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ORIGINAL PAPER

Early Iron Age and Late Mediaeval malt finds from Germany—attempts at reconstruction of early Celtic brewing and the taste of Celtic beer

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Abstract In this paper, we discuss specialised ditch structure from the early Iron Age settlement of Eberdingen–Hochdorf (early La Tène Period, fifth–fourth century BC), that contained large numbers of evenly germinated hulled barley grains. This malt appears to be the result of deliberate germination, given the purity of the finds and the associated unusual archaeological structure, which may have been used for germination and/or as a drying kiln for roasting the malt. The Hochdorf malt most probably was produced for the purpose of beer brewing. To learn more about the morphology of malt and the effects of carbonisation on it, experiments on modern barley grains were undertaken. Their results are compared to the ancient Hochdorf malt. Based on the excavated findings and finds as well as theoretical reflections on the early Iron Age brewing process, attempts at reconstructing the possible taste of early Celtic beer are presented. Additionally, a malt find from late mediaeval Berlin in northeast Germany is presented. A mixture of deliberately sprouted hulled barley as well as rye and oat grains, which were not germinated, was found. The three different cereals could have been used for brewing a typical mediaeval/early modern beer since the use of mixed crops for producing beer has been quite common. Because of a lack of further evidence, it remains unclear whether or not the half-timbered house in the late mediaeval town was a trading place and storehouse for malt or the brewery itself, where the malt was processed to make beer.

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Introduction

The importance of beer in antiquity is well documented in ancient written and iconographic sources, particularly those from Egyptian (Samuel and Bolt 1995; Samuel 1996; Samuel 2000) and Mesopotamian cultures (Wartke 1998). Early inscriptions from both these regions, which list beer as payment for work, also describe different qualities of beer. Ancient Greek and Roman written sources also mention beer although wine was the preferred alcoholic drink (Antique authors cited in Lenz 1859). In fact, both the Greeks and the Romans regarded beer as a barbarian's beverage, especially that of the Celts and Germans (Nelson 2004). Nevertheless, the recovery of malt in Roman contexts of archaeological sites from the northern provinces of the Roman Empire (Piening 1988, van Zeist 1991), as well as excavated structures (Rieckhoff 1992) and documents (Binsfeld 1972) associated with beer making, suggest that the Romans also routinely consumed beer.

Production of a good quality brew requires much experience both in wine and beer processing (Blandino et al. 2003). By definition, beers are alcoholic beverages, produced by transforming starch into sugars to produce a wort (sugared liquid), which is then fermented with yeast (Stika 1998). Early beers differed from our modern beers in both methods of production and taste. In antiquity, fruits and honey were added but with different effects, depending on the stage of processing that they were added. When added to the already fermented brew, the fruit and honey simply sweetened the beer. When added during the wort stage, the naturally occurring yeasts in fruit and honey

stimulate fermentation; the proportions of the different ingredients are what determine whether the result is a wine or a beer.

For the most part, the taste of our modern beer derives from the flavouring agent hops (*Humulus lupulus*). The use of hops started in early Middle Ages and increased during high and late Mediaeval Times (Behre 1999). The Nordic Hansa trade league attained control of the export of hopped beer in the thirteenth and fourteenth century AD and pushed back the gale (*Myrica gale*) beer which was common along the North and Baltic Sea coast in the whole first millennium (Behre 1998). During the Middle Ages, and in early modern times, a wide range of beer additives continued to be used; however, hops has become the accepted flavouring, and is the only one currently allowed by the "German Beer Purity Laws". The "Bavarian Purity Law" signed in the year AD 1516 by Duke Wilhelm IV of Bavaria in the city of Ingolstadt is a regional regulation concerning the production of beer with a restriction to the use of water, barley, and hops only. Yeast was not mentioned in this document because the relevant micro-organisms were not known to be part of the brewing process before Louis Pasteur discovered their role in alcoholic fermentation. There are some earlier beer purity orders with local relevance handed on for the mediaeval towns of, e.g. Ulm and Munich (Krauß 1994). Beer production is rarely identified archaeologically (van Zeist 1991; Ansorge and Wiethold 2002) in contrast with the written sources from ancient, mediaeval, and early modern times. This paper discusses two finds of charred malt from barley (location of the sites in Fig. 1): the early Iron Age site of Eberdingen–Hochdorf (Stika 1996; Stika 2009) close to Stuttgart in southwestern Germany and the late mediaeval site of Fischerinsel/Cölln in Berlin (Stika et al. 2010) in northwestern Germany.

Late Mediaeval malt finds from Berlin

Recent construction in the centre of Berlin at Fischerinsel Nr. 12/Gertraudenstrasse unearthed a burnt half-timbered mediaeval building. In late Mediaeval times, this locality had been part of the town Cölln, one of the basic quarters of later Berlin. Its central position in the mediaeval town and the structure of the building suggest that the building might have been a storehouse, a shop, or a craftsman's workshop. Rescue archaeological excavations, directed by Melisch and Sewell (2010), revealed the half-timbered house to be a minimum of 66 m^2 with no subdivided rooms. The house and an adjacent well, found in front of the house, were dendrochronologically dated to the same period as the malt (radiocarbon dated to the fourteenth century AD) and connected with an all-embracing conflagration in the centre of Cölln at 18th of August in the year 1380 AD, known by historical written sources (cf. Melisch and Sewell, 2010).

A layer of charred grain was found lying on wooden floorboards. It measured approximately 6 cm thick and covered an area of at least 9 m^2. In total, six archaeobotanical sediment samples were taken from different parts of the layer. Archaeobotanical analyses by Stika et al. (2010) determined that the layer consisted primarily of sprouted multirowed hulled barley (*Hordeum vulgare*), as well as unmalted rye (*Secale cereale*), and oat (*Avena sativa*; see Fig. 2), with a few additional grains of probable common wheat (cf. *Triticum aestivum*). Cereal grains dominate the assemblage, few chaff fragments were found. Approximately 20 weed taxa were also present, primarily *Rumex acetosella*, *Spergula arvensis*, and *Chenopodium* cf. *album*, species that are characteristic of poor sandy soils, partly on loamy fertile soils.

Among the identified grains, germinated specimens included primarily barley (4,816 items) as well as a few grains of rye (five of a total of 1,341 rye grains), common wheat (one of a total of 18 grains), and one grain of weedy millet (*Echinochloa crus-galli*). The pattern indicates that only the barley was malted but that the barley malt contained a minute amount of impurities, represented by the other cereal grains. Of the six archaeobotanical samples, five were dominated by germinated barley, while one sample was dominated by rye, with sprouted barley being the second most dominant species. Oat is subdominant in four samples and rye in one.

It appears that the conflagration had caused the three different stored crops barley malt, rye, and oat to become mixed. A huge amount of malt, at least 80 kg, is indicated by the archaeobotanical assemblage recovered from the partly excavated building. With 80 kg malt, one can brew 500 l of beer with an alcohol content of around 5% abv.

The recovery of malt from the burnt mediaeval house raised the possibility that a storehouse for malt, or else a brewery, had been unearthed. All the basic preconditions for brewing were present including a fireplace that was excavated within the house. Wooden brewing containers were not recovered, possibly due to their mixing with structural timber, which was found on the floor of the collapsed building.

Written sources from mediaeval and early modern times (*Tabernaemontanus* 1731, reprint by Grünwald 1975, 637) describe mixtures of cereals such as barley, rye, and oat as common ingredients in late mediaeval beers. Hulled barley is known to produce the best quality malt. Coarsely ground unmalted grain can be added to the brew, when the ground malt gets dissolved in hot water to start the sugaring of the mash.

In former times, typical flavouring additives were *Artemisia absinthum*, *A. vulgaris*, *Hyssopus officinalis*,

Fig. 1 Location of the investigated sites Eberdingen–Hochdorf close to Stuttgart and Berlin–Mitte (Fischerinsel/Getraudenstrasse)

Juniperus communis, *Laurus nobilis*, *Lavandula angustifolia*, *Majorana hortensis*, *Melissa officinalis*, *Picea abies*, *Rosmarinus officinalis*, *Salvia officinalis*, and many others (Behre 1999, see Table 1). These were not found in the burnt down building of Fischerinsel, possibly due to the small number of samples taken from the layer of charred grains. The recovery of whole grains suggested that the malt had not yet been fermented when it was charred by the

Fig. 2 Two sprouted barley grains in dorsal view (*left*); one rye grain (*middle*) and one oat grain (*right*) each in ventral and dorsal view, Berlin–Mitte "Fischerinsel", Late Mediaeval times

fire. It is not possible to address questions about whether brewing was carried out in this house or if the malt was traded for a brew elsewhere. Nevertheless, the huge amount of malt present in the excavated area suggests a large-scale beer brewing operation.

The early Iron Age brewery of Eberdingen–Hochdorf

The early Celtic settlement of Hochdorf (Biel 1991; Biel 2009) dates from early La Tène period, in the fifth/fourth century BC. Due to the well-designed structure and frequency of uncommon finds, e.g. red-fired Attic pot-sherds, a small bronze scale, fine wheel-turned ceramics, Hochdorf was recognised to be more than an ordinary farm. It was identified as a former rural residence of an early Celtic prince associated with the nearby fortified hilltop of "Hohen Asperg" close to Ludwigsburg. This settlement is also directly related to the rich late Hallstatt grave mound of Hochdorf (Biel 1985), which lies half a kilometre to the east of Hochdorf "Reps", as the locality of the excavated Hochdorf settlement site is named.

The excavated features were analysed for archaeological, zoological, and botanical remains. Among the examined structures were a bow-sided house, pit houses, earth cellars, grain storage pits, fence systems, and postholes from storage structures. A total of 250 soil samples, processed by flotation and wet sieving, were collected and analysed for botanical macroremains at Hochdorf and in three neighbouring contemporaneous early Celtic sites (Stuttgart–Mühlhausen, Freiberg a.N.–Beihingen, Heilbronn–Klingenberg) from middle Neckarland (Stika 1999; Stika 2009). Hulled barley (*H. vulgare*) and spelt wheat (*Triticum spelta*) were found to be the main cultivated crops in the analysed region, millet (*Panicum miliaceum*) was subdominant in some sites (Freiberg–Beihingen, Stuttgart–Mühlhausen, Heilbronn–Klingenberg).

Among other structures, six ditches were excavated in Hochdorf "Reps" site (Stika 1996; Stika 2009). They were found to be carefully constructed structures that, in their preserved state measured approximately 5–6 m long, 0.6 m wide, and up to 1.1 m deep. All the ditches were straight, had a U-shaped profile and absolutely straight walls and floors (Fig. 3). As no traces of erosion were observed on the sides, it can be assumed that the walls were supported by wooden boards; however, no organic remains of wood were preserved.

From three of these ditches, eight archaeobotanical samples were collected. The archaeobotanical analysis revealed that each of the ditches contained a different assemblage of charred plant remains. From one ditch, only few plant remains were recovered; the same group of species found in the pit sediments (n=266 specimens in a 10 l volume sediment sample: cereal grains and chaff of barley, hulled and free-threshing wheat species, as well as segetal and ruderal wild plant species). The other two ditches contained thousands of sprouted grains of multirow hulled barley (*H. vulgare*). These assemblages were almost purely barley, containing only a few other types of cereal grains, chaff, or weeds. As well as the characteristics of the ditch structures themselves, the sprouted barley grains suggest that these features formed part of an early Celtic brewery. To test this assumption, a number of experiments were carried out to learn about the morphology of the unearthed malt and the degree of its malting as well as the general conditions during carbonisation in the Hochdorf ditches.

Experiments involving malt processing

To learn about the process of malting, hulled, and free-threshing (i.e. naked) barley grains were germinated. Specimens were germinated both with their glumes intact and dorsally dehusked. After soaking overnight (10 h) in water at room temperature (18–25°C), the grains (one part with glumes and another part dehusked) were divided into three sub-samples and exposed to different temperature, light and climatic regimes: darkened environmental chamber with humidity control (cooled down to 10°C), a dark and damp cellar (14°C), and in daylight at room temperature (Stika 1996; Stika 2009). Sub-samples of 100 grains were removed (after 2, 3, 4, and 5 days) from each sample and examined with a binocular loup to assess the stage of germination. Compared to modern malt production, the best malt qualities were achieved under dark and cool conditions (10°C) with constantly high humidity (80%) in the darkened environmental chamber. After 5 days, the hulled barley grains exhibited exterior signs of germination (coleoptiles, coleorhizae, and germination roots developed), and within the germ exhibited the presence of sufficient enzymes to start the mobilisation of the starch.

In modern malt production, this is the stage of germination at which the malting process is begun. Cooling systems, ventilation, occasional turning, and automatic humidity control are present-day methods used to keep all the grains at a comparable stage of germination. Likewise, special two-rowed hulled barley with low protein and high starch content is grown to produce good quality malt for brewing.

To halt germination, the green malt must be dried. To maintain the enzymes, relatively low heat drying temperatures (around 80°C) rather than high heat, are used. In Central and Northern Europe, a drying kiln is used at this stage. The dried malt can be stored at this stage.

Before brewing, the malt is coarsely ground. After grinding, the malt is dissolved in hot water (50°C) and

Fig. 3 Excavated ditch with barley malt on the bottom, Hochdorf "Reps", early Iron Age

further heated up (max. of 78°C) to convert the starch into sugars, a process that is facilitated by the enzymes that were produced by the cereal germ during malting. The next step is to clarify the mash, which entails separating the glumes and remains of the grain from the pure sugared liquid. To produce the wort, the mash is cooked with hops. Afterwards, the liquid is clarified again to remove the coarse remains of hops, the precipitated protein and the tannins.

Fermentation is started after cooling down the sweet (from sugar) and bitter (from hops) liquid, and adding yeast. Two main types of yeast are used today: brewer's yeast (*Saccharomyces cerevisiae*), which works at high temperature (15–20°C), floats on the brew (ale yeast, top-fermenting yeast), the other, *Saccharomyces carlbergensis*, which works at low temperature (4–9°C), sinks to the bottom (lager yeast, bottom-fermenting yeast). Fermentation can take from 1 day to more than a week, depending on the proportions of sugar, type, and amount of the yeast and the temperature. Normally, fresh beer is matured under cool storage conditions (Stika 1998).

Turning again to our questions about early Iron Age malt, to assess whether the grains from Hochdorf display characteristics of malting, charring experiments were carried out on the modern barley malt using specimens that were extracted during the malting experiments. Damp and dried malt were artificially carbonised at two temperatures (250°C and 350°C). Moist grains that were heated rapidly to 350°C were observed to puff up to approximately twice their original size, while dry malt grains remained morphologically intact throughout carbonisation. Grains that had been left to germinate for 7 days or longer were more poorly preserved by carbonisation regardless of being moist or dry. Our experiments revealed that the sprouts of all carbonised malted grains (no matter of which pre-treatment) are prone to destruction when subjected to mechanical agitation and handling. Unsurprisingly, no sprouts or roots were found preserved in the Hochdorf ditches. Only five fragmented embryos were recovered amongst the carbonised grains. The overlaying sediments caused mechanical pressure on the malt which likely destroyed the sensitive charred germs. The carbonised barley malt from Hochdorf (see Fig. 4) displays groove-like channels or grains are concave on their dorsal sides. In some cases, the coleoptiles and the coleorhizae became more prominent and the germination pits are enlarged towards the top. Other grains broke in the middle, in cross-section, with only their apical half preserved. Most likely the (fragile) sprouts and roots were destroyed during carbonisation and/or by the weight of sediment that was later thrown into the ditches when they were in-filled.

The early Iron Age Hochdorf malt remains are morphologically similar to those of modern malt, after their germs are brushed away to remove enzymes and other protein. From results of the germination and charring experiments and comparisons with modern malting practices, the early Iron Age Hochdorf malt appears to have been processed using methods designed to produce a high quality malt of slightly and evenly germinated grains, in an uncommonly pure (single malt) barley assemblage. Under controlled and cool conditions, this process takes about 5 days. The fact

that the grains survived carbonisation indicates that they were charred in optimal conditions, i.e. the semi-dry malt was exposed to low and even heat with low oxygen access.

Attempts at reconstructing early Iron Age malting

The Hochdorf malt production was done on a large scale. As we learned from the experiments, germination is difficult to control and malting requires that all the grains are evenly sprouted, and in a slightly sprouted state. The well-constructed Hochdorf ditches, with their sheltered walls may have been used for drying the green malt as well as for germination. The soaked barley grains were possibly spread on plates made of woven reed, wickerwork of willow, or textile on the ditch floor. If covered at the top, and therefore kept dark at the bottom, the ditch could have provided the precise, optimum conditions that are necessary for producing good quality malt; constant low temperatures and high humidity. Following germination, the ditch structure could have also have served as a drying kiln; placing the plates of sprouted barley on top of a superstructure made of dried mud brick and a wooden frame, would have sufficiently exposed the malt for drying. A small fire, installed at one end of the ditch, would have created the warm air necessary to dry the malt. Nevertheless, no stokehole or other hearth-related sub-structures were found during excavation.

To explain the present state of preservation, the following scenario is suggested: the wooden support for the nearly dry malt accidentally caught fire due to an errant spark; the organic plates also burned; the structure subsequently would have collapsed, scattering the grains over the bottom of the ditch where they were then covered by the burning wooden frame.

The taphonomy of the excavated ditch 2202/3, which is shown in Fig. 3, suggests this reconstruction. In this ditch, a layer of the pure charred malt lay directly on the underlying loess. In the upper part of the malt/grain layer, pieces of wood charcoal were mixed among the grains. This layer was covered by partly burnt mud brick mixed with coarse charcoal fragments. The upper part of the overlaying in-fill in the ditch consisted of loam, which was probably used to fill in and to level the area after the fire destroyed the structure.

The possible taste of Early Celtic beer

Because we have no detailed information about early Celtic beer production techniques, either from archaeological excavations or from written or iconographic sources, we certainly do not know much about its taste. It might

Fig. 4 Charred barley grains, Hochdorf "Reps", early Iron Age (scale is 0.5 mm)

nevertheless be possible to reconstruct the taste of early Iron Age beer using our interpretations of the Hochdorf excavations and additional theoretical considerations. As the experiments on germination and carbonisation and also comparison with modern malt production have shown, the quality of the Hochdorf malt (pure barley grains only slightly but evenly germinated) was quite high.

From our 'reconstruction' of the drying kiln methods formerly used in the Hochdorf ditches, we can infer that the open fire produced a malt with a smoky taste, as found in a few modern German beers ("Rauchbier"), while the uneven heat in the long kiln might have produced uneven, partly dark malt. The drying process probably worked slowly, causing a high amount of lactic acid bacteria activity. After drying, the malt may have been stored, possibly in dry containers.

The first steps in the brewing process included first the coarse grinding of the malt followed by the addition of water to dissolve the ingredients. No special brewing containers were found among the Hochdorf material remains. It can be inferred that wooden containers were probably used for mashing the dissolved malt into a pulp. In the pulping stage, there was a reactivation of enzymes that had been produced during germination of the barley

embryos, resulting in the converting of more starch into sugars. At Hochdorf, cooking stones may have been used to heat the mushy liquid at low temperatures in order to boost the sugar content of the mash. Contact with the hot stones might have caused the malt sugars to caramelise on the surface of the cooking stones, which would have added a special flavour to the liquid. (This type of caramelisation effect, due to the use of the cooking stone, can be experienced by drinking the rare "stone beers" produced by a very few breweries today.) The lactic acid bacteria from the green malt would have fermented too, causing a low pH level of the liquid, which helps preservation but imparts a sour taste. After the sugaring process, the mash would have been purified by filtering, at which stage the barley glumes might have helped to filter out the coarse ingredients when the pure liquid was drained. This spiced sugared liquid is named wort today.

We do not know if the early Celtic wort was boiled before fermentation, as is done today. Cooking stones might have been used at this stage also, but no such evidence was found during excavation. Most probably fermentation started spontaneously due to the use of yeast-contaminated brewing equipment and/or adding honey and fruit, which again both contain wild yeasts. Roman sources (e.g. the writing of Pliny, Natural History 18.12.68 cit. in Lenz 1859) indicate that the Celts intentionally used beer yeast for baking fluffy bread. We cannot exclude that "*spuma concreta*" was deliberately added to the wort to start fermentation. Most probably the yeast was of the "old type" (*S. cerevisiae*), which is used today for brewing pale beer. This yeast works at high temperatures and floats on top of the brew. The bottom-fermenting yeast (*Saccharomyces carlsbergensis*) needs cooling during fermentation and was introduced to southern Germany on a large scale in the nineteenth century.

In addition to malt and yeast, the main component in the taste of a beer is its flavouring. Today, the more or less intensive taste of hops generally dominates. Hops not only improve the flavour, but also facilitate better preservation of the beer and better digestion upon consumption. As mentioned above, the use of hops started in the Middle Ages. Wild hops finds are absent from early Iron Age Hochdorf but present in the contemporaneous site of Freiberg a.N., about 20 km from Hochdorf (Stika 1996; Stika 2009). Statistical correspondence analyses of datasets of 250 early Celtic archaeobotanical samples, representing four different sites of the middle Neckarland, show that the seeds of mugwort (*Artemisia vulgaris*) and carrot (*Daucus carota*) are spatially associated with malt samples (Stika 1999; Stika 2009). Mugwort, which is particular well known as a flavouring agent for mediaeval herbal and medicinal beers, was used till the eighteenth century (Behre 1998). Carrot seeds are mentioned for medicinal use by Dioskorides (cited in Lenz 1859, 571). Both spices could have been used for the early Celtic Hochdorf beer. Another beer additive well-known from mediaeval and early modern times is henbane (*Hyoscyamus niger*), which adds flavour and also makes the beverage more intoxicating. The Old English word "beolene", once naming the plant henbane, as well as the Old High German word "bilisa" and the modern German plant name "Bilsenkraut" are traced back to Celtic linguistic roots and linguistic connections with the Celtic god "Belenos" are assumed (Hegi 1964, vol 5.4, p. 2574). A few seeds of henbane were found in the early Iron Age Hochdorf samples but statistical correspondence analysis shows that they have no direct connection to the sprouted barley. We can only speculate that henbane may have been used for flavouring the Celtic beer of Hochdorf.

To summarise, the possible taste of the Celtic Hochdorf beer: it was probably a dark, smoky, and slightly sour. A caramelised taste would have decreased the sourness. Floating yeast sometimes produces a light lemon taste. If flavouring agents such as mugwort and carrot seeds were added, this beverage would have had a very different taste from our typical modern beer.

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