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## *Chenopodium* Seeds in Open-Air Archaeological Sites – How to Not Throw the Baby Out with the Bathwater

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### ABSTRACT

Differentiating between charred and uncharred plant remains may appear straightforward but for some taxa (here fat-hen, *Chenopodium album* type) can be very problematic. Recognition of the preservation state is obviously crucial for archaeobotanical data derived from dry, open-air sites. Fat-hen as a common weed, is also one of the most important components of a persistent soil seed bank. It is also a well-known food plant, gathered or cultivated. Numerous findings of fat-hen seeds in unclear states of preservation were noted in the Early Neolithic sites of the Linear Pottery culture in Kuyavia (N Europe). In previous studies such specimens were omitted as probably uncharred. Re-examination of Neolithic finds of fat-hen from that region showed the link of their abundance with the earliest phases of the Neolithic occupation. The plant probably played an important role in the diet of the early Neolithic settlers there. It may indicate intensive use of local, open, fertile, probably alluvial areas. Distinguishing between ancient and modern specimens of that common weedy plant, producing large amounts of small, black, resistant seeds is thus very important, holding a great potential to shed new light on the origins of agricultural societies in this part of northern Europe.

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Soil seed bank; charred seeds; modern contamination; fat-hen; early Neolithic; Kuyavia region

## Introduction

Seeds of fat-hen (*Chenopodium album* type) are among the most common finds in archaeobotanical samples from dry sites of all prehistoric periods, and are usually interpreted as weeds of cultivation (see e.g. Lityńska-Zajac 2005). Fat-hen seeds are particularly numerous in several early Neolithic sites across Europe (Bakels 1978; Bogaard 2004; Kreuz and Schäfer 2011), and have been identified in a few instances as product stored for food, being the main botanical component in distinct features (Knörzer 1967; Bogaard 2011). Immature seeds of fat-hen have also been recorded in archaeobotanical deposits, however, the seeds are usually not documented graphically. The debate about the role of fat-hen in the economy in fact started by Knörzer (1967), who described immature, charred seeds of *C. album* from a site at Lamersdorf in Rheinland. In feature no. 55 he found almost 6000 fat-hen seeds of which about 25% were immature. However, in the same feature 1300 seeds of flax (*Linum humile*) and hundreds of remains of wheat grains and brome grass, single seeds of peas (*Pisum sativum*) and lentils (*Lens culinaris*) were noted, which pointed towards an economic, probably alimentary, significance of the finding. Most of the taxa described in that work were documented graphically except of *C. album*. The problem of interpretation of fat-hen seeds as potential food plant or common weed of root-crops and ruderal

plant has been broadly discussed by Bogaard (2004), who found positive evidence for the collection of *C. album* in the Linear Pottery culture (LBK) Central Europe but could not exclude its presence as weed of cultivation.

The seeds of fat-hen are produced in large quantities by the plant (ca. 100,000 per one plant/year, Tymrakiewicz 1976, 32) and are one of the most important components of the soil seed bank throughout temperate regions (Cavers and Benoit 1989; Janicka 2006; Jędruszczak, Budzyńska, and Gocol 2007). The most common species from the genus, *C. album*, belongs to the persistent soil seed bank, maintaining the ability to germinate for many years (at least 50 according to Symonides 1989). The seeds are able to germinate over several seasons, reflecting plant adaptation to colonisation of disturbed sites, typical of anthropogenic taxa. After germination or after decay the seeds or their fragments can survive in the recognisable form much longer than those of most other plant taxa.

In archaeobotanical material, several types of preservation can be observed, the most common being charring (or carbonisation), waterlogging, mineralisation and desiccation (Lityńska-Zajac and Wasylkowa 2005; VanDerwarker et al. 2016). In archaeological sites from many regions of the world, including central Europe, plants preserved by charring are the most

common finds. Other types of preservation require extremely dry, or extremely wet, or other specific sediment conditions. Apart from archaeological remains, many modern or younger plant remains are usually noted, especially in dry, open-air sites (Brose 1975; Lopinot and Brussell 1982; Pelling et al. 2015), therefore, it is very important to state the type of preservation in every primary result of archaeobotanical studies. As Pearsall wrote in her paleoethnobotanical handbook (2000, 110) ‘Distinguishing charred seeds from their fresh counterparts is probably the biggest headache for the learner’. It must be stressed here that there are several transitional stages between charred (fossilised) and fresh specimens of dormant, resistant seeds like those produced by species of the genus *Chenopodium*. In general, on dry sites charred plant remains reflect past activities and parts of ancient vegetation while all fresh specimens, usually described in archaeobotanical studies as recent contamination belong to the soil seed bank. There is also a third group of specimens: decayed, rotten, fragmented but still suitable for taxonomical identification. They are enduring remains of the soil seed bank, of unknown age, but usually much younger than archaeological remains. In multiperiod archaeological sites, besides modern and later to the archaeological remains contamination, redeposition of older remains is also a possibility (Mueller-Bieniek et al. 2015; Šálková et al. 2016; Nowak et al. 2017). As fat-hen can be either an important component of the persistent soil seed bank, and thus a common weed, or a useful, alimentary plant known in archaeological and ethnographic sources (Behre 2008; Helbaek 1959; Stokes and Rowley-Conwy 2002; Van Zeist and Boekschoten-van Helsing 1991) and in ethnobotany (Twarowska 1983; Łuczaj and Szymański 2007), identifying correctly its preservation and disentangling its origin in archaeological assemblages can significantly add to its interpretation. In this paper the characteristics of charred and uncharred seeds of fat-hen from Ludwiniwo and other selected archaeological sites from Kuyavia, Central Poland are examined (Figure 1), and shed new light on the role of fat-hen in past societies.

### Ludwiniwo Site 7, Eastern Kuyavia

Fat-hen (*C. album* type) seeds from the recently investigated site 7 at Ludwiniwo were examined. The site is located in Eastern Kuyavia, within the fertile Kuyavian Plateau, close to its border with the Vistula River valley (Płock Basin) (Figure 1). Due to large-scale emergency excavations on the A1 motorway route a total area of 11.2 ha with almost 3000 archaeological features was unearthed. Most of the features belonged to the LBK. Traces of 14 posthole buildings were identified, however at least double the number of longhouses is assumed to exist due to the characteristic layout of

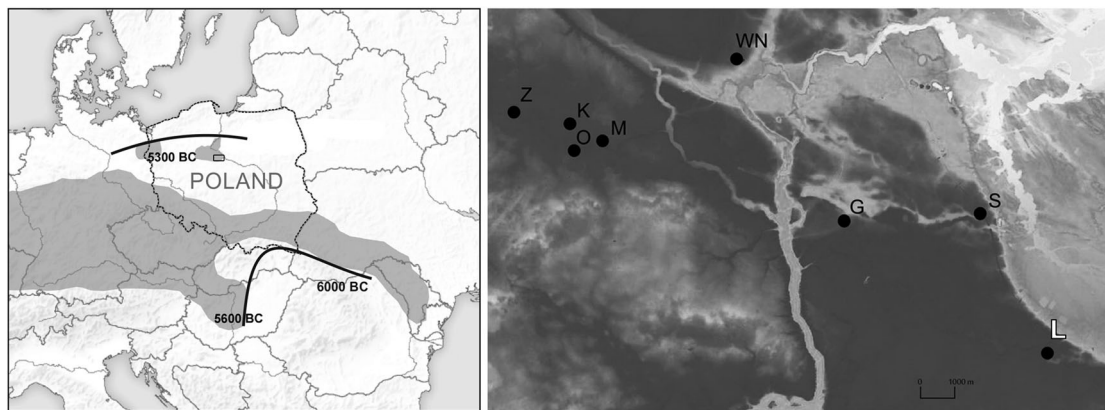
the pits connected with them. According to the results of statistical analysis of the pottery more than six occupational phases could be distinguished, covering almost the whole time span of the Kuyavian LBK: from phase IIA (with some elements of LBK I) to phase III, dated to between 5300 and 5000 cal BC (Pyzel 2013). Ludwiniwo can be thus interpreted as a stable, long-lasting, middle-sized LBK village consisting of at least three to five contemporary households within one occupation phase. The site location within fertile, heavy clay soils may suggest the important role of agriculture in the subsistence of its occupants. The results of the archaeological analysis, however, indicate that the exploitation of domesticated animals, especially cattle (almost 80% of all osteological material: Osypińska 2011) could be equally if not more crucial. Cattle was kept not only for meat, but there were also indications of dairy farming, including pottery sieves for cheese production (Salque et al. 2013). The studies of LBK plant remains from the broader area has, until now, yielded little archaeobotanical information (Bieniek 2002, 2007; Mueller-Bieniek 2016; Mueller-Bieniek et al. 2016).

### Material and Methods

Only a small area of 4400 sqm with five LBK houses and numerous features were sampled for archaeobotanical remains, applying a special sampling strategy: samples were taken from almost every feature, including post-holes. In the case of larger pits several samples from different depths (stratigraphical layers, WN from Polish ‘warstwa naturalna’) and locations were taken. In total 438 soil samples of one-litre volume dated to the LBK were studied archaeobotanically.

The soil samples were collected in 2001 and processed after 14 years of storage in plastic bags. The samples were processed using flotation in the laboratory of the Palaeobotanical Department of the Institute of Botany PAS in Kraków, with the use of a 0.5 mm sieve and fresh water.

The seeds were identified using a binocular microscope with magnifications from 4x to 40x and a modern reference seed collection. To confirm the identity of various *Chenopodium* seeds, recent seeds of *C. album* and *C. murale* were taken from the KRAM Herbarium of the W. Szafer Institute of Botany to be closely examined (Figure 2). The seeds, in varying degrees of maturity, were taken from herbarium sheets, observed under magnification and then charred on a gas cooker, immersed in dry sand, in a heat-resistant vessel. The seeds were charred unevenly, depending on the distance from the heat source and the degree of immersion in the sand (temperature and oxygen availability). In that way it was possible to imitate variable, unpredictable conditions in which specimens could have been carbonised in prehistory. The aim of



**Figure 1.** The range of the early Neolithic cultures (mostly LBK) in temperate Europe (shaded) settled in the sixth millennium BC and the location of the studied Eastern Kuyavian region (black rectangle). The black lines represent frontier zones (adapted from Bogucki 2014; Fernández et al. 2014); the location of the studied sites within the Eastern Kuyavian region, listed also in Table: L – Ludwinowo site 7; S – Smólsk sites 2 and 4; G – Gwoździec site 2; WN – Wolica Nowa site 1; M – Miechowice sites 4 and 4a; O – Osłonki site 1; K – Konary sites 1 and 1a, Z – Zagajewice site 1 (after Mueller-Bieniek et al. 2016, dynamic hypsometry map).

the experiment was not a reconstruction of the charring process (such as in Boardman and Jones 1990; Sievers and Wadley 2008) but to obtain material which had undergone diverse types of carbonisation conditions as a reference comparative collection. Observations were made under the microscope, with the use of a dissecting needle. In a few cases, the studied archaeobotanical seeds were broken, with inevitable irreversible damage.

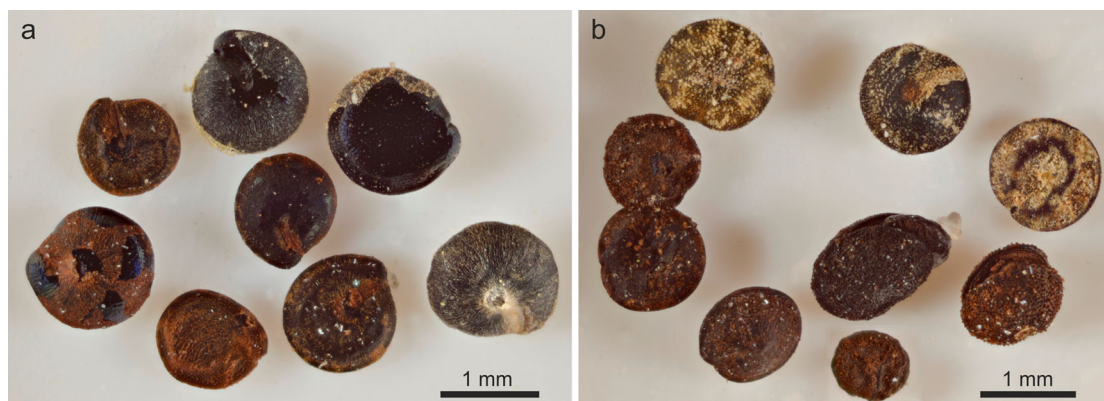
Fat-hen seeds from selected sites from other neighbouring Neolithic sites from Eastern Kuyavia located at the northern frontier of Neolithic occupation in Europe were also re-examined in the light of the fat-hen analysis of Ludwinowo 7 (see below).

### **Chenopodium spp. At Ludwinowo 7: Identification and Preservation**

A large number of *Chenopodium* seeds were recovered, which were identified as *C. album* type. The shape of the majority of the seeds with exposed, very sharp

edges, is however similar with that of *C. murale*. *C. murale* also has a matt and coarse surface (Kulpa 1974) clearly visible in recently charred material (Figure 2 (b)). On the other hand, the sharp edge is characteristic of undeveloped, immature seeds of *Chenopodium* spp., especially *C. album* (Figure 2(a)). Excluding the presence of *C. murale* is important because the plant is not native to that part of Europe (Zajac 1979; Tokarska-Guzik et al. 2012) and nowadays is rare and vanishing. Its appearance at the beginning of the Neolithic in central Europe would be very significant from a palaeoeconomical and environmental point of view. *C. murale* was identified in a few Mesolithic and Neolithic archaeological sites of Europe, a fact that needs further study (Table 1; Blankenhorn and Hopf 1982; Whittle et al. 2000; Mason 2004). Close examination of the seeds from Ludwinowo 7 indicated the absence of *C. murale*.

In the material studied from Ludwinowo site 7 several different forms of preservation of fat-hen (*C. album* type) seeds were observed. Some fresh,



**Figure 2.** Modern seeds of *C. album* (a) and *C. murale* (b), both mature and immature, charred in the lab in varying conditions (photo M. Szewczyk).



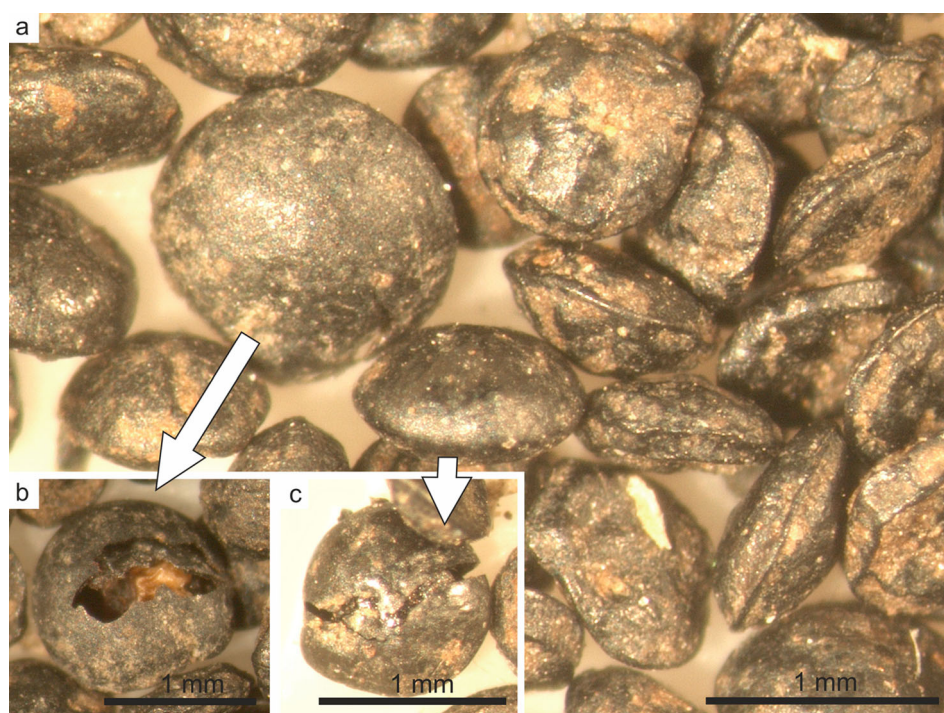
**Table 1.** Archaeobotanical finds of *Chenopodium murale* from European Mesolithic and Neolithic sites, according to EUROEVOL database (Sue Colledge pers. comm.).

Site name	Country/region	Period	Type of preservation	Number	Author
Møllegaet II	Denmark – Ærø island	Late Mesolithic	Waterlogging (cf.)	18	Mason (2004)
Riedschachen	Germany – Southwest (Baden Württemberg)	Late Neolithic	Charring	2	Blankenhorn and Hopf (1982)
Windmill Hill – external features	England – Southwest (Wiltshire)	Early Neolithic	Charring	1	Whittle et al. (2000)

germinating or dormant seeds of fat-hen were found but they were relatively scarce. Their morphology is typical of *C. album* seeds (Kowal 1953; Kulpa 1974), having a glossy surface with pericarp partly preserved. Some of them sprouted after wet sieving or were visibly fresh inside. Nevertheless, most of the clearly uncharred fat-hen seeds were more or less decayed, frequently fragmented, usually brownish with a matt surface and with remains of rotten brown organic matter inside (Figure 3). Their size varied from 1.1 to 1.4 mm (mean 1.28 mm) – in contrast to another group of seeds whose preservation could not be easily determined but seemed to be ‘probably uncharred’ and were usually much smaller (0.8–1.2 mm, mean 0.94 mm) (Table S1). The latter had visible sharp edges and large, irregular depressions on the surface (Figures 3 and 4). Most of the seeds with this indeterminate form of preservation, normally reported as ‘probably uncharred’, were usually empty inside, very brittle, black and glossy. In some cases, they were slightly brownish and covered by a rusty film, that may reflect charring at relatively low temperatures (Boardman and Jones 1990, 2) or mineralisation by iron compounds

(Figure 4). Very few well-developed charred seeds of *C. album* were noted.

To be able to distinguish the ancient or not origin of these indeterminate ‘intermediate’ uncharred fat-hen seeds a set of criteria were developed Table 2. It should be noted, however, that these need to be treated with caution in the case of other regions, soil conditions and time periods. The difference in size was not included in the criteria because most of the charred seeds were immature and the measurement as a reliable, objective criterion needs more taxonomical and morphometric studies. Using our criteria that helped assign the fat-hen seeds as archaeological or not, we chose a sample of 60 immature seeds of intermediate preservation type from one context (pit) at Ludwinowo site 7, identified as *C. album* type, to radiocarbon-date, to further verify our criteria. The results indicated a date of  $6210 \pm 40$  BP (Poz-72392) after calibration giving 5296–5055 BC with 95.4% probability, which confirms their ancient, early Neolithic age. The fat-hen seeds were thus, contemporaneous with einkorn wheat (*Triticum monococcum*, glume bases) remains from the same sample, which were radiocarbon dated to  $6180 \pm 40$  BP (Poz-72393)

**Figure 3.** *C. album* charred and uncharred from the same sample dated to LBK, Ludwinowo site 7: (a) the group of remains; (b) uncharred specimen; (c) charred mature specimen, very scarce in the material.



**Figure 4.** Part of a large assemblage of charred, immature seeds of *C. album* type, brownish in colour, dated to LBK, Ludwinowo site 7 (photo M. Szewczyk).

**Table 2.** Criteria for distinguishing charred and uncharred seeds of *Chenopodium*.

Part of seed	Charred	Uncharred – decayed	Uncharred – fresh
Testa		Surface	
	Matt and/or glossy	Matt	Glossy
	Mostly black but also brownish, 'rusty'	Color	Black
		Usually brown, deep brown	
	Irregular broken lines	Cracks	Curved lines
		Irregular or curved lines	
	Always glossy	Cross section	
		Matt	Glossy
	Usually unchanged if not damaged by deposition	Rachilla space	
		Frequently a hole left by sprouted embryo visible	Frequently sprouting or just sprouted
		Elasticity	
	Brittle, fragile	Brittle or elastic, fragile	Elastic, hard
Embryo	Mature seeds usually have rests of charred embryo inside, visible in partly destroyed specimens	Usually empty or with brown, decayed rests of embryo	Usually fresh, yellow embryo

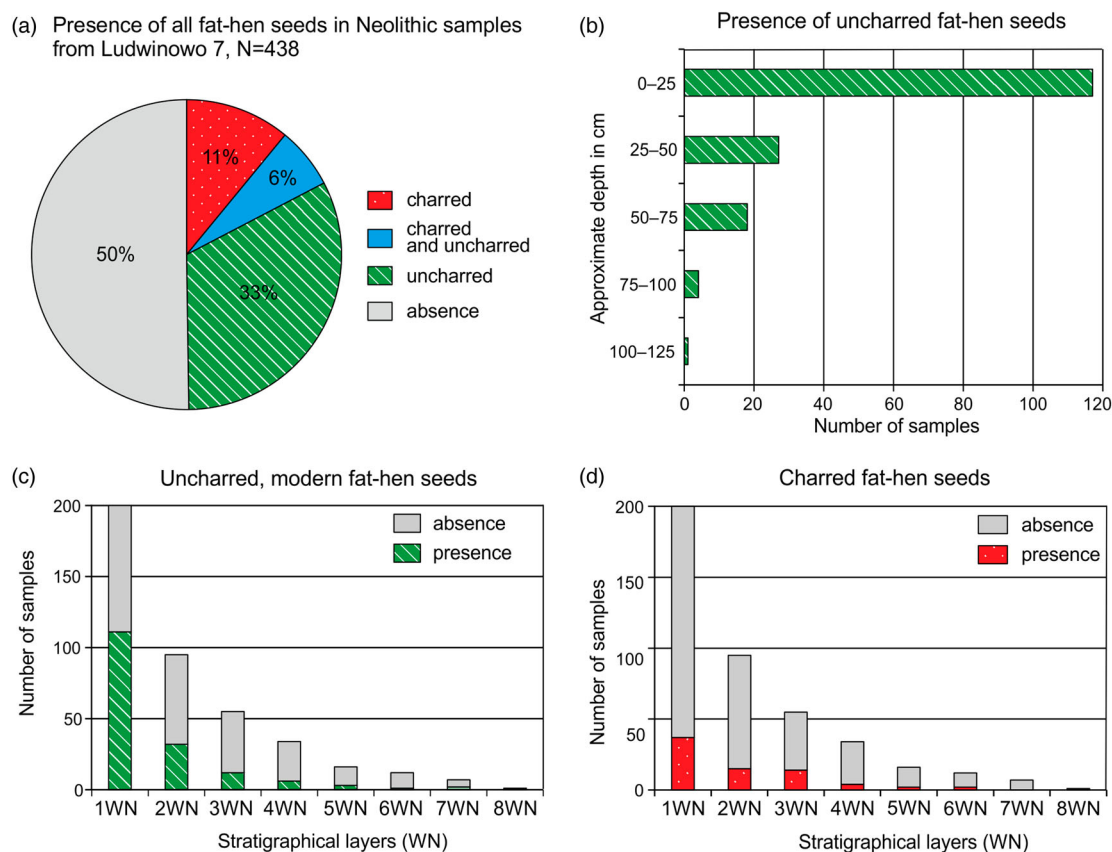
(Nowak et al. 2017), and are classified thereafter as 'charred'.

### Fat-Hen from Ludwinowo 7 in Context

Uncharred, recent fat-hen (*C. album*) seeds were found in 170 samples from Ludwinowo Site 7 while charred ones were found in 74 samples (out of 438 samples in total, Figure 5(a)). Only in 28 samples, both charred and uncharred fat-hen seeds were preserved together. Two hundred and twenty of the studied samples contained no fat-hen seeds. As might be expected, uncharred seeds were found mostly in the uppermost layer of the studied soil collected from the archaeological features (Figure 5(b)) but it should be stressed that most of the studied samples were taken from that layer. Information about the presence/absence of fat-hen seeds in stratigraphic layers (WN) is given for comparison (Figure 5(c,d)). It should be noted that most of the studied

features had only one layer the depth of which in most cases (95%) was not deeper than 20 cm. In this layer, more than 50% of the studied samples contained uncharred fat-hen seeds and both the number of samples and percentage of samples containing uncharred seeds decreased in deeper layers. The deepest layer where uncharred fat-hen seeds were noted was at 110–124 cm while the lowermost sample in the whole site was taken from a layer at 128–138 cm. The distribution of charred fat-hen seeds was slightly different. It oscillated between 10% and 20% of the samples taken from layers 1WN, 2WN, 4WN – 6WN and was most frequent in layer 3WN (25%). The uncharred seeds were found mostly in the samples from the uppermost layer while the charred seeds were found in similar frequency in all layers. The charred fat-hen seeds were not found deeper than 100 cm, whereas, as already noted, uncharred seeds were found deeper. The stratigraphic layers are given here only for some general view of the





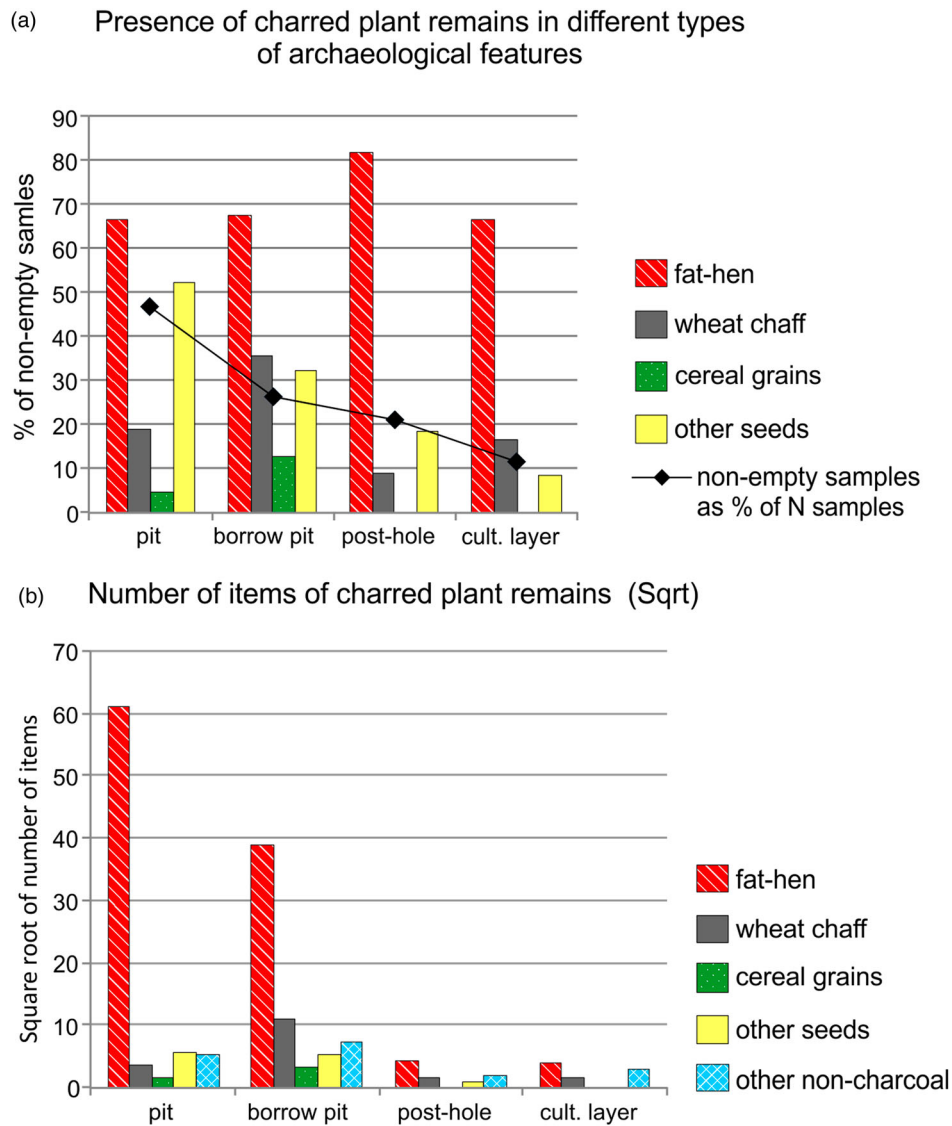
**Figure 5.** Distribution of *Chenopodium* seeds in the Neolithic archaeological samples from Ludwinowo site 7: (a) overview on presence of fat-hen seeds in the samples ( $N = 438$ ), half of the samples did not contain any fat-hen seeds; (b) number of samples according to their depth with uncharred fat-hen seeds present as a reflection of modern soil seed bank remains; (c, d) share of samples with uncharred (c) and charred (d) seeds in stratigraphical layers (WN), 1WN – the top layer.

vertical seeds' distribution but obviously the layers were not defined for the whole settlement but for each feature.

The overall plant remains were generally few. The black line in Figure 6(a) shows the general distribution of archaeobotanical remains in the different features – only in pits almost half of the studied samples contained charred plant macroremains while only 10% of all samples taken from cultural layers and 20% from post-holes contained charred macroremains. Most fat-hen seeds were found in pits, in post-holes they were almost the only plant macroremains found although in very low numbers (Figure 6(b), Table S2). In total 3708 fat-hen charred seeds were found in pits, 1503 of which in borrow pits (Table S2). In those features, the fat-hen seeds are clearly the dominant plant remains in comparison to wheat chaff, cereal grains and other seeds and fruits, including also undetermined items (but excluding charcoal) (Figure 6(b)). Cereal remains are neither frequent nor numerous in the whole assemblage of Ludwinowo site 7. Considering the context and association of fat-hen with other archaeobotanical material, it seems unlikely that fat-hen seeds represented weeds of cultivation. They seem to have been probably used as food as they largely outnumbered crops and other plant

remains. As most of the seeds were immature (or boiled?) (Capparelli et al. 2015) before charring, however, their palaeoeconomical interpretation needs experimental studies.

In such archaeobotanical contexts usually fat-hen remains of dubious preservation have been equivocally treated as recent contamination and not published or radiocarbon dated. Taking this into account, we decided to re-examine *Chenopodium* seeds from other Kuyavian sites in the light of our new criteria, including those previously omitted as probably uncharred (Bieniek 2002, 2007; Mueller-Bieniek et al. 2016). Our analysis produced new, significant data about the appearance of charred seeds in the studied region (Figure 1). In Table 3 the number of fat-hen seeds is given before and after correction of the state of their preservation. It is also likely that several charred specimens were excluded in the first stage of the research, during sorting of the sieved samples. Nevertheless, in most cases, both charred and uncharred remains were stored in the archaeobotanical collection, even if interpreted as recent contamination. All the archaeobotanical material is stored in the W. Szafer Institute of Botany PAS. The most important result is the significant change in the number of early Neolithic remains dated to



**Figure 6.** Plant composition in different types of archaeological LBK features from Ludwinowo site 7: (a) presence of groups of charred plant macroremains given as percentage of samples containing any archaeobotanical remains (excluding wood charcoal); (b) number of plant macroremains given as a square root of the sum found in all samples in each archaeological feature.

**Table 3.** Reviewed list of charred fat-hen (*C. album* type) seeds and other charred plant remains from the Neolithic sites of eastern Kuyavia.

Archaeological culture Site	LBK							SBP/L S2	L							TRB	
	G2	M4	S4	S2	WN1	Z1	L7		G2	K1	K1a	M4	M4a	O1	Z1	S2	WN1
Plant remains																	
<b><i>C. album</i> type corrected</b>	<b>1</b>	<b>433</b>	<b>5</b>	<b>24</b>	<b>24</b>	<b>9</b>	<b>5255</b>	<b>5</b>	<b>0</b>	<b>3</b>	<b>20</b>	<b>4</b>	<b>50</b>	<b>16</b>	<b>0</b>	<b>0</b>	<b>28</b>
<b><i>C. album</i> type before correction</b>	<b>1</b>	<b>50</b>	<b>5</b>	<b>24</b>	<b>24</b>	<b>9</b>	<b>na</b>	<b>5</b>	<b>0</b>	<b>7</b>	<b>15</b>	<b>4</b>	<b>47</b>	<b>13</b>	<b>0</b>	<b>0</b>	<b>28</b>
Crop grains	6	7	7	5	47	21	13	1118	5	11	5	172	58	731	4	55	51
Crop chaff	14	341	3	9	102	1	167	244	27	66	61	4064	465	333	129	0	185
Other cultivated	0	2	2	1	2	4	8	0	0	0	0	0	1	1	0	0	9
Stipa awns	1	0	0	2	0	0	0	19	0	519	696	122	761	504	0	0	0
Others	11	68	62	5	77	29	52	179	1	26	43	83	194	50	7	6	131
Volume of studied soil [litres]	16	16	49	48	189	56	438	46	8	20	62	64	130	80	89	16	92

Abbreviations: LBK – the Linear Pottery culture, SBP/L – the Stroke Band Pottery culture and/or the Brześć Kujawski group of the Lengyel culture, L – the Brześć Kujawski group of the Lengyel culture, TRB – the Funnel Beaker culture; G2 – Guźlin 2, M4 – Miechowice 4, S4 – Smólsk 4, S2 – Smólsk 2/10, WN1 – Wolica Nowa 1, Z1 – Zagajewice 1, L7 – Ludwinowo 7, K1 – Konary 1, K1a – Konary 1a, M4a – Miechowice 4a, O1 – Osłonki 1 (site locations and detailed archaeobotanical data in Bieniek 2002, 2007; Mueller-Bieniek et al. 2016).

the (LBK) from the site of Miechowice 4 (M4), which alters the proportions of all charred plant macroremains from that site. In regards to later periods, the change in the number of fat-hen seeds is insignificant.

## Discussion

The seeds of fat-hen (*C. album* type), as one of the most common components of the soil seed bank, appear frequently in soil samples from archaeological sites both



as charred and uncharred items. Their interpretation is strictly connected with the type of preservation and type of archaeological site in relation to the ground-water level. As the main component of the persistent soil seed bank (Charles, Jones, and Hodgson 1997; Symonides 1989) they have relatively resistant seeds (Dzwonko and Loster 1987), especially their testa, which results in several intermediate stages between fresh and completely rotted specimens. Thanks to their small size, the seeds can easily spread into deeper soil layers, a process supported by the activity of soil fauna. Modern ecological studies about vertical distribution of seeds in soil usually do not go deeper than 20 cm of depth (Janicka 2006) as botanists and ecologists are interested mostly in viable seeds. In the studied site 7 of Ludwinowo the uncharred (modern) seeds appeared mostly in the upper layer (Figure 5(b, c)) but they were also found at lower depths, in deeper layers than charred ones. This can be explained by constant every-year inflow of new, uncharred seeds and by the activity of soil fauna (especially primary consumers) for whom fresh seeds can be edible while the charred seeds have no alimentary value. In the site of Ludwinowo the large number of archaeological fat-hen seeds (more than 5200) which previously could not have been easily classified by any specific preservation state, charred or uncharred, waterlogged or mineralised, led to their detailed study and radiocarbon dating. As the seeds are usually empty inside, with no visible remains of charred internal tissues, this type was formerly treated as probably modern contamination (Bieniek 2002, 2007). The revision (Table 3) of former studies in the light of the new criteria set in this study revealed a higher representation of fat-hen seeds, mostly the immature type, in the archaeological features dated to the earliest Neolithic (LBK) in that region, which was at that time an agricultural northern frontier zone in Europe (Bogucki 1982; Grygiel 2004; Bocquet-Appel et al. 2012; Salque et al. 2013).

Fat-hen is an annual plant that can reach 200 cm of height and produces two types of seeds: black, resistant, in large numbers and some brown, adapted to immediate germination. Nowadays the plant grows mostly in anthropogenic habitats, as weed and ruderal, but can also grow in alluvia without any human influence. It prefers open, fertile habitats and can develop quickly from dormant seeds preserved in the persistent soil seed bank when favourable conditions appear. It is also known that manuring and soil disturbance cause an increase in germination of its dormant seeds (Cavers and Benoit 1989; Janicka 2006; Jędruszczak, Budzyńska, and Gocol 2007). Its broad ecological adaptability, including its ability to grow in very salty soils (NaCl content ca. 21 dS/m, A. Piernik personal communication), and the 'invasive' character of fat-hen being the main component of the soil seed bank, especially its persistent type, could have influenced

the selection of the plant in the economy of the Neolithic incomers. Its ability to accumulate salt (Hamidov et al. 2007) together with the presence of inland salt marsh habitats in the studied area (Piernik 2012; Bogucki 2017) could have contributed to its selection by the settlers.

In the light of these new data on the role of fat-hen in the early Neolithic of Central Poland, some discussion on the processes of plant selection and cultivation during this period is needed. In recent studies of the origin of agriculture in the Near East, some new ideas on plant domestication appeared (Fuller, Willcox, and Allaby 2011) suggesting a protracted and geographically diffuse process rather than a monophyletic rapid domestication. The authors hypothesised that the reasons domestication happened in parallel numerous times were that human groups drew upon a collective memory and deep cultural traditions of plant tending that developed much before the Neolithic, which can be also supported by archaeobotanical and ethnographic observations (Fuller, Willcox, and Allaby 2011, 14; also Weiss, Kislev, and Hartmann 2006; Willcox 2012; Willcox, Buxo, and Herveux 2009). This view may be also applicable in the case of Neolithic dispersion in Europe (Coward et al. 2008; Bocquet-Appel et al. 2009, 2012; Banks et al. 2013), taking into account the role of local environmental conditions and autochthonous Mesolithic tribes. The appearance of 'lost crops' (Jones, Valamoti, and Charles 2000; Jones and Valamoti 2005; Ruas et al. 2011; Medović and Horváth 2012; Fritz et al. 2017) and 'secondary cultivars' (for example: Behre 1992; Mueller-Bieniek and Gluza 2011) in archaeobotanical data supports the multi-layered development of agricultural societies and their adaptation and dispersion. The other problem, well known in archaeobotanical studies, is the underrepresentation of remains of vegetables (leafy vegetables and roots, e.g. Karg and Robinson 2002) and foods for which the first stages of meal preparation were not connected with high temperature but rather with soaking (e.g. pulses, Mueller-Bieniek, Walanus, and Zaitz 2015). In archaeobotanical sites where most ancient remains are preserved by charring, remains of these foods are very rare or very difficult to identify (Mueller-Bieniek 2012; Colledge and Conolly 2014; Kubiak-Martens 2005). In the case of the northern European agricultural frontier zone, the process of Neolithization was not simple and is still not well defined. The new data from eastern Kuyavia (Salque et al. 2013; Mueller-Bieniek et al. 2016) with the finding of numerous immature seeds of fat-hen (*C. album*) in contrast to the very few finds of typical cultivars, especially from the newly studied site 7 at Ludwinowo (Table 3), give important information about the exceptional subsistence pattern in the area. This was most probably concentrated on animal husbandry and dairy products as well as on the so-called

wild plant growing, and including now the possible use of fat-hen. Even when the alien species, *C. murale*, can be excluded in the case of Neolithic Ludwinowo and other Kuyavian sites, the most probably local, autochthonous fat-hen (*C. album* s.str.) seems to have been intensively used (gathered or even cultivated) by the LBK settlers. It may reflect adaptation to the local environment including contacts with Mesolithic hunter-gatherers or may be a trace of early cultivation (pre-cultivation?) of the plant, which was later abandoned.

In the *The Cultural History of Plants* Renfrew and Sanderson (2005) and Nesbitt (2005) describe *C. album* as a potentially lost crop. In our part of the world, the plant is known mostly as a cosmopolitan weed and ruderal plant, but it is still cultivated in India as a traditional leaf vegetable and also in the western Himalayas and Sichuan as a grain crop (Renfrew and Sanderson 2005, 119). Fat-hen is the Old-World counterpart of quinoa (*C. quinoa*); its domesticated forms are cultivated on a small scale in Nepal and northern India for bread, gruel, and fermented beverages (Nesbitt 2005, 59). Several species of *Chenopodium* are also cultivated in the New World (see, e.g. VanDerwarker et al. 2016). In Europe fat-hen (*C. album* agg.) is a broad taxon including several 'small' species, some of which are known as plants introduced by humans (anthropophytes: *C. ficifolium*, *C. pedunculare*, *C. opulifolium*, *C. strictum*, *C. striatifolium*, *C. suecicum*). The most common *C. album* s. str. is known as a native species in Central Europe. All 'small' species (subspecies) of *C. album* agg. can cross-breed (Trzcińska-Tacik 1992). On the basis of visibly immature seeds, exact identification of the findings is impossible. Independently from the varying uses of fat-hen, gathering, maintaining or cultivating the whole plants were most probably an important source of food or fodder. All above-ground parts of the plant are edible, the seeds have been found in archaeobotanical assemblages, including intestines of bog bodies, indicating their role as an edible plant in the past (Helbaek 1959; Bogaard 2004; Behre 2008). Fat-hen seeds are in fact common in soil samples from every archaeological period. Usually, they are not very numerous, constituting a small percentage of all plant macroremains. Nevertheless, data concerning only potential weeds from LBK sites compared with Iron Age sites (Kreuz and Schäfer 2011) showed that fat-hen (*C. album*) was very numerous in the Neolithic samples in comparison with other wild plants and with later periods. That plant is actually commonly found in most of the archaeological sites dated to the LBK (Kreuz 1990; Kalis et al. 2016) but usually not as abundantly as at Ludwinowo site. Uncharred (waterlogged) seeds of fat-hen, for example, were very numerous in LBK wells from Kückhoven (Knörzer 1998) and Leipzig-Plaußig, where they constituted 30% of all

archaeobotanical remains (Maier 2017). In contrast to this observed pattern, in South Poland in regards to LBK data (Table S3; according to Lityńska-Zajac, Czekał-Zastawny, and Rauba-Bukowska 2017) it seems that fat-hen was not such an important component in the studied sites and instead crop remains were much more significant. Only at the site of Targowisko 16 fat-hen constituted almost 50% of the findings (288 out of 692). However, in LBK sites from SE Poland also a number of millet as well as spelt grains were present, which are normally later additions, and these have not been radiocarbon dated yet. The emerging new data indicate an increasing significance of the role of fat-hen in the spread of Neolithic culture into northern areas of Europe, which urgently needs a revision by re-examining primary data and comparing fat-hen seeds with other cultivated plants and food sources.

## Conclusions

Fresh, modern, naturally black seeds of fat-hen (*Chenopodium*, especially *C. album*) are one of the most important components of the recent soil seed bank and frequent contamination of archaeobotanical assemblages. On the other hand, the plant is a well-known source of food in prehistory and ethnographic studies. The differentiation between fossilised (here charred) and fresh or partly decayed specimens is frequently ambiguous. It is especially difficult in the case of immature, underdeveloped specimens or fragments of testa. In this paper very abundant, immature, specimens of fat-hen (*C. album*) of dubious preservation were examined and were identified as charred. A sample of these was radiocarbon dated to the end of sixth millennium BC. As they were found in the early Neolithic, LBK sites in the Eastern Kuyavia region, the northernmost exclaves of early agriculture in the Northern European Plain, their palaeoeconomical and environmental meaning is significant. They were accompanied by very scarce remains of cultivated plants and weeds, usually well represented in archaeobotanical data from other regions. This strongly suggests that fat-hen played a larger role in the diet of the early Neolithic settlers in the area of Eastern Kuyavia than previously thought, even if consumed by primary consumers, at a lower level of the dietary chain, as green fodder. In previous studies, such immature fat-hen seeds were interpreted as modern contamination as they usually did not contain any noticeable charred rests of embryo and were frequently brownish in colour. Reinvestigation of all Neolithic fat-hen finds from this region, using a new set of criteria that help distinguish charred from fresh seeds, showed their significance in the earliest phases of the Neolithic occupation (LBK), which seems to decline in later periods. The new archaeobotanical data indicate intensive use of local open areas, probably fertile alluvia, or

even some intermittent cultivation of the native plant (*C. album*) at the beginnings of agriculture and probably frequent crop failures, which may also reflect the difficulties of the acclimatisation of the Near Eastern grain crops to the northern European climatic conditions. The role of fat-hen in the Neolithic diet can provide a significant, different angle to help understand the processes involved in the origins of agriculture in the area. Still a lot of work is needed to fully understand fat-hen management and usage, that would include: (1) detailed experimental studies on modern seed material of fat-hen (*C. album*) and other close relatives, charring of the material at different stages of maturity, different types of food processing of the seeds and the whole plants, cow dung studies, and detailed anatomical studies of the seed coat; (2) morphometric analysis of archaeological fat-hen seeds from different periods in various archaeological sites; (3) radiocarbon dating of fat-hen seeds previously well documented, of diverse type of preservation, including decayed, seemingly uncharred seeds from open-air sites interpreted as modern contamination; (4) examination of other indicators of fat-hen seeds usage as food through phytoliths in dental calculus or stone grinding tools.

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