



Plant use at Funnel Beaker sites: combined macro- and microremains analysis at the Early Neolithic site of Frydenlund, Denmark (ca. 3600 BCE)

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Abstract

Understanding the neolithisation process in northern Europe requires detailed knowledge of both the type of crop plants as well as gathered food plants from Neolithic Funnel Beaker sites (4000–2800 BCE). However, although many sites from this culture are known, significant gaps remain in our knowledge on which taxa were used as well as on how plant food was prepared. Here, we present the results of combined plant macro- and microremains from the Early Neolithic site of Frydenlund in present-day Denmark. The macroremains include carbonised seeds, fruits and underground storage organs from a variety of contexts. The microremains are phytoliths and starch granules recovered from 14 grinding stones that are among the oldest from Denmark as well as the first from this region analysed using state-of-the-art methods. The data are discussed in the context of an updated overview of crop spectra, evidence of gathered plants and of plant food preparation techniques at Funnel Beaker sites in the Netherlands, Germany, Denmark and Sweden. The results from the Early Neolithic site of Frydenlund show that the macroremains assemblage was dominated by *Triticum turgidum* ssp. *durum* (durum wheat), *T. turgidum* ssp. *dicoccum* (emmer wheat) and *Hordeum vulgare* var. *nudum* (naked barley), which apart from durum wheat fits the observed pattern from other Funnel Beaker sites in northwestern Europe. These crops were presumably cultivated separately as summer crops. *Corylus avellana* (hazel), *Rubus fruticosus* (blackberry) and *R. idaeus* (raspberry) were probably consumed as well, and possibly *R. caesius* (dewberry). While cereals were abundant in the macroremains assemblage, the microremains from the grinding stones indicate that these were used for grinding solely wild plants. The carbonised cereal grain fragments are therefore interpreted as possible evidence of cereal consumption mainly in the form of porridge or gruel, which corresponds well to comparable finds at other contemporary northwestern European sites. Future analysis of comparable high-quality data on combined macro- and microremains analysis is necessary to further refine our understanding of plant diets and plant food preparation techniques of the Funnel Beaker Culture as well as during the neolithisation process.

Keywords Funnel Beaker Culture · Food processing · Archaeobotanical macroremains · Underground storage organs · Phytoliths and starch · Grinding stones

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Introduction

The Mesolithic/Neolithic transition, involving the subsistence shift from hunting and gathering to arable farming, can be understood amongst others by studying plant use within Mesolithic and Neolithic cultural groups, and, more precisely diet. One of the early Neolithic cultures that play a role in the introduction of agriculture in major parts of northern Europe is the Funnel Beaker (FB) culture (4000–2800 BCE), which emerged in northern Europe. Archaeobotanical overview studies on particularly carbonised assemblages from present-day northern Germany, Denmark, Sweden and the Netherlands (Bakels 1991; Regnell and Sjögren 2006; Robinson 2007; Kirleis et al. 2012; Sørensen and Karg 2014; Kirleis 2019, 2022; Vanhanen et al. 2019) have allowed for the crop assemblage in the northern and western FB influence sphere to be relatively well-known (introduction 4000 BCE, Sjögren 2012; ca. 3800 BCE, Bunbury et al. 2023). However, despite this large number of studies on plant use at FB sites, gaps in our knowledge remain. For example, observations may be biased by the scarcity of sites with waterlogged preservation. Furthermore, systematic sampling is still not always applied. The significance of crops that are only represented by few remains and/or found at few sites remains unclear and a systematic overview of the direct evidence of use and preparation of wild plants other than those preserved in a carbonised state is lacking. Finally, up to now not much is known about plant food products and their modes of preparation. This can be remedied by the analysis of microbotanical remains from charred food crusts, dental calculus, and coprolites or on food-related artefacts, e.g. grinding stones.

This study aims to expand our knowledge on plant use and plant food preparation at FB sites by providing:

- 1) An updated overview of crops, gathered plants and evidence of food preparation techniques identified at FB sites in the Netherlands, Germany, Denmark and Sweden. The Polish FB sites are not considered due to their significantly different geographical location, cultural influence sphere, climate and environment (for an overview, see Nowak et al. 2020).

- 2) A comparative analysis of the carbonised macroremains as well as phytolith and starch analysis of 16 samples from 14 grinding stones from the Early FB site of Frydenlund in Denmark. While some macroremains and taxa from Frydenlund have already been reported by Roehrs et al. (2013), Kirleis and Fischer (2014), Andreasen (2017, 2020) and Kirleis (2019), all data are, for the first time, synthesized and related to their archaeological context. The grinding stones from Frydenlund are among the oldest in Denmark and the microremains analysis thus

provides data for the earliest neolithisation in the region. The purpose of the analysis of Frydenlund is to examine the types of plants consumed, the role of the grinding stones in terms of plant food preparation as well as to study in detail any clues provided about the processing of cereal food products.

Overview of the crop spectra and evidence of wild plant use of northern and western Funnel Beaker sites

Funnel Beaker crop analyses from northern Germany, Denmark, Sweden and the Netherlands show assemblages that are generally dominated by *Hordeum vulgare* var. *nudum* (naked barley) and *Triticum turgidum* ssp. *dicoccum* (*T. dicoccum*, emmer), while *T. monococcum* ssp. *monococcum* (*T. monococcum*, einkorn) and *T. aestivum* ssp. *aestivum* and/or *T. turgidum* ssp. *durum/turgidum* (*T. aestivum/T. turgidum*, free-threshing wheat) frequently occur in small quantities (Table 1). The presence of *T. monococcum* always in combination with *T. dicoccum* indicates that this was cultivated as a maslin crop with emmer or potentially represents grains from the top of the ears of *T. dicoccum* (Nesbitt and Samuel 1996, p 56) rather than actual *T. monococcum*. Free-threshing wheat has usually been considered as *T. aestivum* (bread wheat), primarily based on the climatic preferences of the various free-threshing taxa. However, *T. durum/turgidum* (hard/rivet wheat) has been unequivocally demonstrated at Frydenlund (Kirleis and Fischer 2014; Andreasen 2017 and below). In addition, small quantities of apparent free-threshing wheat grains may also represent *T. dicoccum* deformed during carbonization (cf. Braadbaart 2008; Kirleis 2019, p 122; see also Out 2009, app. III, pp 150–152). The material from the single FB site from which carbonised material of possible hulled *Hordeum* is reported (Behre and Kučan 1994, p 26) would be relevant to revisit (cf. Kirleis 2022, p 441). *Triticum aestivum* ssp. *spelta* (*T. spelta*, spelt) and possible spelt finds are regularly mentioned as being present in FB crop assemblages. Despite this, carbonised awn bases that can unmistakably be identified as spelt have not been reported to date (Hjelmqvist 1975; Engelmark 1992; Robinson et al. 1995; Regnell and Sjögren 2006 based on Andersson 1999; Robinson 2007; Rudebeck 2010; Larsson and Broström 2011). Moreover, the crop assemblages of Early Neolithic cultures from which FB people could have obtained their crops do not include *T. spelta*. Until substantial quantities of spelt awn bases have been identified, we recommend interpreting suggested spelt finds as well as any *T. dicoccum/spelta* finds from FB sites in northwestern Europe as *T. dicoccum*.

Oil plants *Linum usitatissimum* (linseed) and *Papaver somniferum* ssp. *setigerum* (opium poppy) occur very scarcely, and mostly from the Middle Neolithic onwards

Table 1 Crop plants of the Funnel Beaker Culture and related cultures in northern Europe relevant to this study

Culture	FBC						FBC/other	Other
	DK	DK	DE	DE	SE	NL		
Country	DK	DK	DE	DE	SE	NL	SE	NL
Period (cal BCE)	4000–3300	3300–2800	4000–3300	3300–2800	4000–3300	4000–2800	3300–2800	4000–2800
<i>Triticum turgidum</i> ssp. <i>dicoccum</i> (emmer)	xx	xx	xx	xx	x	xx	x	xx
<i>T. monococcum</i> ssp. <i>monococcum</i> (einkorn)	x	x	x	x	x	x	x	
<i>T. aestivum/durum/turgidum</i> * (bread/hard/rivet wheat)	x	x	x	x	x	r	x	x
<i>T. aestivum</i> ssp. <i>aestivum</i>	x							
<i>T. turgidum</i> ssp. <i>durum/turgidum</i>	r							
<i>Hordeum vulgare</i> var. <i>nudum</i> (naked barley)	xx	xx	xx	xx	xx	xx	xx	xx
<i>Linum usitatissimum</i> (linseed)		r	r	r	r	r**	r	x
<i>Papaver somniferum</i> ssp. <i>setigerum</i> (opium poppy)				r				x

References in text and references therein (Dutch data: also based on De Man 2002)

DK Denmark, DE Germany, SE Sweden, NL the Netherlands, xx dominant, x present, r rare, **Triticum aestivum* subsp. *aestivum*/*Triticum turgidum* subsp. *durum*/*Triticum turgidum* subsp. *turgidum*, ** 3300–3000 cal BCE, Other other culture(s), 4000–3300 BCE early Neolithic, 3300–2800 middle Neolithic

(linseed: Sweden: 3520–3350 BCE, Andreasen et al. unpublished; Andreasen et al. submitted; ca. 3000 BCE, Andreasen 2018; Denmark: ca. 3100 BCE, Andreasen et al. unpublished; Andreasen et al. submitted; The Netherlands: ca 3300–3000 BCE, van Zeist 1970; Bakker 1992; Germany: 3300–3050 BCE, Kirleis 2019, pp 111, 215; poppy: ca. 3300–3050 BCE, Kroll 2007; Kirleis 2019, pp 111, 126, 216), but *Linum* has also been reported from one Early Neolithic site (3520–3100 BCE, Kirleis 2019, pp 79–82, 211; see ESM 1 for an overview). Finds at Dutch wetland sites belonging to the Middle and Late Swifterbant cultures (4300–3950 BCE, 3900–3400 BCE) and the Vlaardingen Group (3400–2500 BCE), the latter a western counterpart of the FB culture, indicate that *Linum* and *Papaver* are probably underrepresented at FB sites due to depositional and/or taphonomical factors (poppy: Vernimmen 2004: 3950–3700 BCE; Out 2008a: 4200–3900 BCE; Out 2009 app II; linseed: Kuijper 2010; Out and Dörfler 2017). In contrast to starch-rich seeds/fruits, these oil-rich remains easily burn away when in contact with fire. In addition, sites with waterlogged preservation where remains of these taxa may remain preserved are rare.

Pulses are not considered part of the FB crop spectrum (Kirleis 2019), and early identifications, mostly based on impressions (Schiemann 1958; Hjelmqvist 1979, p 11; Hallgren 2008, p 117), have not been confirmed by identifications of more recent carbonised finds. However, finds of carbonised *Pisum sativum* (pea) from Dutch wetlands (Brinkkemper in Meirsmann and Moree 2006: 3660–3380 BCE) indicate that these may be underrepresented.

Wild fruit remains preserved as carbonised remains include e.g. *Corylus avellana* (hazelnut), *Malus sylvestris* (crab apple), *Crataegus monogyna* (common hawthorn), *Rubus fruticosus* (blackberry), *R. idaeus* (raspberry), and *Viscum album* (mistletoe, from a hearth), while use of *Prunus spinosa* (sloe) is suggested by a single imprint (Jessen 1939; Hjelmqvist 1975; Jørgensen and Fredskild 1978; Nielsen 1984; van Heeringen and Theunissen 2001; Robinson 2007; Kirleis et al. 2012; Brozio et al. 2014; Kirleis 2019). Besides the very narrow range of the above-mentioned wild food plants, there are also carbonised remains of other wild plants taxa, potentially representing collected plants. However, contextual and/or systematic evidence supporting their economic importance at FB sites is scarce.

Plant food preparation at Funnel Beaker sites

Presently, not much is known about plant food products and modes of preparation at FB sites in northwestern Europe. Concerning cereals, a recent study of organic residue on ceramic sherds shows preparation of possibly sprouted *T. dicoccum*, milk-ripe (unripe) *Hordeum* and, in one case, combined use of cereals and *Chenopodium album* (fat-hen; Kubiak-Martens et al. 2024). From various sites, half apple fruits are known (Jørgensen and Fredskild 1978; Brozio et al. 2014; Kirleis 2019), suggesting drying and storage, as well as some carbonised seeds of *Malus* sp./*Pyrus* sp. (crab apple/wild pear) found as food remains on the inner side of a pottery sherd (Jessen 1939), suggesting cooking of crab apples. Phytolith analysis of food crusts from Neustadt,

Holstein, indicate the likely use of *Alliaria petiolata* (garlic mustard; phytoliths consistent with those of *A. petiolata*) for food preparation (Saul et al. 2013), while starch analysis also indicated the use of wild plants (starch grains consistent with those of *Quercus* sp. (oak), other taxa not excluded; Saul et al. 2012). A specific artefactual context that may reveal evidence of food preparation techniques concerns grinding stones, as further discussed below.

Botanical microremains analysis from grinding stones in Neolithic northwestern Europe

Microbotanical analyses of plant remains preserved on grinding stones are becoming increasingly common, also in northwestern Europe (e.g. Verbaas et al. 2011; Devriendt 2014; Hamon et al. 2021). Grinding stones are frequent at FB sites and their use for cereal grinding has commonly been assumed, but although studies on the grinding stones exist (Lidström Holmberg 2008), plant microremains analyses using current methodologies are absent, thus leaving questions about the precise function of these stones unanswered. Alternative functions of the stones such as for grinding of wild plant remains, possibly for non-food purposes, and/or polishing stone or bone can thus not be excluded (cf. van Gijn and Houkes 2006, p 178f; van Gijn 2010, p 185; Hamon et al. 2021). Furthermore, in addition to their utilitarian function, grinding stones may also have had a symbolic function, as is sometimes indicated by deposition in graves, hoards and/or intentional fragmentation (e.g. Andersen 1999, pp 239–241; Lidström Holmberg 2008; Verbaas and van Gijn 2008; Graefe et al. 2009; Brozio et al. 2014; Devriendt 2014; Hamon 2020; Hamon et al. 2021).

Types and analyses of microbotanical remains from grinding stones: background

Phytoliths are microscopic bodies consisting of opal (hydrated amorphous silica, $\text{SiO}_2 \cdot n\text{H}_2\text{O}$) that form within cells, cell walls and/or intercellular spaces in living plants. These are released into soils when plants die and decay (Piperno 2006). Since opal is preserved in a wide range of environments, including exposure to high heating, phytoliths are usually common at archaeological sites.

Phytolith production differs between plant taxa, plant parts and plant cells, and depends on both genetic and environmental factors such as climate and silicon availability in the groundwater. Due to differential phytolith production between plant taxa, archaeological phytolith assemblages in northwestern Europe tend to be dominated by phytoliths from grasses (Poaceae, belonging to the clade of the Monocotyledons), while herbs and woody taxa (Dicotyledons) are underrepresented (e.g. Wade et al. 2021; de Wolf et al. 2022; also see Power

2018). Grasses produce phytoliths in non-edible plant parts, especially in the epidermis of the chaff surrounding cereal grains, but not within the grains themselves. Phytoliths of cereal chaff and rachises/leaves/culms can nevertheless be expected on grinding stones, depending on the details of the food preparation process and since food products were hardly ever cleaned perfectly, particularly but not exclusively in case of free-threshing cereals (see e.g. Portillo et al. 2017).

At archaeological sites in northwestern Europe, phytolith analysis often allows for identifications at taxonomic ranks including many different taxa such as Monocotyledons/Dicotyledons or, in other words, e.g. grasses and sedges versus woody plants (e.g. Hart et al. 2015). Within the grass family, it is nevertheless possible to differentiate subfamilies, which for example allows distinguishing millets (*Panicum/Setaria*) from taxa like *Triticum* and *Hordeum*. In exceptional cases, genus and/or species identifications may also be possible (e.g. Saul et al. 2013; Out et al. 2022). There are no standardised identification criteria for the distinction between the wild and domestic grasses that may occur at archaeological sites in northwestern Europe, but quantity, context and the degree of ornamentation of ELONGATE DENDRITIC from chaff can be considered. Apart from taxonomical identifications, phytoliths allow for the distinction of plant parts such as culms, leaves and inflorescences.

Starch grains are produced in the edible plant parts, like seeds, fruits and underground storage organs, of starch-rich plants, including, among others, cereals, pulses and tubers (Torrence and Barton 2006). Starch is usually scarce at archaeological sites since it easily degrades due to a range of physical, chemical and biological mechanisms (Barton and Matthews 2006). Nevertheless, multiple archaeological studies show that starch grains may remain preserved in protected micro-environments, such as embedded in dental calculus, charred residues on pottery and within pits and cracks on artefact surfaces, including grinding stones (Crowther 2020).

The analysis of phytoliths and starch grains from archaeological grinding tools has provided valuable information regarding tool use and plant processing activities. These analyses have been particularly useful for identifying the use of tools to process cereals, pulses and underground storage organs at prehistoric agricultural sites worldwide (see e.g. Piperno et al. 2009; Portillo et al. 2009; García-Granero et al. 2015; Liu et al. 2016; Santiago-Marrero et al. 2021). Experimental studies have also contributed to illustrate how representative microbotanical assemblages from grinding tools are and, also, how taphonomic processes affect microbotanical remains during grinding processes (Hayes et al. 2017; Portillo et al. 2017; Ma et al. 2019; Li et al. 2020).

The early Funnel Beaker site of Frydenlund: site and its grinding stone samples

The site of Frydenlund, located near Hårby on the island of Fynen, 2 km east from the causewayed enclosures of Sarup, was excavated in 2009–2012 by Moesgaard Museum (Andersen 2015, 2019a, b). The excavations revealed an area of 1,200 m² with traces of activities dating to the FB culture (Early Neolithic Ib), Single Grave culture (Younger Neolithic) as well as Late Bronze Age and Early Iron Age (for time periods see Jensen 2001–2004; Kirleis et al. 2012). Parts of the site were preserved relatively well because it had been covered by a Late Bronze Age burial mound (ca. 800 BCE, diameter 28 m), while other parts were disturbed by wind throws and construction of the BA barrow. The early FB occupation was characterised by two short phases that took place immediately after each other (ca. 3600 BCE). During the earliest FB phase, phase a, there was a settlement with two longhouses, northern house A (106 m²) and southern house B (64 m²) (Fig. 1), with a refuse layer preserved, also at the location of house A. During FB phase b, both houses were covered by two long monuments, so-called *barkær* monuments, that consisted of stone tablets, and which were not, unlike contemporary un-chambered long barrows, covered by earth mounds (Eriksen and Andersen 2016, pp 97ff). These monuments represent Denmark's

oldest monuments. During phase b, a plank coffin and grave goods were placed at the centre of the place where earlier house B had been, while the larger area of this grave was enclosed by a palisade. West of each monument, deep facade trenches indicate that distinctive facades of five to eight m high wooden planks were placed (Andersen 2015, 2018, 2019a). The site revealed 11,504 finds, particularly ceramics and flint, including ceramic discs that can be interpreted as baking plates. A total of 1,369 sediment samples were collected for analysis of phosphate, charcoal and carbonised botanical macroremains. Early FB sites comparable to Frydenlund include e.g. Stengade house I and Siggeneben-Süd in present-day Denmark and northern Germany, respectively (Skaarup 1975; Meurers-Balke 1983).

Contextual information about the grinding stones is provided in Fig. 2 and Table 2 (for 3D-images of the stones, see <https://sketchfab.com/nha/collections/grinding-stone-frydenlund>). All 14 stones are tentatively assigned to phase a, based on the expected activities and the site function during the two phases and the expected function of the stones. Six stones were found in primary context inside and outside the two houses dating to phase a (X8914, X8915, X8916, X8922, X8923, X8934). These are not located in one specific area but are instead dispersed throughout the site. All others were found in monumental structures of phase b, as part of the stone tablet in the *barkær* feature on top of house



Fig. 1 The location of Denmark in Europe (left above), the location of Frydenlund in Denmark (left below), and the main structures at Frydenlund: Funnel Beaker structures A and B that functioned

as houses during phase a and as burial monuments during phase b. 1=palisade (phase b), 2=facade (phase b), 3=Bronze Age burial mound that explains partial disturbance of structure B

Fig. 2 Frydenlund (Funnel Beaker phase), location of the grinding stones and sediment control samples. Precise find locations are not known for non-displayed stones (see text). It is assumed that the grinding stones date to phase a and that some were used during the construction of the monuments during phase b (see text)



A, to cover the coffin of grave A18 on top of house B and to support the planks of the facade. The precise contexts and locations of four stones (X8929–X8932) are unknown because they were only recognized as grinding stones when retrieved from stone heaps that were collected during excavation (thus no longer located *in situ*). It is nevertheless assumed that they can safely be related to the FB phase since the stone heaps were primarily generated when excavating the stone tablets and facade ditches. Some of the stones clearly are fragments from larger stones, but there are no indications that they were fragmented after their use as grinding stones.

Materials and methods

Macroremains analysis

As part of the excavation, samples containing carbonised macroremains (seeds, fruits and underground storage organs) and wood charcoal were systematically collected, mostly from FB features and structures but also from a Single Grave culture grave and Bronze Age features. This paper focuses on macroremains from the FB phase; results of the other phases are included in a supplementary file to

present all macroremains data from this site together but will not be discussed further here, while the charcoal analysis will be presented in a forthcoming paper. The FB samples were collected from the culture layer and hearth inside house A (phase a), the culture layer outside house A, pits and postholes inside as well as outside house A, pits, a stone tablet relating to the occupation phase a, and from the facade trenches, stone tablets, palisade, pits and coffin relating to the monumental phase b. From house B, phase a, relatively few samples are available because this house was partly destroyed by construction of the Bronze Age barrow (Fig. 1).

Samples from phase a correspond to 29% of the samples, corresponding to 47% of the analysed sediment volume, while the remaining 71% belong to phase b. The majority of the phase a-samples originate from house A (only two from house B), while 1/3 of the phase b-samples came from monument A and 2/3 from monument B (ESM 2). The samples, ranging from 0.11–35 l, were floated with 0.25 mm sieves at Moesgaard Museum.

The macroremains were analysed by E. Fischer at Kiel University in 2014 (Kirleis 2019) and M.H. Andreasen in 2017 at Moesgaard Museum (Andreasen 2017), while later charcoal analysis resulted in some additional identifications (W.A. Out and M.H. Andreasen, analysis 2023). In addition to the analysis of carbonised macroremains, ca. ten silicon

Table 2 List and description of the grinding stones sampled in this study

Find no	Side	Context	Ph	Size stone (cm)	Damaged (use surface)	Type	Shape (use surface)	Rock type	Rock subtype	Texture	Mineralogy
X8911		Stone pavement on top of house A, A150	b	40.5 × 34 × 16	Surface indentation (12 × 9 cm)	Block grinding slab/quern	Flat	Sedimentary (clastic)	Conglomerate	Coarse-grained clasts in a fine-grained matrix	Clasts
X8912		Upper stone layer grave A18	b	24.2 × 20.6 × 10.5	Side probably missing over 8 cm (small part)	Block grinding slab/quern	Flat	Metamorphic	Gneiss	Coarse-grained, foliated banding	Feldspars, quartz and mafic minerals
X8914		*Outside house B	a	14.8 × 13 × 7		Block grinding slab/quern	Flat	Igneous	Graphic granite	Coarse-grained, intergrowth of quartz and feldspar	Feldspars, quartz and mafic minerals
X8915		*Outside house B, A27	b	28.5 × 23 × 14.4	-	Block grinding slab/quern	Flat	Metamorphic	Gneiss	Coarse-grained, foliated banding	Feldspars, quartz and mafic minerals
X8916		Inside house B	a	27.7 × 19.6 × 12.5	Crack, surface partially removed (13 × 6 cm)	Block grinding slab/quern	Flat	Sedimentary (chemical)	Chert	Micro-crystalline	SiO ₂
X8918		Facade trench, A36	b	23.2 × 15 × 16		Block grinding slab/quern	Slightly concave	Metamorphic	Gneiss	Coarse-grained, foliated banding	Feldspars, quartz and mafic minerals
X8921		Upper stone layer grave A18	b	18.2 × 13.4 × 10.6		Block grinding slab/quern	Flat	Igneous	Micro granite	Medium-grained with coarse phenocrysts	Feldspars, quartz and mafic minerals
X8922		*Outside house A, A37	a	19.8 × 17.8 × 9.6	Surface indentation (3 × 1.5 cm)	Block grinding slab/quern	Flat	Metamorphic	Gneiss	Coarse-grained, foliated banding	Feldspars, quartz and mafic minerals
X8923	A (top, above find number)	*Inside house A, A38	b	19.4 × 14.8 × 7.6	-	Block grinding slab/quern	Flat	Igneous	Micro granite	Medium-grained	Feldspars, quartz and mafic minerals
X8923	B (bottom)	*Inside house A, A38	b	19.4 × 14.8 × 7.6	Surface indentation (2 × 5 cm)	Block grinding slab/quern	Flat	-	-	-	-
X8929		Stone heap, pre-cise location unknown	b	21 × 15.6 × 6.8	-	Saddle-shaped grinding slab	Concave	Igneous	Micro granite	Medium-grained	Feldspars, quartz and mafic minerals
X8930		Stone heap, pre-cise location unknown	b	25.8 × 21.2 × 6.5		Block grinding slab/quern	Flat	Igneous	Granite	Coarse-grained	Feldspars, quartz and mafic minerals

Table 2 (continued)

Find no	Side	Context	Ph	Size stone (cm)	Damaged (use surface)	Type	Shape (use surface)	Rock type	Rock subtype	Texture	Mineralogy
X8931	A (main surface)	Stone heap, precise location unknown	b	13.2 × 10.6 × 6.8	Partially cracked	Block grinding slab	Flat	Metamorphic	Granitic gneiss	Coarse-grained, foliated banding	Feldspars, quartz and mafic minerals
X8931	B (side)	Stone heap, precise location unknown	b	13.2 × 10.6 × 6.8		Block grinding slab	Flat	-	-	-	-
X8932		Stone heap, precise location unknown	b	12.6 × 10.6 × 6.7	-	Block grinding slab/quern		Igneous	Granite	Coarse-grained	Feldspars, quartz and mafic minerals
X8934		*Between houses A and B, A12	b	? × 13.8 × 8.8		Block grinding slab/quern	Slight concave	Metamorphic	Gneiss	Coarse-grained, foliated banding	Feldspars, quartz and mafic minerals

Context: A-nr = feature number (see also Fig. 1). Type: sensu (Wright 1992)

*Context presumably representing the primary find context

Ph. Phase

casts of seeds and fruit imprints in pottery were identified by M.H. Andreasen in 2024. Counts of carbonised macroremains (e.g. glume bases/spikelet forks) from the two laboratories were carefully harmonized. At Moesgaard Museum, the analysis focussed on samples rich in macroremains and, because of their exceptionality for this period and region, samples that contained durum wheat remains (as detected during screening of the samples). The selection procedure of samples analysed in Kiel was based on their archaeological context. The involvement of two different laboratories led to minor discrepancies concerning the precision of taxonomic identifications. Additionally, one laboratory counted complete cereal grains as well as fragments while the other quantified complete grains only (see ESM 2). Identification of wheat rachis segments follows Jacomet (2006).

For interpretations of the macroremains, taxa have been divided into four groups: cereals, woodland taxa, taxa of various types of open, disturbed terrain and grasslands that represent potential arable weeds, and unidentified remains (ESM 2). Some taxa classified as potential arable weeds have a wide ecological range and may also represent woodland taxa.

Interpretations on evidence of handling of macroremains by people are based on criteria like the carbonised state, edibility and nutrient content, their archaeological context, finds of concentrations and fragmentation (cf. Dietsch 1996; Bakels 2005; Out 2009).

To investigate whether a relationship exists between the archaeological context, chronological phase and sample content, correspondence analysis was applied to the macroremains samples including taxa occurring in $\geq 5\%$ of the samples and containing > 30 remains (cf. Jones 1991), using the software PAST (version 4.12b, Hammer et al. 2001; see Jones (1991) and Smith (2014) for methodological details). To assure a sufficiently large data set, some identifications were combined (see ESM 2 for details of the statistical analysis).

Grinding stone analysis

To determine the type of the geological raw material used for the grinding stones, these were examined visually after sampling microbotanical remains, using hand lens, Moh's hardness set and 10% hydrochloric acid.

Microremains analysis

For the study of the microremains from the grinding stones, two types of samples were collected: a) 16 samples from the stones and b) five sediment samples from various contexts as controls, when interpreting the remains from the grinding stone (ESM 3). Both sample types were subjected to phytolith and starch analysis. The grinding stones were superficially cleaned in the field but none of

the stones was washed prior to sampling. The grinding stones retrieved from stone heaps created during the excavation ($\times 8929$, $\times 8930$, $\times 8931$ and $\times 8932$) may have been exposed to rain in the field. Apart from these and a large stone ($\times 8911$), all stones were packed and stored in individual plastic bags until sampling took place at Moesgaard Museum in 2022.

For the remaining sediment control samples, ca. 20 g sediment was subsampled from five sediment samples available in 2022, collected with the aim of covering both activity areas A and B and representing both undisturbed contexts and contexts that would possibly provide a general refuse signal.

Sampling of microbotanical remains took place at Moesgaard Museum, processing took place at IMF-CSIC, phytolith analysis took place at Moesgaard Museum and starch analysis at IMF-CSIC. Sampling and processing followed protocols outlined in García-Granero et al. (2017, see also ESM 3). Residue recovery from the grinding stones' active surface(s) consisted of a two-step process in which the outer layer of sediment was first dry brushed (dry sample). Subsequently, the inner layer of sediment was brushed with deionised water (wet sample). Once the outer layer of sediment (dry sample) was removed from the artefact's active surface(s), the chances of contamination from the archaeological matrix where the artefact was embedded would have decreased considerably (Hart 2011). For this reason, microbotanical remains from grinding stones were analysed only from the wet samples. The wet samples as well as the sediment control samples were chemically processed at the BioGeoPal Laboratory (IMF-CSIC) to isolate and recover starch grains and phytoliths following a series of preestablished steps, which included the application of 5% sodium hexametaphosphate ($[\text{Na}(\text{PO}_3)_6]$) to deflocculate clays, sodium polytungstate ($\text{H}_2\text{Na}_6\text{O}_{40}\text{W}_{12}$) at a specific gravity of 1.8 g/cm^3 to isolate starch grains, 5% hydrochloric acid (HCl) to dissolve calcium carbonates, 30% hydrogen peroxide (H_2O_2) to oxidise organic matter and sodium polytungstate at a specific gravity of 2.35 g/cm^3 to isolate phytoliths (see ESM 4 for a detailed description of the extraction protocol). During laboratory processing, a blank sample (an empty, new and sterile plastic centrifuge tube) was subjected to the same steps as the archaeological samples to check against potential environmental contamination from modern starch grains (Crowther et al. 2014).

Phytolith samples were analysed at Moesgaard Museum using a Nikon Eclipse Ci at $630\times$ equipped with a Nikon DS-Fi1 camera. Slides from sediment samples were scanned until ca. 300 phytoliths were identified, whereas slides from grinding stone samples were fully scanned and every observed phytolith was morphologically identified.

The phytolith nomenclature follows the International Code for Phytolith Nomenclature v. 2.0 (ICPT 2019).

The phytolith data include the acid insoluble fraction (AIF), indicating the siliceous material present in the sample, including heavy minerals, quartz, clay and phytoliths (Albert and Weiner 2001) and the number of phytoliths per gram of the AIF. The latter value facilitates comparison between samples and sites independent of possible sediment diagenesis.

Starch grain samples were analysed at IMF-CSIC with an Olympus BX51 microscope attached to a Zeiss Axiocam 208 colour camera for microphotography. All samples were fully scanned at $200\times$ magnifications, and all starch grains were photographed under plain and cross-polarised transmitted light at $400\times$ magnifications and measured (maximum length) with the Zeiss Zen Blue 3.4 software. Starch grain description follows the International Code for Starch Nomenclature (ICSN 2011). Archaeological grains were compared with the modern starch reference collection housed at IMF-CSIC, which includes the starch-rich domestic and wild plants most commonly recovered in FB sites in Denmark (see Introduction amongst others: *Triticum* and *Hordeum* spp., *Corylus avellana*, *Quercus* spp., *Arrhenatherum elatius* ssp. *bulbosum* (tuber oat-grass), *Persicaria maculosa* (red-shank), *Rumex* spp. (dock), *Chenopodium album* and tubers of *Ficaria verna* (lesser celandine), as well as *Fagopyrum esculentum* (buckwheat), a crop that was commonly cultivated on Fynen in the recent past).

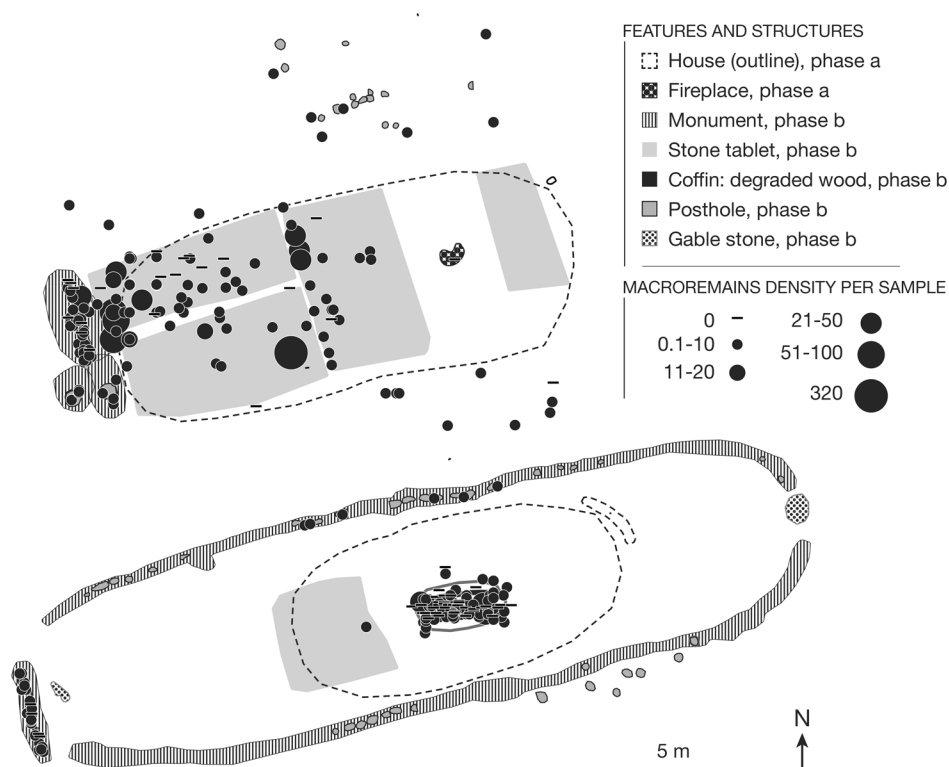
Results

Macroremain samples – general observations

The average number of finds of the 313 analysed macroremain samples of the FB phase (phase a and b together), with a total sample volume of 3,094 L and 13,750 remains, was 4.4 carbonised seeds, fruits and/or underground storage organs (tubers)/L. 20.8% of the samples contained no macroremains, 46.6% 1–10 remains, 26.8% 11–100 remains and 5.8% > 100, up to 2,178 remains per sample (Fig. 3).

Overall, the FB find material included cereal grain and chaff (83%), taxa of woodland vegetation (7%), potential arable weeds (4%) and unidentified material (6%) (Table 3, ESM 5), all preserved in carbonised state. 29% of the samples, 47% of the sample volume and 75% of the macroremains date to phase a. With the exception of one sample from house A, all phase a-samples consist predominantly of cereal remains (84% of the phase a-assemblage) and come primarily from the cultural layer inside the house (63% of phase a). The phase b-samples, representing 71% of the samples, 53% of the sample volume and 25% of the macroremains, are also dominated by

Fig. 3 Frydenlund, Funnel Beaker phase, spatial distribution and density of the macroremains samples (number of finds/litre), based on samples subjected to macroremains analysis (ESM 5)



cereals (65% of the phase b-assemblage). 41% of the phase b-remains originate from the facade trench, stone tablets and pits of monument A and 59% to the facade trench, palisade, a stone tablet and coffin that form monument B (Table 3).

Macroremain samples – cereals, weeds and cultivation practices

The main cereals include tetraploid free-threshing *T. durum/turgidum*, interpreted as durum wheat (see ESM 1: grains and rachis segments), *T. dicoccum* grains, spikelet forks and glumes and *H. vulgare* var. *nudum* grains and few rachis internodes (Table 4, ESM 6). The cereal remains were particularly found in and around the western part of house A and in features of phase b that can be interpreted as sediment from phase a, which was deposited secondarily (Fig. 4). There are no clear differences in the spatial distribution of the various cereal taxa (Fig. 4a). Cereal grains are found inside and at various locations outside house A while chaff is found mostly directly west of house A (Fig. 4b and unpubl. data of cereal grain and chaff ratios). The chaff concentration outside the house can be interpreted as an outdoor cereal processing area. It is also in this area where cereal grain fragments and unidentifiable cereal remains are found. Low quantities of scattered cereal grain remains outside the house may reflect secondary deposition patterns.

Triticum durum was quantitatively dominant, which may partly result from sample selection (see Materials and

methods), with *T. dicoccum* and *Hordeum* as secondary crops. However, *Hordeum* was most ubiquitous (occurring in 44% of the samples), while the large quantity of unidentified cereals hampers the interpretations of the actual cereal ratios. *Triticum monococcum*, present in moderate numbers only (<50 grains, 65 glume bases), could represent einkorn or poorly developed material from the top of emmer ears (Nesbitt and Samuel 1996, p 56). The presence of *T. aestivum* (bread wheat) cannot be excluded from the free-threshing grains but is only confirmed by a single rachis segment. In the case of *Hordeum*, caryopses (grains) were much more common than internodia, and this crop may therefore have arrived at the site as a cleaned product consisting primarily of grains (possibly imported from further away or cultivated nearby and cleaned off-site). In the cases of *T. dicoccum* and *T. durum*, hundreds of spikelet forks and rachis remains found in the cultural layers of house A, phase a, indicate the presence of complete ears, which were processed here on a regular basis and thus presumably also stored. Particularly, the rachis segments of free-threshing wheat suggest that the fields of this crop were not far away and that the assemblage represents products resulting from various stages of crop processing. However, the absence of more culm and rachis fragments (not demonstrated in the phytolith analysis of the sediment samples either) as well as the low quantity of cereal weeds (see below) suggest that it concerns household activities rather than threshing or another processing stage shortly after harvesting.

Samples	Volume (l)	Ph	House/ Context	Absolute numbers	Percentages
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Table 3 (continued)

Samples (n)	Volume (l)	Ph	House/ monument (A or B)	Context	Absolute numbers			Percentages								
					Cereals, grains	Cereals, other		Cereals, grains	Woodland arable weeds	Indet	Total	Cereals, grains	Cereals, other weeds	Woodland arable weeds	Indet	Total
34	247	b	B	Coffin, fill	336	194	29	21	30	610	3.1	1.8	0.3	0.2	0.3	5.6
32	207	b	B	w	254	270	43	4	16	587	2.3	2.5	0.4	0.0	0.1	5.4
3	41	b	B	Coffin, floor area	4	0	1	1	4	10	0.0	0.0	0.0	0.0	0.0	0.1
4	19	b	B	Coffin, underneath	2	0	3	0	3	8	0.0	0.0	0.0	0.0	0.0	0.1
28	178	b	B	Coffin, outside	45	1	30	12	19	107	0.4	0.0	0.3	0.1	0.2	1.0
Total		b	B		745	491	178	65	156	1,635	6.8	4.5	1.6	0.6	1.4	15.0

Cereal grain fragments: four fragments have been counted as one cereal grain. See ESM 5 for the results from the Single Grave Culture and Bronze Age

Due to their different anatomy, affecting plant processing, *T. durum* and *T. dicoccum* were most likely cultivated separately and not as a maslin. The fact that naked *Hordeum* chaff is scarce while rachis fragments of free-threshing wheat are common suggests that also these crops were cultivated separately, which makes sense considering the divergent ecological preferences and tolerances of naked barley and durum wheat (although slightly differential preservation cannot be excluded, Boardman and Jones 1990).

The potential arable weeds include a wide range of taxa, most of which occur in very low numbers only. The most common finds are fruits of the grass family (Poaceae, n=306, in 10% of the samples, possibly representing underdeveloped cereal grains) and the legume family (Fabaceae, n=91, in 10% of the samples, see also ESM 7 for their spatial distribution). These taxa were also found in a relatively large quantity (>10) within a single sample, and in both cases, in a sample rich in cereals (X7520 and X7521), suggesting that these taxa are true arable weeds. Taxa found less frequently and in smaller numbers, but that also likely represent arable weeds, are *Bromus* sp. (brome grass), *Atriplex* sp. (orach), *Chenopodium album*, *Fallopia convolvulus* (black-bindweed), *Persicaria maculosa*, *Rumex acetosella* (red sorrel), *Stachys arvensis* (field woundwort), *Stellaria media* (chickweed), *Veronica hederifolia* (ivy-leaved speedwell), *Vicia* sp. (vetch) and possibly *Galium aparine* (cleavers, though see also below). These taxa, so far identified at species/genus level, are predominantly spring-sown annuals or indifferent, indicating summer crop cultivation and long-lasting cultivation at more or less permanent plots, where perennials have limited chances to grow due to intensive cultivation practices (Behre 1981; Bogaard 2004, pp 96–99; Bogaard and Jones 2007; Kreuz and Schäfer 2011; cf. Out 2009).

Macroremain samples – gathered plants including spatial analysis

The woodland taxa include carbonised seeds/fruits of *Tilia* sp. (lime), *Quercus*, *Corylus*, *Rubus fruticosus*, *R. idaeus*, *R. caesius*/*R. idaeus* and tubers of *Ficaria verna* (see Table 4 and ESM 5). A single imprint was identified as *Malus/Pyrus* (X3050, phase b, A89). Finds of *Corylus* shell fragments and tubers of *Ficaria* clearly dominate this group (both ca. 400 finds) and were also found in many samples (42% and 35%, respectively); *Tilia* fruits were found regularly (including cf.: ca. 100), while the other taxa occur in minor quantities only. Overall, the density of finds of these taxa is, like that of the arable weeds, very low. None of the woodland taxa occurs in obvious anthropogenic concentrations (see ESM 7 for the spatial distribution of *Tilia*, *Corylus* and *Ficaria*). The fragmented state of the hazelnut shells and their edibility support that the

Table 4 Frydenlund, Funnel Beaker phase, percentage and frequency in the assemblage

Taxa	Plant part	N _{total}	%	Frequency (%)
Crop plants				
<i>Hordeum vulgare</i> (barley)	Grain	215	1.6	28
<i>H. vulgare</i> var. <i>nudum</i> (naked barley)	Grain/rachis internode	242/13	1.8/0.1	32/2
<i>Triticum aestivum/durum/turgidum</i> * (bread/hard/rivet wheat)	Grain/rachis segment	915/1,732	6.7/12.6	25/12
<i>T. aestivum</i> ssp. <i>aestivum</i> /cf. <i>aestivum</i> ssp. <i>aestivum</i>	Rachis segment	1/1	0.0/0.0	0/0
<i>T. turgidum</i> ssp. <i>durum/turgidum</i> (hard/rivet wheat)	Rachis segment	1,263	9.2	10
<i>T. turgidum</i> ssp. <i>dicoccum</i> (emmer)	Grain	280	2.0	16
<i>T. turgidum</i> ssp. <i>dicoccum</i>	Spikelet fork/glume base	124/728	0.9/5.3	4/11
<i>T. monococcum</i> ssp. <i>monoc.</i> (einkorn)/cf. <i>monoc.</i> ssp. <i>monoc.</i>	Grain	26/1	0.2/0.0	4/0
<i>T. monoc.</i> ssp. <i>monoc.</i> /cf. <i>monoc.</i> ssp. <i>monoc.</i>	Glume base	63/2	0.5/0.0	3/0
<i>T. monoc.</i> ssp. <i>monoc.</i> / <i>T. turgidum</i> ssp. <i>dicoccum</i>	Glume base/spikelet fork	286/368	2.1/2.7	7/5
<i>T. cf. timopheevii</i> (cf. Timopheev's wheat)	Glume base	3	0.0	0
<i>Triticum</i> sp. (wheat)	Grain/rachis segment	97/86	0.7/0.6	7/2
Cerealia indet.	Grain/grain fragment	1,063/3,766	7.7/27.4	32/25
Cerealia indet.	Rachis segment	165	1.2	4
cf. Cerealia indet.	Culm node/culm	3/4	0.0/0.0	1/1
Woodland taxa				
<i>Tilia</i> sp. (lime)/ cf. <i>Tilia</i> sp.	Fruit	47/48	0.3/0.3	7/6
<i>Corylus avellana</i> (hazel)	Fruit, fragment/perianth	405/4	2.9/0.0	42/1
<i>Quercus</i> sp. (oak)	Cupula/pericarp, hilum	1/1	0.0/0.0	0/0
<i>Rubus fruticosus</i> agg. (blackberry group)/ <i>R. idaeus</i> (raspberry)	Fruit	12/3	0.1/0.0	3/1
<i>Rubus idaeus/caesius</i> (rasp-/dewberry)/ <i>Rubus</i> sp.	Fruit	5/6	0.0/0.0	2/2
<i>Ficaria verna</i> (lesser celandine)/cf. <i>F. verna</i>	Tuber	379/4	2.8/0.0	35/0
Potential arable weeds				
<i>Avena</i> sp. (oats, presumably wild)	Grain	4	0.0	1
cf. <i>Panicum miliaceum</i> (broomcorn millet)	Grain	0	0.0	0
<i>Arrhenatherum elatius</i> ssp. <i>bulbosum</i> (tuber oat-grass)/cf	Bulb	15/2	0.1/0.0	4/1
<i>Atriplex</i> sp. (orache)	Fruit	1	0.0	0
<i>Brassica</i> sp. (cabbage/mustard)	Seed	1	0.0	0
<i>Bromus</i> sp. (brome grass)	Fruit	9	0.1	2
<i>Carex muricata/vulpina</i> (rough/true fox sedge)	Fruit	2	0.0	1
<i>Carex</i> sp., bicarpellate/tricarpellate (two/three-sided fruits)	Fruit	2/1	0.0/0.0	1/0
Caryophyllaceae (carnation family)	Seed	3	0.0	1
<i>Chenopodium album</i> (fat hen)/ <i>Chenopodium</i> sp. (goosefoot)	Fruit	3/3	0.0/0.0	1/1
Fabaceae (legume family)/cf. Fabaceae	Seed	91/8	0.7/0.1	10/1
<i>Fallopia convolvulus</i> (black-bindweed)	Fruit	11	0.1	3
<i>Festuca/Lolium</i> (fescue/perennial ryegrass)	Fruit	1	0.0	0
<i>Galeopsis</i> sp. (hemp-nettle)	Fruit	2	0.0	1
<i>Galium aparine</i> (cleavers)/ <i>Galium</i> sp.	Fruit	9/23	0.1/0.2	3/5
cf. <i>Galium</i> sp.	Fruit fragment	2	0.0	0
cf. <i>Hypericum</i> sp. (cf. St. John's wort)	Seed	2	0.0	0
Lamiaceae (mint family)	Fruit	15	0.1	3
<i>Lathyrus/Pisum/Vicia</i> (grass pea/pea/vetch)	Seed	5	0.0	2
<i>Linum catharticum</i> (purging flax)	Seed	1	0.0	0
cf. <i>Medicago lupulina</i> (hop clover)/cf. <i>M. minima</i> (bur medick)	Seed	1/4	0.0/0.0	0/0
<i>Melilotus/Medicago/Trifolium</i> (sweet clover/medick/trefoil)	Seed	9	0.1	2
Panicoideae (panicoid grass subfamily)	Fruit	1	0.0	0
<i>Persicaria maculosa</i> (redshank)/ <i>P. maculosa/lapathifolia</i>	Fruit	3/1	0.0/0.0	1/0
<i>Plantago lanceolata</i> (ribwort plantain)	Seed?	2	0.0	1
Poaceae (grass family)/Cerealia indet. (cereals)	Fruit	325	2.4	10

Table 4 (continued)

Taxa	Plant part	N _{total}	%	Frequency (%)
Polygonaceae (knotweed family)	Fruit	4	0.0	1
<i>Polygonum aviculare</i> (common knotgrass)/ <i>P.</i> sp. (knotweed)	Fruit	3/1	0.0/0.0	1/0
<i>Ranunculus</i> sp. (buttercup)	Fruit	2	0.0	1
<i>Rumex acetosella</i> (red sorrel)	Fruit	3	0.0	1
<i>Rumex conglomeratus</i> (clustered dock)	Fruit	4	0.0	1
<i>Rumex obtusifolius</i> (bitter dock)/ <i>Rumex</i> sp. (dock)	Fruit	1/12	0.0/0.1	0/3
<i>Stachys arvensis</i> (field woundwort)/ <i>Stachys</i> sp. (hedgenettle)	Fruit	3/3	0.0/0.0	1/1
<i>Stellaria media</i> (chickweed)	Seed	1	0.0	0
<i>Trifolium</i> sp. (trefoil)	Seed	5	0.0	1
<i>Veronica hederifolia</i> (ivy-leaved speedwell)/ <i>Veronica</i> sp.	Seed	9/1	0.1/0.0	3/0
<i>Vicia</i> sp. (vetch)	Seed	1	0.0	0
<i>Viola</i> sp. (violet)	Seed	1	0.0	0
Unidentified remains				
Indet.	Seed, fruit/unknown	505/3	3.7/0.0	29/1
Indet.	Vegetative/flower	99/1	0.7/0.0	14/0
Indet.	Mush, fruit, processed food	10	0.1	0
Indet.	Tuber/cf. tuber	9/20	0.1/0.1	3/3
Indet.	cf. Tuber, fragment	115	0.8	11
Total		13,750	100	

Frequency: % of 313 samples. Cf.=uncertain identification. *Triticum aestivum/durum/turgidum*=*Triticum aestivum* subsp. *aestivum*/*Triticum turgidum* subsp. *durum*/*Triticum turgidum* subsp. *turgidum*

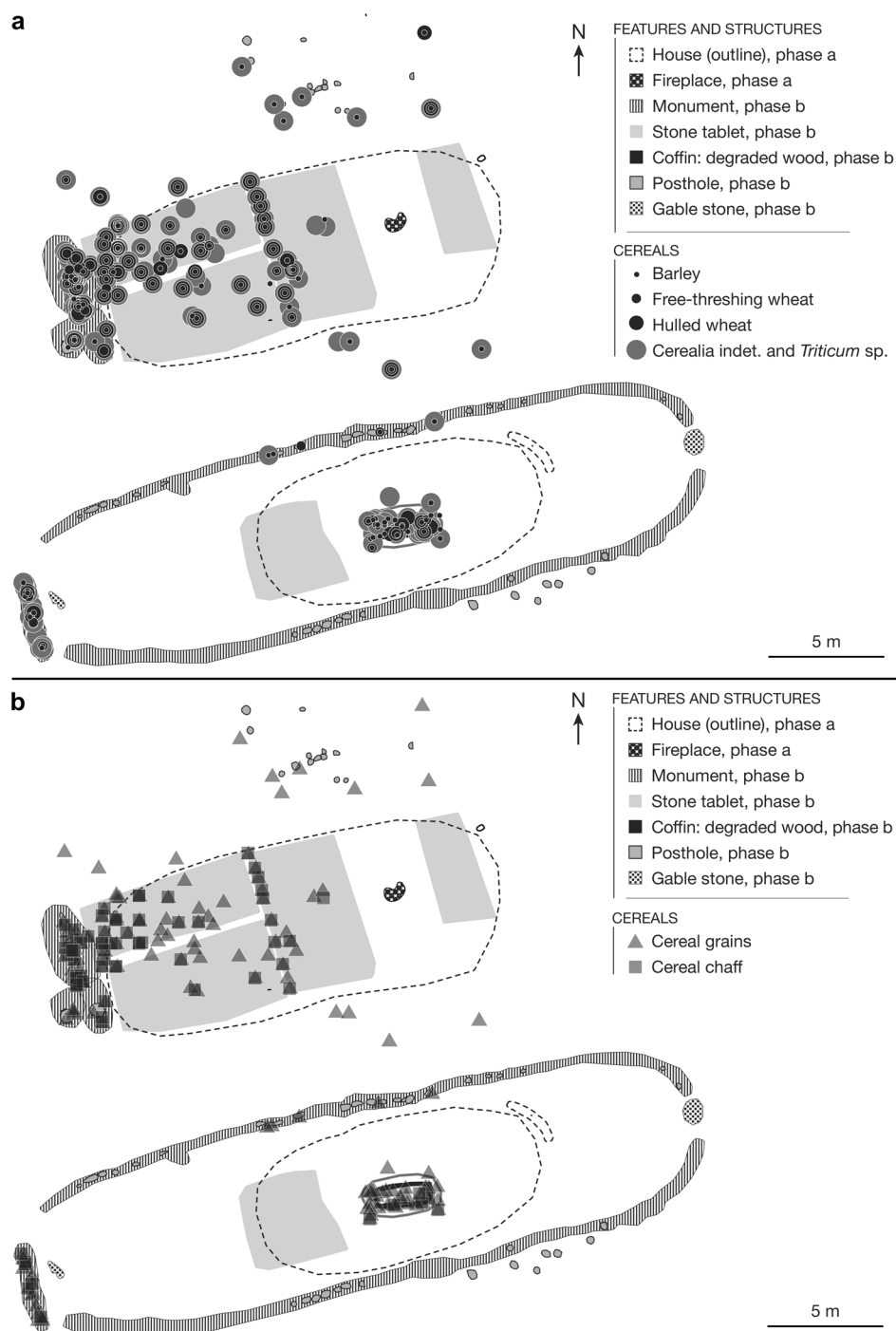
nuts were consumed. People may have eaten blackberry and raspberry as well, but other than 26 carbonised fruits (“seeds”, not berries), evidence of handling by people is lacking. The presence of lime fruits and acorns can be explained as the use of these taxa as fuel and/or for other purposes. The function of the tubers of *Ficaria* remains unclear. The tubers are edible (Klöß et al. 2016), but the fact that they are as common as hazelnut shells could equally indicate that the taxon at this site represents waste rather than a food source. Perhaps it grew on the spot and got carbonised by accident. Its spatial distribution does not necessarily support consumption either (ESM 7). Similar to various other taxa (ESM 7), its distribution matches the distribution of carbonised remains, particularly clustering in and around the western part of house A, during phase a, while it is found evenly spread over features during phase b. The latter indicates that refuse from phase a was redeposited during phase b and does not reflect primary activity or deposition zones.

Macroremains – relation between context, location and content?

The results of the correspondence analysis (Fig. 5), based on 43 samples, shows no significant differentiation between samples from phases a and b nor an association between the sample content and context (Fig. 5a, see also Table 3).

The assemblage from the hearth in house A does not stand out either. Nevertheless, three clusters can be distinguished (Fig. 5b). The first axis, explaining 30% of the variance, separates samples characterised by cereal chaff and grass family grains (including small cereal grains and/or arable weeds) on the one hand (in the upper left quadrant) and samples less characterised by chaff on the other hand (Fig. 5b: encircled in the lower middle part and on the right). The samples characterised by cereal chaff are all located directly west of house A (apart from sample X7523), suggesting that some cereal processing took place outside, close to the house wall. The second axis, explaining 17% of the variance, primarily separates remains of cereal grains (lower part of graph) from chaff and wild plants such as *Corylus avellana*, *Tilia*, *F. verna*, Fabaceae and unidentified tubers (upper part graph), possibly separating food and non-food or waste samples. These samples are all either located in the middle of house A, outside the house or date to phase b, and are spatially unrelated to the cereal concentration(s) in the western part of and west of house A. This indicates that the wild taxa in the right upper part of Fig. 5b were not processed and/or stored together with cereals and did probably not function as arable weeds.

Fig. 4 Frydenlund, Funnel Beaker phase, spatial distribution of the cereal species, grains and chaff. **a** distribution of the various taxa, **b** distribution of grains versus chaff. **b** the category chaff includes all remains other than grains: culm fragments, rachis fragments, spikelet forks and glume bases. The largest quantities of chaff are found west of house A



Grinding stones analysis

The grinding stones were predominantly made of medium to coarse-grained granites or gneisses; rock types that are characterised by a high hardness given their formation at high temperature and pressure (12 out of the 14 grinding stones, see Table 2). The two remaining grinding stones were sedimentary rocks made from conglomerate and chert, respectively (X8911 and X8916). The raw material used for

the grinding stones reflects the easy availability of such rock types amongst ice-deposited boulders in the surrounding landscape likely combined with the knowledge that coarse-grained stones better tear and grind vegetative matter, while smooth fine-grained rocks such as chert functions best for polishing (e.g. Dubreuil 2001).

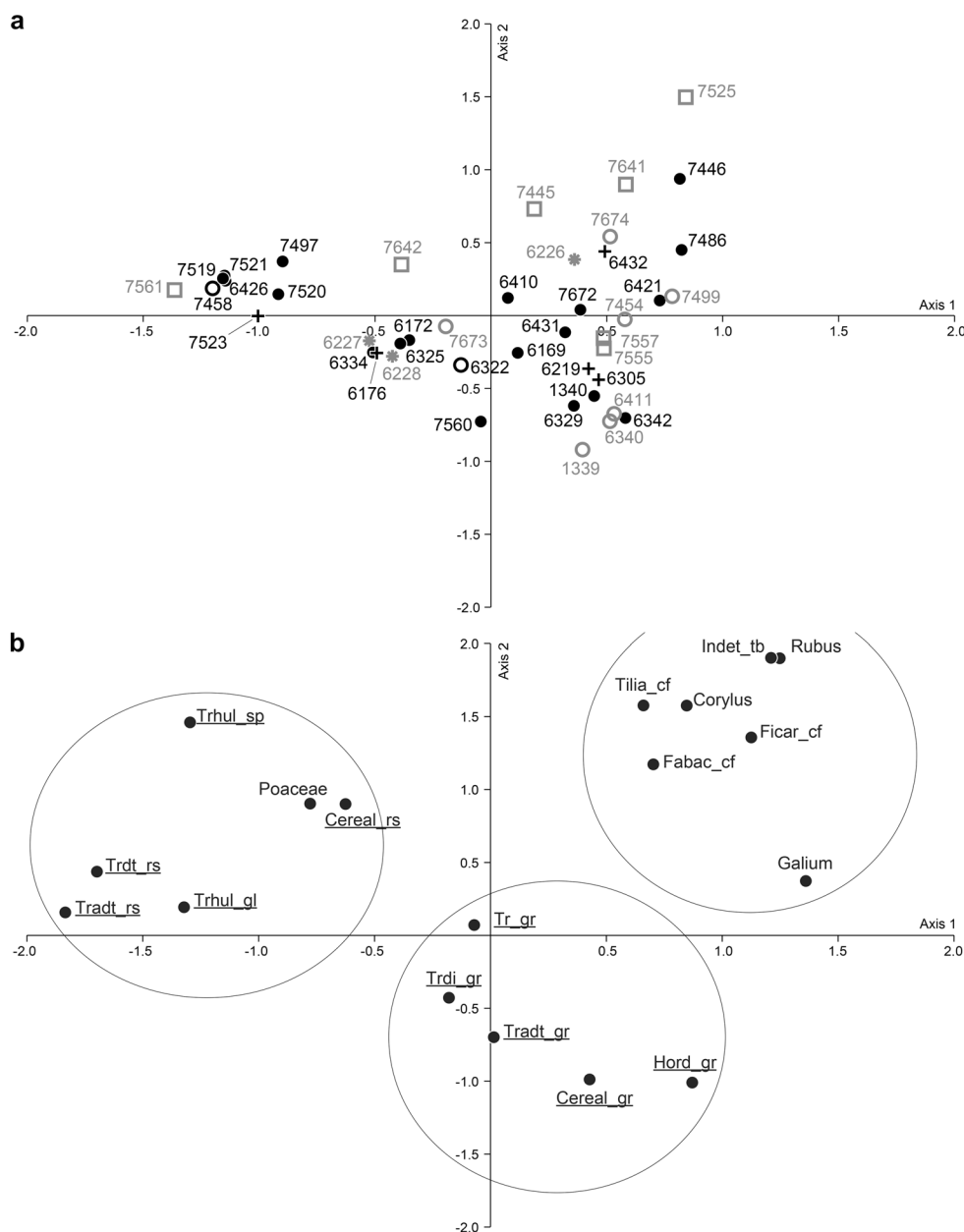


Fig. 5 Biplot of the correspondence analysis of carbonised macroremains (expressed in % per sample), first two eigenvectors representing the main variance in the data set, **a** samples labelled by phase and context; **b** taxa incl. plant part (cereals underlined). Reading instructions: The samples shown in e.g. the left part of the plot in **a** are more than other samples characterised by taxa and remains (plant parts) shown in the same part of the plot in **b**. **a** shows that there is no clear relationship between phase or context and content since there are no

clear clusters of colours (grey tones) or symbols. **a** samples: Symbols: *black* phase a, *grey* phase b, *filled dot* cultural layer, *open circle* stone tablet, *open square* facade trench and facade posthole, *+* posthole, *star* coffin. **b** taxa and remains: *Hord* *Hordeum* sp., *Tr* *Triticum* sp., *Cereal* *Cerealia*, *adt* *aestivum/durum/turgidum*, *dt* *durum/turgidum*, *didicocum*, *Fabac* *Fabaceae*, *Ficar* *Ficaria* sp., *hul* hulled, *gr* grain, *rs* rachis segment, *gl* glume, *tb* tubers (underground storage organs). See ESM 2 for further explanation of the codes of the plant names

Microremain samples: phytoliths from the grinding stones

The phytolith concentration of the sediment control samples varied between 0 and 4,400 phytoliths/g of AIF (acid insoluble fraction) (Table 5). This implies that phytolith

production in the region was probably low and that phytolith preservation at the site is very variable (discussed further below). Remains other than phytoliths common in the sediment samples were sponge spicules, which are commonly found in soils in northwestern Europe.

Eleven of the 16 samples from the grinding stones revealed ≤ 20 phytoliths (see Table 5) and are therefore considered as sterile. The remaining samples that contained larger numbers of phytoliths were derived from grinding stones X8911, X8912, X8914, X8916 and X8934, which were retrieved from inside and outside of house B and between houses A and B (all phase a), the stone pavement of house A (phase b), and above the stone layer of the coffin in monument B (phase b). Stones X8912 and X8934 were presumably found in primary context, while the other three were not.

The phytolith concentration of the grinding stone samples (Table 5, ESM 8, ESM 9) varied between 0 and 58,000 phytoliths/g of AIF. The samples primarily yielded CRENATE, TRAPEZIFORM and RONDEL phytoliths, which in temperate climates are characteristic of the Pooideae grass subfamily as well as BILOBATE and some POLYLOBATE including TRILOBATE that are typically assigned to the Panicoideae subfamily, although they may also occur in other taxa within the Poaceae (e.g. Arundinoideae). Based on the Neolithic crop assemblage, only remains of Pooid crops are expected, although admixture with Panicoid weeds cannot be excluded (the macroremains assemblage contained one carbonised Panicoideae seed). Other dominant morphotypes are ELONGATE ENTIRE, ELONGATE DENTATE (of which a part possibly represents weathered ELONGATE DENDRITIC), ELONGATE SINUATE, ELONGATE WEATHERED and ACUTE BULBOSUS. Comparison of the phytolith assemblages of the grinding stones from phases a and b does not point to any substantial differences.

Microremains – starch from the grinding stones

A total of 48 starch grains were recovered from one sediment sample (five starch grains) and 13 samples from grinding stones (43 starch grains; Table 6), while starch was not observed in the blank sample. Nine different morphotypes were identified in the archaeological samples, among which two could be identified to different taxonomic levels (Table 7, Fig. 6, ESM 10). See ESM 11 for detailed morphotype descriptions and additional photographs of starch granules of archaeological and modern material (including *Ficaria verna*). Unequivocal starch grains from cereals, pulses and wild edible plants such as *Corylus avellana*, *Quercus* spp. and *Ficaria verna* were not identified.

Discussion

Plant use at Frydenlund in comparison to other Funnel Beaker sites: crops, cultivation practices and use of wild plants; implications from macroremains.

The carbonised macroremains assemblage from Frydenlund, dominated by naked *Hordeum*, *T. dicoccum*, *T. durum* and *Corylus avellana*, complemented by small percentages

of potential arable weeds and potential wild food plants such as *R. fruticosus*, *R. idaeus*, tubers of *F. verna*, *A. elatius* ssp. *bulbosus* and various herbs edible as greens, generally matches the assemblages of other FB sites in Denmark, Germany, Sweden and the Netherlands (Bakels and Zeiler 2005; Regnell and Sjögren 2006; Hallgren 2008; Sørensen and Karg 2014; Kirleis 2019, 2022; Table 1). Considering the short activity period at Frydenlund, the assemblage of crops and other plant food resources is remarkably varied, but besides many similarities, the assemblage also deviates from other FB sites in several ways. For instance, *Linum* and *Papaver*, known from other FB sites, are apparently absent at Frydenlund, but this can possibly be attributed to depositional and taphonomical aspects (see Introduction). Moreover, *T. durum* is almost unique for this part of Europe and points to southwest oriented connections in Europe (e.g. Michelsberg culture and/or Bischheim group, Bakels 2008; Kirleis and Fischer 2014; Kreuz et al. 2014; Roushannafas et al. 2023, also Swifterbant culture, Kubiak-Martens 2023). At one comparable FB site, the causewayed enclosure of Albersdorf LA68, Dieksknöll (3760–2500 cal BCE, Early to Younger Neolithic), few imprints of *T. durum* rachis fragments were found on a ceramic disc (Kirleis and Fischer 2014; Kirleis 2019, p 72), while at the archaeologically comparable sites Stengade I and Siggeneben-Süd its presence is practically unknown (Hjelmqvist 1975: single impression of free-threshing wheat; Meurers-Balke 1983: no macroremains). *Triticum durum*, apparently the dominant cereal at Frydenlund, requires deep rich soils and is suited to warm and relatively dry conditions while ripening (compared to northern European standards; Roushannafas et al. 2023). Despite *T. durum*'s preference for rich soils, isotope analysis ($\delta^{15}\text{N}$) of 20 *T. durum* and naked *Hordeum* grains from Frydenlund shows (with one exception) values matching those for unmanured fields (Gron et al. 2021 suppl. data), as is the case for *T. dicoccum* from Sarup (Fraser et al. 2011; Bogaard et al. 2013). This is in partial contrast to the Middle Neolithic FB site of Oldenburg LA77, ca. 120 km to the southeast, where *T. dicoccum* was manured, while *Hordeum* was not (Filipović et al. 2019).

The presence of *T. durum* may suggest the consumption of food products consisting of fragmented cereal grains (e.g. bulgur), since it does not produce a flour as fine as that of *T. aestivum* (Alonso 2019). Indeed, many fragmented cereal grains were present at Frydenlund. However, although the thousands of unidentified cereal grain fragments have not been systematically analysed for indications of food preparation, shiny surfaces indicative of parboiling of fragments prior to charring were not observed (see ESM 6), and analysis of a subsample did not reveal any indications of bulking that results from fragmentation before charring (cf. Valamoti et al. 2021). It is therefore most parsimonious to assume that the fragmentation of the cereal grains was caused by

Table 5 Quantitative phytolith data, expressed in absolute numbers. Counts of multi-cell phytoliths are included in the overall counts. Undet. = morphotype classified, but not further attributed; Conc. = Phytolith concentration (phytoliths/g of AIF); rounded

Taxon	Phytoliths										Sponge spicule fragm
	Poaceae	Poaceae	Poaceae	Poaceae	Poaceae	Poaceae	Poaceae	Poaceae	Poaceae	Poaceae	
Cell type	Short cells	Short cells	Short cells	Short cells	Short cells	Short cells	Short cells	Short cells	Short cells	Short cells	
Taxon/plant part	Pooid	Panicoid	Undet	Undet	Undet	Undet	Undet	Undet	Undet	Undet	
Sediment samples (sample ID)											
4589	101	28	11	74	31	43	2	28	41	316	4400
8808	70	24	13	66	46	43	2	12	18	294	2900
8810	2	1		1				2	1	7	<50
8813	79	50	12	28	76	37	1	7	14	306	1000
8815					1					1	<50
Grinding stone samples (sample ID)											
8911	65	20	16	23	15	17	1	10	21	192	2800
8912	37	6	11	35	4	18	2	14	11	138	1400
8914	10	2		26	1	14		13	10	76	700
8915									1	0	0
8916	2	1		16		1		4	10	31	500
8918									2	0	0
8921	1	1		4				1	5	12	75
8922	1								2	2	<50
8923A				1					3	2	<50
8923B		2	1	1	1	3	1	1	2	11	250
8929		1		1				3	4	9	250
8930				1				1	2	4	150
8931A										0	0
8931B										0	0
8932										0	0
8934	51	5	3	11	8	5		4	10	97	58,000
											5

Table 6 Starch grain identifications of the sediment samples and the grinding stones

Type	1	2	3	4	5	6	7	8	9	Total
Sediment samples										
X4589										0
X8808										0
X8810	3		1	1						5
X8813										0
X8815										0
Grinding stone samples										
X8911				1						1
X8912	2									2
X8914				2	1					3
X8915	1	1				1				3
X8916	1			1						2
X8918	3		1	3						7
X8921	2						1			3
X8922										0
X8923 A	2					1		1		4
X8923 B	4									4
X8929	1		1	1						3
X8930	5			1					1	7
X8931 A	1									1
X8931 B										0
X8932										0
X8934	3									3

Table 7 Starch grain morphotypes identified in the archaeological samples

Type	N	Size (µm)		Shape	Taxonomy
		Range	Mean (StD)		
1	28	14.126–23.266	18.180 (2.449)	Polyhedral	Panicoideae-type
2	1	13.567	–	Ovoid	cf. USO
3	3	22.559–25.709	24.079 (1.578)	Irregular	Unknown 1
4	10	10.849–17.827	13.853 (2.446)	Ovoid	Unknown 2
5	1	15.683	–	Bell-shaped	Unknown 3
6	2	19.367–21.350	20.359 (1.402)	Ovoid	Unknown 4
7	1	12.933	–	Elongated polyhedral	Unknown 5
8	1	11.249	–	Spherical	Undiagnostic
9	1	16.260	–	Sub-round	Unknown 6

taphonomisation after charring (though before excavation, as supported by morphological analysis) rather than by intentional fragmentation as part of food preparation. This is supported by the absence of evidence of cereal processing from the grinding stones (see below).

The low quantity and density of potential arable weeds from Frydenlund hamper detection of a straightforward arable weed assemblage that can directly inform about cultivation practices, but nevertheless the weeds suggest careful weeding, spring-sown cultivation and plots with a permanent character (cf. Gron and Rowley-Conwy 2016). The low number of weeds corresponds with other studies of FB

assemblages (Robinson 2003, p 163; Kirleis 2019), while the cultivation practices align with those deduced for the Swifterbant culture (Out 2009).

Wild plants, an apparent outstanding aspect of the macroremains assemblage from Frydenlund, include a large number of tubers of *F. verna* (and fragments of unidentified tubers), whose function remains unknown (see discussion in Jensen et al. 2010; Roehrs et al. 2013; Kloof et al. 2016). Wild food sources that are remarkably absent in the Frydenlund macroremains assemblage include fruits of *Prunus spinosa* and *Malus sylvestris*, considering the chances that these taxa were available in the exploitation

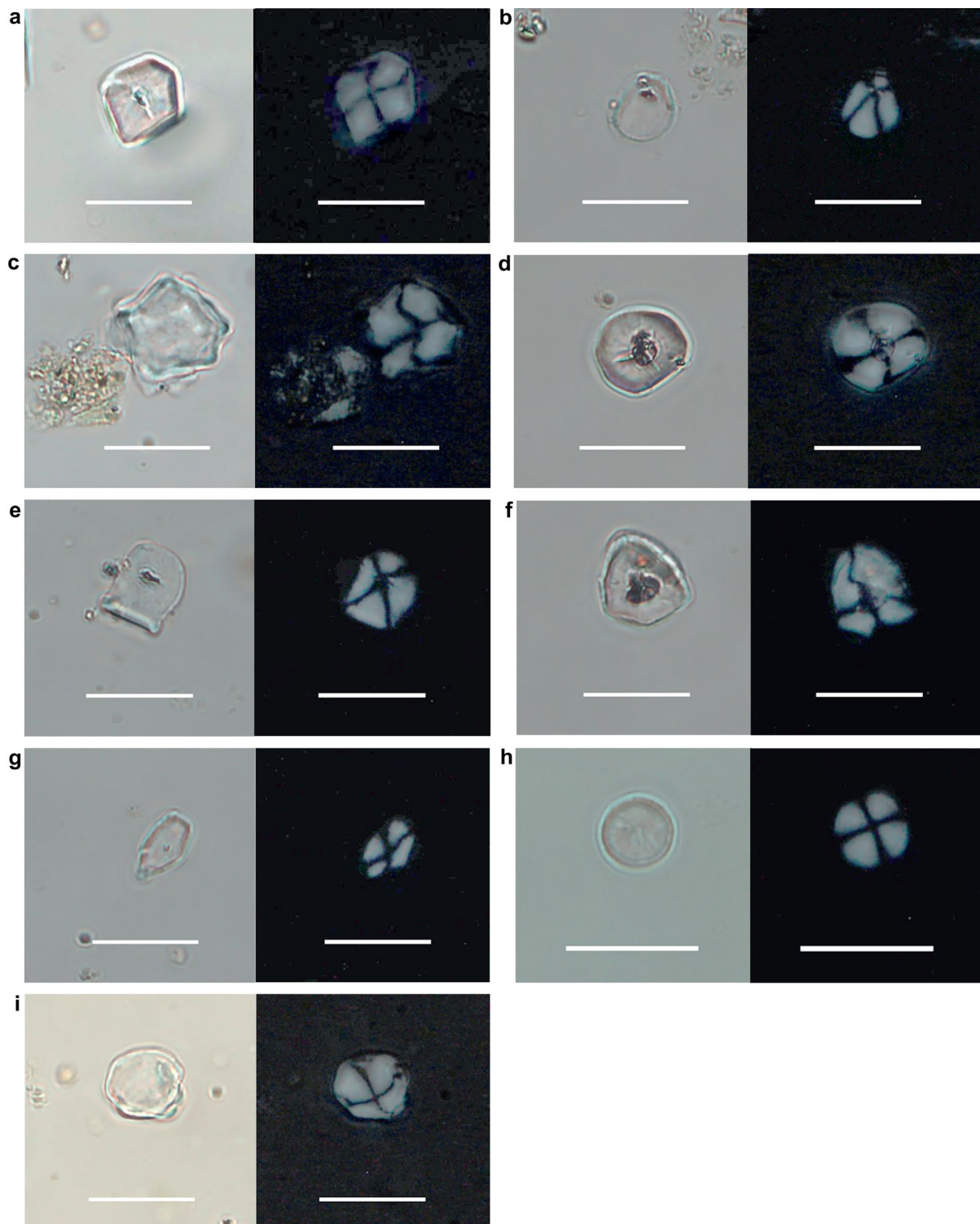


Fig. 6 Frydenlund (Funnel Beaker phase), archaeological starch granules from grinding stones. Morphotypes: **a** Type 1 (Panicoideae-type) from X8912, **b** Type 2 (cf. USO=underground storage organ) from X8915, **c** Type 3 (unknown 1) from X8929, **d** Type 4 (unknown 2) from 8914, **e** Type 5 (unknown 3) from X8914, **f** Type 6 (unknown

4) from X8915, **g** Type 7 (unknown 5) from X8921, **h** Type 8 (undiagnostic) from X8923A and **i** Type 9 (unknown 6) from X8930. For each image: left part image=plane polarized light, right part image=cross-polarized light. Scale bar=20 μm . Photos C.N. Patús

area of the occupants of Frydenlund and the fact that these taxa were likely consumed at other sites of the FB culture. Their potential presence is supported by the occurrence of charcoal of both *Prunus* sp. and Maloideae (apple subfamily) in very restricted and more abundant quantities, respectively (Out, Olsen and Andersen unpubl.). However, the presence of crab apple fruits is only supported by one imprint of *Malus/Pyrus* while there are no macroremains finds of *Prunus* sp. Possible explanations for the absence of *P. spinosa* and *M. sylvestris* as seeds/fruits could be that the fruit fragments remained unidentified or did not come into contact with fire during food preparation or discard. An alternative explanation is that the charcoal does represent other taxa than *P. spinosa* and *M. sylvestris* and that the relevant taxa were simply not consumed. Based on the edibility and presence of a wide range of taxa, it is likely that many more plants were consumed and used than demonstrated by the carbonised macroremains. This hypothesis is supported by the starch evidence.

Diachronic patterns, spatial patterns and site formation processes at Frydenlund; implications from macroremains

Comparison of the macroremains assemblages of phases a and b from Frydenlund did not show substantial differences (Table 3, Fig. 5). Spatial analysis gave slightly more information (Figs. 3 and 4, ESM 7). Concentrations of cereals, partly present as ears, were particularly found in house A, phase a. Samples rich in chaff were particularly found directly west of house A, indicating that cereal processing and possibly food preparation may have taken place there. It cannot completely be ruled out that a cereal storage from inside the house spread westward after the disappearance of the house wall, but a more parsimonious assumption is that cereal processing took place outside the house.

The limited association between the macroremain distribution and contexts other than the cereal concentration in house A and west of it probably indicates that the remaining macroremain samples, although reflecting activity zones, concern secondarily deposited material rather than primary depositions. Material from the refuse layer from phase a seems to have ended in the subsoil during the construction of the burial monuments during phase b. This corresponds with the preliminary results of the charcoal analysis (Out, Olsen and Andersen unpubl.).

Lack of evidence of cereal grinding: microremains production and taphonomy at Frydenlund

The grinding stones provide additional evidence on plant food consumption and food preparation. While the phytolith evidence is not unequivocal, the absence of starch grains

of cereals combined with the presence of starch grains of various unknown types indicates that the grinding stones were used for grinding of wild plants. These interpretations are discussed in further detail below.

In case of de-husking and/or grinding of cereals, one would particularly expect ELONGATE DENDRITIC and ELONGATE DENTATE phytoliths that occur in grass chaff, together with RONDEL and PAPILLATE. Particularly ELONGATE DENTATE were found, and a single ELONGATE DENDRITIC on X8911, but these morphotypes occurred in similar quantities in the sediment samples, casting doubt on whether the morphotypes are associated with the grinding stones. In addition, most other morphotypes common within the grinding stone microremains assemblages are also common in the reference samples. This means that while cereal grinding is not excluded, the phytolith samples do not provide evidence of cereal and grass processing. The processing of other taxa remains unknown since these tend to be underrepresented in the phytolith assemblage.

Considering the substantial number of cereal rachis segments at the site, the phytolith concentration in the reference samples was surprisingly low (Table 4, ESM 8). One explanation could be the climate and/or availability of silica in the soil affecting phytolith production. While well-preserved, thick phytolith deposits in northwestern Europe are indeed not as commonly observed or at least recognized as in drier regions (e.g. southwest Asia), similar low concentrations are not known from other phytolith studies in Denmark (Out, unpubl. data). It should be noted, however, that the concentrations at the other sites are calculated based on another method (based on marker addition instead of AIF) and therefore not perfectly comparable. Another explanation could be taphonomy: the carbonised macroremains point to taphonomisation, probably at least for some part at the time of the formation of the refuse layer, which is supported by the presence of unidentified short and longcell phytoliths. Considering the number of cereal rachis remains, ELONGATE DENDRITIC representing chaff phytoliths are also rare, but this may be ascribed to deformation in response to weathering. As a result, these phytoliths may be present among the ELONGATE DENTATE and weathered ELONGATE that are found in substantial numbers in both some sediment and grinding stone samples. Their scarcity may thus result from selective preservation. Overall, however, the preservation of phytoliths, including Elongates, was reasonably good in multiple samples (see ESM 9), contradicting this explanation. Finally, the fact that the grinding stones collected from the stone heaps did not yield many phytoliths could result from them being stored outdoors during the excavation (e.g. due to exposure to rain), but comparison with the other grinding stones indicates that this is not necessarily the case. All this does, however, not change the phytolith evidence of cereal grinding: while

cereal grinding cannot be excluded based on the phytolith evidence, corresponding phytolith assemblages from the sediment samples and grinding stone samples do not provide evidence of cereal and grass processing either. It is particularly the evidence from the starch analysis (Tables 5, 6, Fig. 6 and ESM 10–11) that excludes cereal processing: 1) the grinding stone starch assemblage contained several morphotypes not found in the sediment samples and 2) large starch grains of *Triticum* and *Hordeum* are expected to survive better than some of the smaller starch grains found in this study (Haslam 2004, Table 1). This evidence also makes it highly unlikely that the absence of evidence of cereal grinding at Frydenlund could be related to the analysis of the stones years after the excavation and the fact that some stones were exposed to rain during the excavation.

Food preparation at Frydenlund in regional context

The discussion above shows that, unexpectedly, there is no evidence that the grinding stones were used for cereal de-husking and/or grinding, since cereal chaff phytoliths and cereal starch grains could not be positively demonstrated. Instead, the presence of starch indicates the use for grinding of unknown wild plants. Since use-wear analysis has not been conducted on these artefacts to date, the possibility of grinding of material other than plants, such as stone or bone, cannot be excluded (e.g. Hydén 2014).

The high abundance of carbonised cereals combined with the absence of cereal grinding evidence suggests that while cereals were consumed, they were not ground for breadmaking but instead consumed as gruel or porridge. This matches the common presence of cooked porridge- and gruel-like cereal products at other northern European Neolithic sites, including at the FB sites of Syltholm II and Oldenburg LA 77 (Fuller and Gonzalez Carretero 2018; Demirci et al. 2021; Hammann et al. 2022; Lucquin et al. 2023; Kubiak-Martens et al. 2024). At Syltholm II, the cereals were mixed with wild plants and alternatively with fish (Lucquin et al. 2023). At Oldenburg the results indicate cooking of emmer and barley in water (Kubiak-Martens et al. 2024). The dominance of porridge-like products in the FB diet does not necessarily rule out the possibility of bread completely, and in this respect finds of heated polysaccharides, interpreted as originating from cereals, on two sherds of FB ceramic discs at Oldenburg LA77 believed to have been used as baking plates (*ibid.*), indicate a direction for further research by means of phytolith and starch analysis, which can also be applied to Frydenlund.

Other northwestern European Neolithic sites have provided evidence of both wild plants and cereals grinding (van Gijn and Houkes 2006; Hamon et al. 2021), and use-wear studies likewise supports this (Knippenberg et al. 2011; van Gijn and Siebelink 2013; Devriendt 2014;

Houkes and Verbaas 2014, 2017; Hamon et al. 2021; De Nijs 2022). At Frydenlund, however, the absence of evidence of cereal grinding may be related to the site function and/or its particularly short occupation period (while the starch indicates grinding of seeds of wild plants). Moreover, it is only assumed that all grinding stones are associated with occupation phase a instead of monumental phase b. Particularly in the Early Neolithic, grinding stones may not only have had a practical function, as indicated by their shape, but also a more symbolic function, as indicated by the many broken grinding stones at Sarup (ca. 3400 BCE, Early Neolithic II, Andersen 1999). Future microremains and use-wear analyses of other northern FB grinding stones are needed to shed further light on their precise functions.

Conclusions

This paper presents a detailed insight into plant use at the Early Neolithic Funnel Beaker site of Frydenlund based on the combined use of botanical macro- and microremains, within the framework of an updated overview of crop plants and evidence of plant food preparation at FB sites in present-day northern Germany, Denmark, Sweden and the Netherlands. The overview of FB crops is updated; the FB crop spectrum in northern Europe included the main crops naked *Hordeum* and *T. dicoccum*, as well as, to a smaller degree, *T. durum*, *T. monococcum* (perhaps only cultivated as a maslin and/or representing emmer), *L. usitatissimum*, *Papaver somniferum* and possibly *T. aestivum*. There is evidence of the availability of a wide range of edible wild plants, but while this research field is expanding, indications for use of wild plants other than finds of carbonised remains, some rare impressions in pottery and some food remains are relatively scarce, probably partly because of low find densities.

At the Early Neolithic site of Frydenlund, there is evidence of the consumption of a relatively wide spectrum of cereals, complemented by wild plants. *Triticum durum*, *T. dicoccum* and naked *H. vulgare* were the main crops (not necessarily in this order) and were probably cultivated separately as spring-sown crops without manuring. Cereal processing took place at the site, likely resulting in meals consisting of gruel or porridge. When looking at the macroremains assemblage, cereals appear to have been more important to the diet than wild plants, but differential chances to carbonization may have biased this interpretation (Jones 2000). While the carbonised macroremains suggest that cultivated plants dominated the plant diet, the grinding stones indicate that people grinded wild plants, highlighting their importance. The continued use of wild plant food is in line with evidence from other FB and north European Neolithic cultures (Göransson 1995; Out 2008b, 2009;

Brinkkemper et al. 2011; Kirleis et al. 2012; Out and Dörfler 2017; Kirleis 2019, 2022; Treasure et al. 2019; Cagnato et al. 2023; Lucquin et al. 2023).

Thus, although the number of archaeobotanical studies on FB sites is increasing, this updated overview reveals gaps in our knowledge. Critical future research at FB sites in northern and northwestern Europe is needed to gain better understanding of diet and food preparation during the Neolithic revolution with a focus on a) the occurrence and role of *T. durum*, *T. aestivum*, and *T. monococcum* (these crops may have been more, less and less important than until now assumed, respectively), as well as *L. usitatissimum* (Andreasen et al. submitted) and *P. somniferum*; b) the use and role of wild plants, the spatial distribution of botanical remains (cf. Out 2017), and analysis of both plant macroremains (cf. Valamoti et al. 2021) and microremains from grinding stones, organic residues and ceramic discs. Integrating such detailed knowledge with other archaeological methods would significantly contribute to the major debates and controversies on the understanding of Neolithic societies and neolithisation processes.

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