünkern* rather than fully ripe grain might be due to different nutritional composition. No differences are observed in the total values of the analysed macronutrients between ripe and unripe grains, but a different composition of amino acids cannot be excluded. Great variability has been found in components as regards the



Graph 4. Comparison of the breadth between the charred archaeological spelt-like and *Grünkern*-like grains. The letters a and b indicate a significant difference between the means ($p < 0.05$, HSD Tukey post-hoc test).



Graph 5. Histograms showing a bimodal distribution of breadth sizes of charred grains that correspond to two different groups within a given assemblage (experimental, above, and archaeological, below).

spelt variety and cultivation conditions in general, as well as soil quality and manuring regimes (Miedaner and Longin, 2016). The stable isotope analysis of the assemblage studied here and recovered from Find 1505/1 showed that spelt was manured moderately while hulled barley was manured heavily. This has also been established as a habitual practice at other contemporaneous prehistoric sites in Southwest Germany (Styring et al., 2017).

4.1. The assemblage in context

The experimental data generated and analysed here have shown that the *Triticum spelta* assemblage recovered at Hochdorf represents two different degrees of grain maturity. The clear presence of two different groups of grains recovered from the same sample at the site points towards the deliberate harvesting of green as well as ripe cereals. The charred grain assemblage was found in a sunken floor house (Fig. 13), filling a precise rectangular pit dug in the centre of the structure (in yellow). Three hearths were also documented inside the same building. All this together shows the plausibility of the processing of green cereals at the site. Within the assemblage, ripe and unripe grains were found together with other plant remains (e.g. einkorn grains and chaff remains). If the structure was used for the storage of staples, these remains may correspond to different storage episodes, which would explain why ripe and unripe grains appear together. At Iron Age Celtic sites, pit-houses are dwelling structures, which were used at the same time as workshops (e.g. weaving houses) and for food storage, since they maintain a uniform cool and moist indoor climate: in winter warmer and in summer cooler than outside. For some pit-houses, silo pits are adjacent with access from the house interior (Biel, 2015). As other authors point out for structures identified as "corn driers" (van der Veen, 1989; Nesbitt and Samuel, 1996), these may have possessed more than one function. Precisely, the pit-house discussed here presents spatially separated features of different activities, with finds of web looms indicating textile production and evidence of grain processing/storage.

However, for this particular case, it seems less likely that it was used for middle/long term grain storage, since hulled wheats are generally stored in the ears or in spikelets, and then dehusked in small quantities as needed for daily use, particularly in wet climates of northern Europe (Nesbitt and Samuel, 1996). That is the case even today, since the chaff protects the kernels against fungi and pests. Thus, either it was a structure where small quantities of grain were stored for relatively

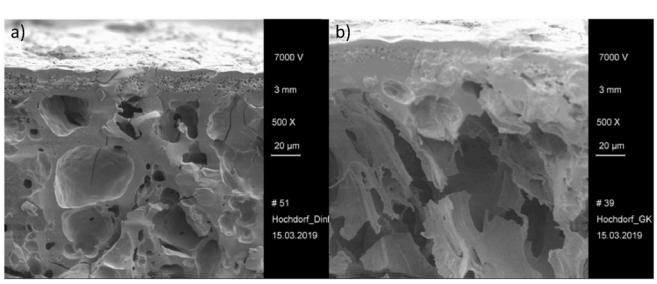


Fig. 11. SEM micrographs of the appearance of the endosperm of charred archaeological spelt (a) and *Grünkern*-like grains (b).

Fig. 12. Charred grains of a) experimental ripe spelt and b) experimental *Grünkern*; c) archaeological spelt and d) archaeological *Grünkern*-like grains.

immediate consumption, or other activities related to grain processing were taking place in this specific pit-house. Therefore, although it is possible they were charred while stored, these grains may have been carbonised during processing: while drying, while dehusking, or while cooking (and then deposited in the pit).

On the other hand, even when still covered by glumes during charring, the assemblage does not necessarily show large amounts of carbonised glume remains. Glumes might have burnt into ashes while the grains remained in a charred state, as was detected in the LBK site of Hilzingen "Fosterbahn" (Kreis Konstanz) (Stika, 1991).

All in all, we cannot be sure of the reason that led to the harvesting of the spelt before being fully ripe. However, it can be assumed that the inhabitants of Hochdorf were aware that unripe grains require immediate processing in order to avoid post-harvest losses during storage. The necessity of processing the unripe cereals in a short period of time directly after the harvest implies a large workload. This requires the capacity of mobilising assistants and rapidity before the unripe grains start to decay.

As mentioned above, the harvesting of cereals when still green is a well-known phenomenon and may respond to a diversity of causes. It might have been a way to acquire cereal food one month earlier than the usual harvest time to compensate for the depletion of the stored grains from the year before; a method to secure the crop in a year of adverse climatic conditions; or even a culinary preference that led the Iron Age

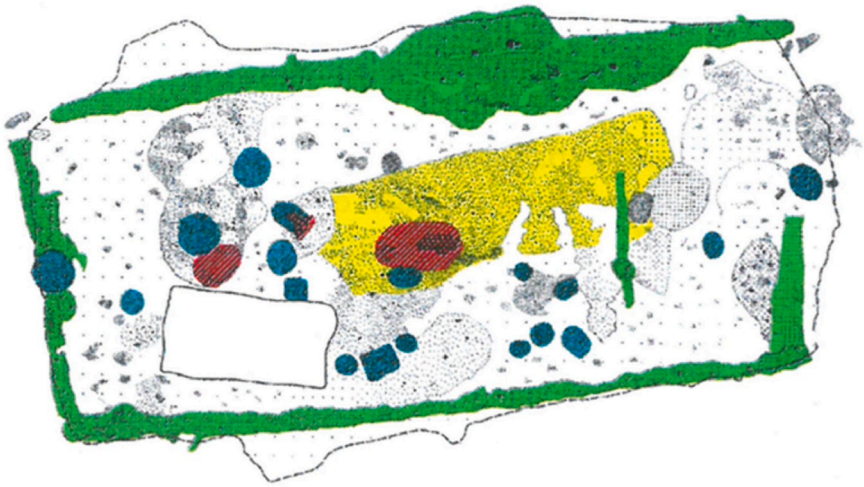


Fig. 13. Plan of the pit-house (Find 1505/1) where the studied assemblage was recovered. The hearths are shown in red; the yellow rectangle represents the contemporary deepening within the sunken house (©Landesamt für Denkmalpflege im RP Stuttgart). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

inhabitants of Hochdorf to harvest spelt when still unripe. Whatever the motivation, the unripe cereals had to be rapidly processed to avoid any yield losses, since they cannot be stored unprocessed. Consequently, an extra investment of labour was necessary. Whether the use of unripe spelt is a risk-minimising strategy in wet summers; a workload-sharing strategy enabling a longer harvesting time window; or a question of special taste and preferred dishes, it requires particular crop-processing activities.

5. Conclusions

Using experimental charring, we have demonstrated that charred grains of ripe spelt and *Grünkern* differ in morphology and size. We have considered only one landrace of spelt, so therefore cannot exclude the possibility that different landraces might yield different results. However, it is significant that within the same landrace, clear differences were observed between charred ripe and unripe spelt.

As experimentation showed, charring may have dramatic consequences regarding grain deformation and thus difficulties in subsequent identification. Nonetheless, under perfect experimental charring conditions, the morphometric differences increase and allow differentiation between unripe and fully-ripe harvested spelt grains. Based on these observations, we have been able to confirm that the differences in shape and size detected in the archaeological assemblage of spelt grains found at the La Tène period Hochdorf site indeed correspond to two different stages of grain maturity.

We consider the method that we have tested is a reliable way to assess the presence of two different degrees of maturity. However, the possibility that computer-assisted image processing, assessing morphometric features like shape (e.g. ovoid vs. ellipsoid), would increase the power of the classification, still needs to be tested. The identification of unripe harvested spelt in Hochdorf suggests that the inhabitants chose to harvest part of their cereals prior to the full ripening of the grains, and that they most likely performed post-harvest activities that involved the drying or roasting of the unripe grains. The experimental work undertaken here and its application to archaeobotanical material can be extended to other species and archaeological sites, in order to identify similar processes at other sites and thus can be regarded as an analytical tool that can help to understand the diversity of cereal food products in Prehistory. It is nevertheless worth highlighting that *Grünkern* is still an important traditional food in some parts of central Europe and, according to our results, it might have its origins in the Iron Age, if not earlier.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jas.2020.105143.

References

Al-Azm, A., 2009. The importance and antiquity of frikkeh: a simple snack or a socio-economic indicator of decline and prosperity in the ancient Near East? In: Fairbairn, A.S., Weiss, E. (Eds.), From Foragers to Farmers. Papers in Honour of Gordon C. Hillman. Oxbow Books, Oxford, pp. 112–116.

Anderson, R.A., 1976. Wild rice: nutritional review. Cereal Chem. 53, 949–955.

Anderson, R.A., 1978. Wild rice: its history, current production, use. Rice J. 81, 34–38.

Anderson, R.A., Vojnovich, C., Navickis, L.L., Bagley, E.B., 1979. Parching studies in wild rice. Cereal Chem. 56, 371–374.

Bayram, M., 2008. An analysis of scorched immature wheat: frekeh. Cereal foods world 53, 134–138.

Berihuete-Azorín, M., Stika, H.-P., Bourliva, A., Papadopoulou, L., Valamoti, S.M., 2019. "Fresh from the Oven": experiments on *Triticum spelta* and a protocol for carbonising specimens for archaeobotanical comparison collections. J Archaeol Sci Rep 26, 101865. https://doi.org/10.1016/j.jasrep.2019.05.030.

Biel, J., 2015. Hochdorf IX, Die eisenzeitliche Siedlung in der Flur Reps und andere vorgeschichtliche Fundstellen von Eberdingen-Hochdorf (Kreis Ludwigsburg). Forschungen und Berichte zur Vor- und Frühgeschichte in Baden-Württemberg Band 111. Landesamt für Denkmalpflege im Regierungspräsidium, Stuttgart.

Brestel, T.J., 2019. Einflussreich über den Tod hinaus. Denkmalpflege in Baden-Württemberg–Nachrichtenblatt der Landesdenkmalpflege 48, 112–116.

Cappers, R.T.J., 2018. Digital atlas of traditional food made from cereals and milk. Groningen Archaeological Studies. Barkhuis, Eelde, p. 33.

Hubbard, R.N., Al-Azm, A., 1990. Quantifying preservation and distortion in carbonized seeds; and investigating the history of friké production. J. Archaeol. Sci. 17, 103–106. https://doi.org/10.1016/0305-4403(90)90017-Y.

Huebner, F.R., Kaczkowski, J., Bietz, J.A., 1990. Quantitative variation of wheat proteins from grain at different stages of maturity and from different spike locations. Cereal Chem. 67, 464–470.

Jacomet, S., 2006. Identification of Cereal Remains from Archaeological Sites. Basel University, Basel.

Körber-Grohne, U., Haas, K., Vorwohl, G., Wurster, R., 1985. Die biologischen Reste aus dem hallstattzeitlichen Fürstengrab von Hochdorf, Gemeinde Eberdingen (Kreis Ludwigsburg) in Hochdorf I. Forschungen und Berichte zur Vor- und Frühgeschichte in Baden-Württemberg, vol. 19. Theiss, Stuttgart, pp. 85–265.

Kraska, P., Andruszczak, S., Dziki, D., Stocki, M., Stocka, N., Kwiecińska-Poppe, E., Różyło, K., Gierasimiuk, P., 2019. Green grain of spelt (*Triticum aestivum* ssp. *spelta*) harvested at the stage of milk-dough as a rich source of valuable nutrients. Emir. J. Food Agric. 31, 263–270. https://doi.org/10.9755/ejfa.2019.v31.i4.1931.

Markus, M., 1989. La presence de l'epeautre dans l'espace carpatique. L' peautre (*Triticum spelta*), histoire et ethnologie. In: Devroey, J.-P., Van Mol, J.-J. (Eds.), L'épeautre (*Triticum spelta*): histoire et ethnologie. Editions Dire, Treignes, pp. 123–127.

Meynen, E., Schmithüsen, J., 1953. Hrsg.) Handbuch der naturräumlichen Gliederung Deutschlands. Bundesanstalt für Landeskunde (Remagen/Bad Godesberg).

Miedaner, T., Longin, C.F.H., 2016. Neglected Cereals: from Ancient Grains to Superfood. Agrimedia, Clenze.

Nesbitt, M., Samuel, D., 1996. From staple crop to extinction? The archaeology and history of the hulled wheats. In: Padulosi, S., Hammer, K., Heller, J. (Eds.), Hulled Wheats. Promoting the Conservation and Use of Underutilized and Neglected Crops. IPGRI. Rome, ISBN 9789290432883, pp. 41–100.

Nüske, G.F., 1977. Landwirtschaftliche sonderkulturen in baden-württemberg. Kommission für Geschichtliche Landeskunde in Baden-Württemberg, Historischer Atlas von Baden- Württemberg. Erläuterungen, Stuttgart, pp. 1–16.

Peña-Chocarro, L., 1999. Prehistoric Agriculture in Spain. The Application of Ethnographic Models, British Archaeological Reports, 1999 (BAR Series 818), (Oxford).

Reed, K., Sabljić, S., Šoštarić, R., Essert, S., 2019. Grains from ear to ear: the morphology of spelt and free-threshing wheat from Roman Mursa (Osijek), Croatia. Veg. Hist. Archaeobotany 28, 623–634.

Schwenkenbecher, G., 1949. Die Entwicklung und wirtschaftliche Bedeutung von Dinkel und Grünkern. Doctoral dissertation. Giessen University, Faculty of Agriculture.

Stika, H.-P., 1991. Die paläoethnobotanische Untersuchung der linearbandkeramischen Siedlung Hilzingen, Kreis Konstanz. Fundberichte aus Baden-Württemberg 16, 63–104.

Stika, H.-P., 2009. Landwirtschaft der späten Hallstatt-und frühen Latènezeit im mittleren Neckarland–Ergebnisse von pflanzlichen Großrestuntersuchungen. In: Schatz, K., Stika, H.-P. (Eds.), Hochdorf VII, Archäobiologische Untersuchungen zur frühen Eisenzeit im mittleren Neckarraum. Forschungen und Berichte zur Vor-und Frühgeschichte in Baden-Württemberg, vol. 107. Konrad Theiss Verlag, Stuttgart, pp. 125–339.

Styring, A., Rösch, M., Stephan, E., Stika, H.-P., Fischer, E., Sillmann, M., Bogaard, A., 2017. December. Centralisation and long-term change in farming regimes: comparing agricultural practices in Neolithic and Iron Age south-west Germany. Proc. Prehist. Soc. 83, 357–381. https://doi.org/10.1017/ppr.2017.3.

Takruri, H.R., Humeid, M.A., Umari, M.A., 1989. Protein quality of parched immature durum wheat (Frekeh). J. Sci. Food Agric. 50, 319–327.

van der Veen, M., 1989. Charred grain assemblages from Roman-period corn driers in Britain. Archaeol. J. 146, 302–319. https://doi.org/10.1080/00665983.1989.11021292.

Wallace, M., Bonhomme, V., Russell, J., Stillman, E., George, T.S., Ramsay, L., Wishart, J., Timpany, S., Bull, H., Booth, A., Martin, P., 2019. Searching for the origins of bere barley: a geometric morphometric approach to cereal landrace recognition in archaeology. J. Archaeol. Method Theor 26, 1125–1142. https://doi.org/10.1007/s10816-018-9402-2.