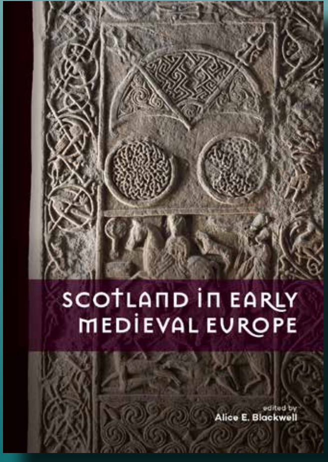
Edited by:

WIEBKE KIRLEIS, MARTA DAL CORSO, DRAGANA FILIPOVIĆ

MILLET AND WHAT ELSE?

The wider context of the adoption of millet cultivation in Europe

SCALES OF TRANSFORMATION IN PREHISTORIC AND ARCHAIC SOCIETIES | 14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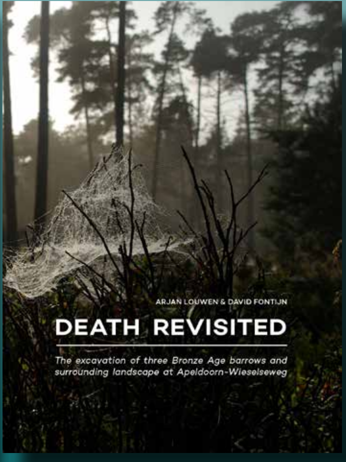
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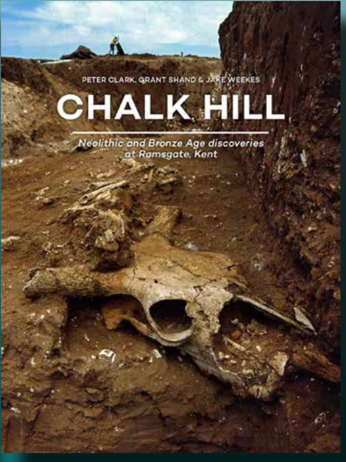
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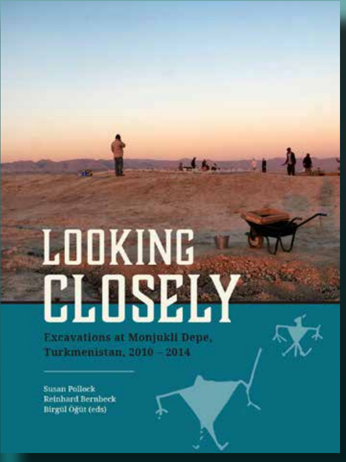
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MILLET AND WHAT ELSE?

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SCALES OF TRANSFORMATION | 14

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Contents

Preface by the series editors

With this book series, the Collaborative Research Centre 1266 *Scales of Transformation: Human-Environmental Interaction in Prehistoric and Archaic Societies* (CRC 1266), at Kiel University, enables collective and timely presentation of its research outcomes relating to the multiple aspects of socio-environmental transformations in ancient societies. As the editors of this publication platform, we are pleased to be able to publish monographs containing detailed primary data and comprehensive interpretations from different case studies and landscapes, as well as the output from scientific meetings and international workshops. The book series is dedicated to the fundamental research questions of the CRC 1266 related to transformations on different temporal, spatial and social scales, here defined as processes leading to a substantial and enduring reorganisation of socio-environmental interactions. Some of the general questions are: What are the transformations that describe human development from 15,000 years ago to the beginning of the Common Era? How did interactions between the natural environment and human populations change over time? What role did humans play as cognitive actors in the changing social and natural environments? Which factors triggered transformations that led to marked societal and economic inequality?

Understanding human practices within the often intertwined social and environmental contexts is one of the most fundamental aspects of archaeological research. Moreover, in current debates, the dynamics and feedback involved in human-environmental relationships have become a major issue, particularly when we look at the detectable and sometimes devastating consequences of human interference with nature. Archaeology, with its long-term perspective on human societies and landscapes, is in the unique position to trace and link comparable phenomena in the past, to study human involvement with the natural environment, to investigate the impact of humans on nature, and to outline the consequences of environmental change on human societies. Modern interdisciplinary research enables us to reach beyond simplistic, monocausal lines of explanation and overcome evolutionary perspectives. Looking at the period from 15,000 to 1 BCE, the CRC 1266 takes a diachronic view in order to investigate transformations in the development of Late Pleistocene hunter-gatherers, horticulturalists, early agriculturalists, and early metallurgists, as well as early state societies, thus covering a wide array of societal formations and environmental conditions.

The volume *Millet and what else? The wider context of the adoption of millet cultivation in Europe* brings into focus the contribution of dietary innovations to socio-environmental transformation processes, here in the context of the Bronze Age, which is characterised by increasing social complexity and intensified global interconnectedness. Broomcorn/common/proso millet (*Panicum miliaceum*) has recently become a major topic of interest in archaeobotanical as well as archaeological research in Europe and Asia. Its origin in the far-from-Europe East Asia, its 'late' arrival in Europe (compared to *e.g.* wheat and barley), its distinctive biological traits, and the multiple available methods for tracing this species in the archaeological record make millet an exciting and attractive object for research. This edited volume sets an important benchmark for the current state of the art in millet-related research. It is the outcome of the CRC 1266 workshop 'Millet and what else? The wider context of the adoption of millet cultivation in Europe', which was held in November 2019 in Kiel and was aimed to inspire a deeper discussion on the circumstances and consequences of the introduction of broomcorn millet cultivation in Europe in the Bronze Age. The workshop also marked the closing of the CRC 1266's 'Millet Dating Programme' – the large, collaborative effort of the European archaeobotanical community, which was initiated by CRC 1266's archaeobotanists and led by Dragana Filipović. This volume presents and elaborates the topics and insights presented and discussed at the workshop, and raises new questions. It thus serves as a roadmap for future research and collaboration in the studies of millet, and agricultural or dietary innovations in general.

Both this volume and the workshop from which it proceeds cover the areas and topics investigated by the CRC 1266's subprojects *F3: Dynamics of Plant Economies in Ancient Societies*, and *D1: Population Agglomerations at Tripolye-Cucuteni Mega-sites*. We are grateful in particular to Dragana Filipović for the editorial work, carried out jointly with Marta Dal Corso and Wiebke Kirleis. We cordially acknowledge the support of the external reviewers. We are very thankful to our graphic illustrators, Anna Carina Lange and Carsten Reckweg, for their valuable help in the preparation of the publication. We also thank Karsten Wentink, Corné van Woerdekom and Eric van den Bandt, of Sidestone Press, for their unfailing support in completing this volume, and to Nicole Taylor, scientific coordinator of the CRC 1266, for overseeing the publication process.

Wiebke Kirleis and Johannes Müller

Millet and what else? The wider context of the adoption of millet cultivation in Europe

Wiebke Kirleis, Dragana Filipović, Marta Dal Corso

Introduction

This small-grained cereal – broomcorn/common or proso millet (*Panicum miliaceum*) – has in the past 10-15 years gained massive attention within the field of archaeology, as well as in discussions on modern global food security and sustainable agriculture. It can be considered a special crop in Europe, different from the Neolithic 'founder crops' in that it was domesticated in the Far East, namely China, and arrived in Europe 'late' – not before the full establishment of metallurgy, in the Bronze Age, when trade and exchange and production levels also peaked. Its distinctive biological, nutritional and ecological traits made this species particularly attractive to farmers in recent and modern communities and, together with its 'special' pathway of spread from its region of origin, likely contributed to its widespread and relatively quick adoption by communities in the past. As both previous and new research shows, including that presented in the book in front of us, broomcorn millet is an excellent example of a foodstuff that acted as a social agent in the (trans)formation of society, economy, culture and identity.

Broomcorn millet cultivation and its biological, ecological and nutritive traits

Taxonomically, broomcorn millet (Fig. 1) is part of the Poaceae family and the Panicoideae subfamily. Broomcorn millet (henceforth referred to as 'millet') emerged as a cultivar in the Far East and has since been commonly used as a crop grown for food, beverage and forage. The primary cultivation areas of this small-grained cereal adapted to short-day cycles are found in the dry tropics or the subtropics. Millet is warmth loving, drought resistant and sensitive to frost. It cannot cope with temperatures below −2°C, and the germination requires ca. 8-10°C. The most important growth factor is the availability of sunlight and water during

Figure 1. Broomcorn millet (Panicum miliaceum) *before harvest, in the Archäologisch-Ökologisches Zentrum Albersdorf, Schleswig-Holstein, end of August 2018 (photo: Wiebke Kirleis).*

the germination time. Millet can grow on poor soils that warm up easily. However, due to the small size of the grains, fine seedbeds are beneficial (Becker-Dillingen 1927, 563-575; Lieberei and Reisdorff 2007; Miedaner and Longin 2012, 80-82). Millet has a rather wide ecological tolerance and can grow in higher altitudes as well as in floodplains (Chen *et al.* 2014; Moreno-Larrazabal *et al.* 2015; Miller *et al.* 2016; d'Alpoim Guedes 2018). However, millet cannot grow beyond 60° northern latitude (Motuzaite-Matuzeviciute pers. comm.). The northernmost archaeobotanical evidence originates from Slavonic sites in Novgorod and Staraja Ladoga, in Russia, and dates to medieval times (Alsleben 2012). The short growing cycle of millet, lasting only 60-90(100) days from seeding to harvesting, makes this species attractive in multiple ways: 1) In northerly regions, it allows millet to be used as a buffer crop to mitigate failure of the primary crops destroyed by late frosts, thus securing a summer crop yield. 2) In Mediterranean climates, it allows millet to be used as second (summer) crop in order to enhance the yearly crop yield (Taylor and Doudu 2020). 3) At higher altitudes which offer a very short vegetation period, it may render millet superior to other crops (*e.g.* nowadays, broomcorn millet is grown as a summer crop at 3500 m asl. in the Himalayas, as noted by workshop participant Stefania Grando, International Crops Research Institute for the Semi-Arid Tropics, ICRISAT (pers. comm.)). 4) Among semi-sedentary or nomadic groups, such as mobile pastoralists, it also makes millet appealing since it fits with short-term camp occupation (Hermes *et al.* 2019; Dal Corso *et al.* 2022).

The **labour investment** for growing millet varies over the growing period (Fig. 2). Since a fine seedbed is beneficial for plant growth, the soil has to be tilled (ploughed and harrowed or raked) before sowing. Further maintenance is necessary when the plants begin to sprout and push out 3-5 leaves. Because the early leaf production is slow and the faster-growing weeds may outcompete the young millet plants simply by casting shade over them, intensive weeding is necessary (Miedaner and Longin 2012, 80). The weeding has to be carried out with utmost care because the predisposition for the yield is established in the early, 3-5-leaf stage of the plant's growth. Later in the growing period, hardly any labour input is needed.

However, millets are beloved fodder for birds prior to (and post-) harvesting. The plant thus requires effective protection measures that, again, may be labour-intensive. Another issue with millet is the uneven ripening of the grains in the panicle, whereby the ripening starts at the top of the panicle. It takes an experienced farmer to determine the optimal harvesting time and thus avoid grain loss. Despite being high maintenance, millet is an attractive crop because of its high propagation rate compared with *e.g.* rye, with high ratios of planted to harvested grain, even though the grain size is half of that of large-seeded cereals, such as rye or wheat. Further, the silica-rich glumes protect the grains from mildew and allow for long-term storage (Becker-Dillingen 1927, 572-575; Anderson and Greb 1987; Miedaner and Longin 2012, 80-82; Taylor and Duodu 2020).

Millets are adapted to hot and dry environments by following a **C4 pathway** of photosynthesis, which gives them high assimilatory power to produce biomass by reduction of CO_2. Plants normally close their stomata when the ambient temperature is high in order to limit water loss through evaporation. However, this makes the absorption of CO_2 for photosynthesis more difficult. C4 plants have developed a mechanism that enables them to use even the smallest amounts of CO_2 to produce biomass. This comes with increased energy costs, but these costs are buffered by the C4 plants' unique leaf anatomy, which allows CO_2 to concentrate in the so-called bundle sheath cells.

In C4 plants, the fixation of CO_2 is a two-step process. CO_2 is pre-fixed in the mesophyll cells close to the open stomata, where the enzyme PEP is transferred into a four-carbon molecule (*e.g.* malate). The latter is then actively transported with extra energy supply into the so-called bundle sheath cells, where CO_2 is released again and – also when stomata are closed – incorporated into the Calvin cycle to be fixed in sugar molecules (glucose). C4 plants are thus able to continue CO_2 fixation when the highest light intensity of the day is reached (around noon) and stomata are closed, while C3 plants fall back at a light intensity of 50 klx. In full sunlight, C4 plants have higher CO_2 assimilation rates above 30°C than C3 species and are thus better adapted to non-shaded (sub-)tropical habitats. Further, C4 plants have a high water and nitrogen use efficiency (Sitte *et al.* 1991, 277-288; Brown 1998, 479-485). These traits are particularly relevant when millet is grown in subtropical and tropical environments.

But is there a benefit to growing the C4 plant millet in the temperate climatic zone? Does millet allow for higher biomass production and higher yields if compared with C3 plants in central and northern Europe, with its temperate climate? The limiting factor for plant growth in higher latitudes is the availability of light. However, the uneven distribution of biologically effective global irradiance has only minor influence on biomass production (Geisler 1988, 83).

Figure 2. 2a-d – Broomcorn millet (Panicum miliaceum) *planted on 6 May 2018, in the Archäologisch-Ökologisches Zentrum Albersdorf, Schleswig-Holstein: 2a-2b. Early growth, 30 May 2018; 2c-d. One week later, 6 June 2018; 2e-f. Late harvesting, 29 August 2018. 2g-2h – Broomcorn millet* (Panicum miliaceum) *planted on 27 April 2019, in the Archäologisch-Ökologisches Zentrum Albersdorf, Schleswig-Holstein: 2g. Early growth and intensive weeding, 24 May 2019; 2h. Weeds outcompeted, 21 June 2019 (photos: 2a-d Marta Dal Corso; 2e-f Angelika Hoffmann; 2g-h Wiebke Kirleis).*

The observation that C4 plants have a higher net-photosynthesis efficiency than C3 plants and are more productive with respect to biomass production is valid only if C4 and C3 plants are compared under their respective optimal growing conditions. Direct comparison under temperate climate conditions does not allow us to infer variability in biomass production as being stimulated by the different pathways of photosynthesis (Brown 1998). This argument is further supported by the fact that there are hardly any C4 plants among the native wild plant species in temperate central Europe (Brandes 1995; Pyankov *et al.* 2010). What can we conclude from these observations on C4 plant metabolism? And what is the relevance of this for the northward spread of millet in the 2nd millennium BCE?

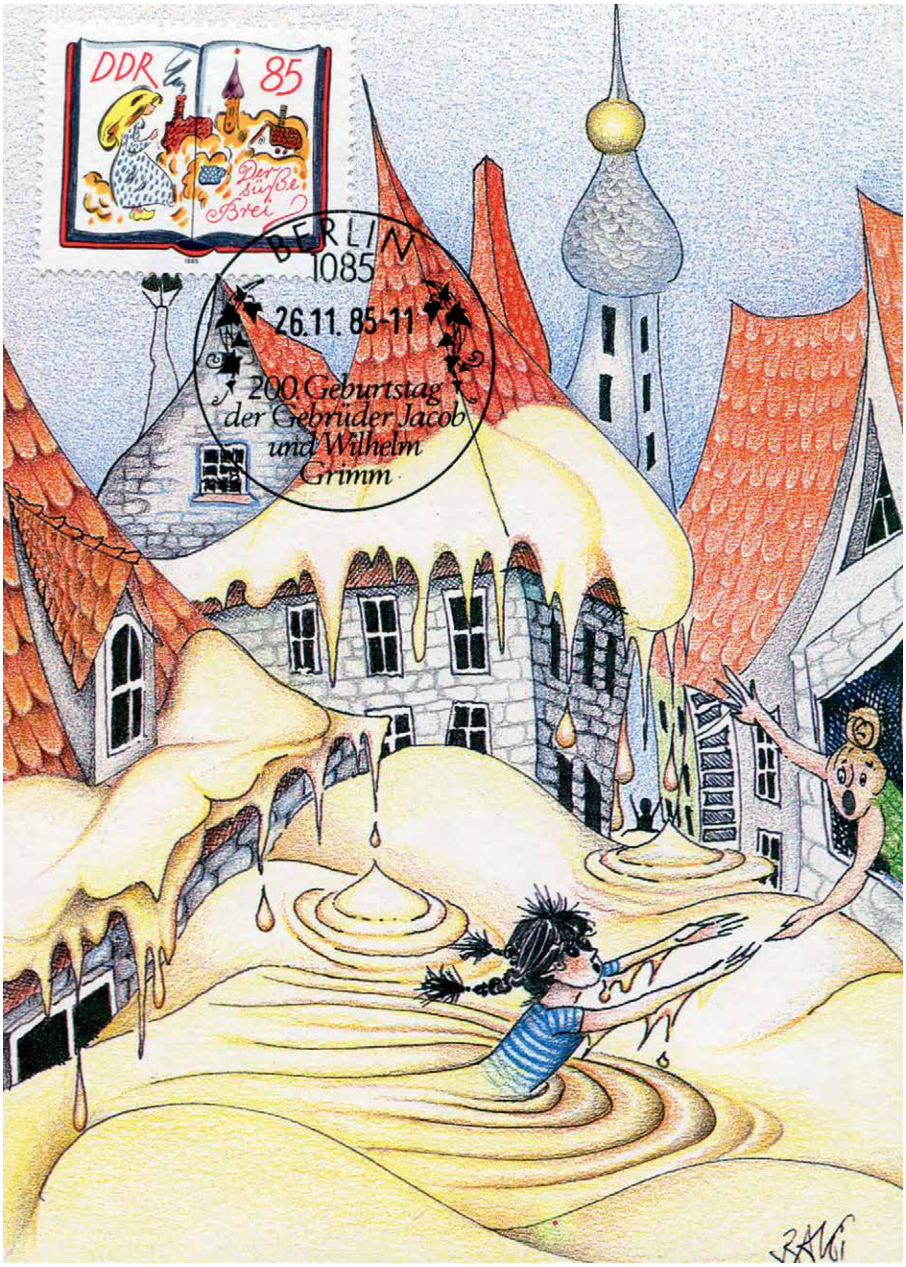

Figure 3. Illustration from the fairy tale 'Der Süße Brei', by the brothers Grimm (Maximumkarte, DDR 1985, Verlag Bild und Heimat).

In temperate regions, the rate of evapotranspiration through the leaf surface is low, and plants rarely suffer from drought because humidity in the central and northern parts of Europe is relatively high compared with the Mediterranean climate zone in southern Europe. The C4 metabolism can hardly count as a trigger for the northward spread of early millets. Whether weather extremes, such as drought events, fostered the spread of millet is still a desideratum for future research. In modern times, it has been observed that non-plant factors, such as soil type and fertility, length of the growing season, and disease and insect pressures, exert a strong influence on the selection and production of crops and that the selection of crop species by farmers is based more on economic concerns and (culinary) tradition than on biological traits (Brown 1998, 486).

From a **dietary perspective**, millet is rich in the three main macro-nutrients. The carbohydrate content (measured in % of the dry weight) is, as is typical for cereals, high, with the reported values ranging between 60% and 75% (*e.g.* Saha *et al.* 2016; Das *et al.* 2019). The protein content varies between 8% and 13% and can be improved through plant breeding to be as high as 18%. The fat content is about 4-6%. Millet is a gluten-free cereal, easy to digest, and high in dietary fibre and antioxidants, the latter reducing the risk of cardio-vascular diseases (Stefania Grando pers. comm.). The iron content of millet is three times higher than that of wheat, meaning that daily iron requirements of humans can be met with only 50g of millet grains. The optimal nutritional uptake of iron, however, depends on the parallel consumption of vitamin C. Millet contains vitamin E and provitamin A and is particularly rich in vitamin B and minerals. It is in many ways beneficial for human metabolism and health.

Millet is today often promoted as a health-improving product, with benefits for hair, nails and connective tissue because the plant has a high silica content. However, the silica is embedded in the glumes and thus not part of human diet, because it is the dehusked (*i.e.* glume-free) grains that are consumed (Miedaner and Longin 2012, 83; Taylor and Duodu 2020). The hard glumes are essential when it comes to the storage of millet, however, as they perfectly protect the grains from mildew.

During cooking, millet grains gain in size considerably when soaked in hot water or boiled. Thus, although it is a small-seeded cereal, with far lower grain weight than large-seeded cereals (the mass of 1000 grains of millet is 4-9 g and of wheat, 40-50 g; Miedaner and Longin 2012, 80), millet is perceived as a highly filling food. This perception has even found its way into cultural memory through fairy tales. The remarkable swelling of millet grain in food preparation is, for instance, described in 'Der Süße Brei' ('Sweet Porridge') tale by the brothers Grimm (Fig. 3). The main foods that can be made from millet are porridge, soup, flatbread and beer.

Sociocultural dimensions of millet consumption

The cultural dimensions associated with millet and the meanings ascribed to this staple crop are discussed in ethnohistorical studies on the recent past in central Europe (Wiegelmann 1967, 112-156), as well as in ethnological studies on modern-day India (*e.g.* Erler *et al.* 2020; Hardenberg 2021). These studies show that the sociocultural dynamics of foodstuffs in general, and millet in particular, are multidimensional. They are related to and affect societal reality and are evident in the ritual and religious spheres as well as the economic sphere. Some crops have individual agency and play a role in ideology and other cultural behaviours (*e.g.* Hastorf 2017); they are highly dynamic and transformative.

In the 19th century, the cultivation of millet in central Europe rapidly declined. The reasons for this are manifold, and to understand the context, it should be emphasised that, at the time, the production of millet served two highly divergent purposes. It is astonishing that one and same cereal, millet, was attributed two entirely opposite meanings – as a highly valued grain and a symbol of fortune and as food for the poor. On one hand, it was an everyday food for the poor and was widely used in communal kitchens and military hospitals, while it also served as famine food. On the other hand, it was a component of festive meals and was prepared for Christmas, New Year's Eve and weddings, because of the belief in inherent happiness related to the property of millet to 'grow' when made into gruel, which was perceived as a signal that it provides endlessly increasing wealth.

The traditional inclusion of millet in festive meals continued through the 19th century, but as an everyday food it was replaced by potato, especially in areas where millet was less important. One reason for this was a change in consumption habits. At the time, millet was consumed as gruel only, while potato offered a wide range of applications, and was prepared as a bake, gruel, soup or salad, and turned into flour for making dumplings and pancakes. The change in culinary choice from millet to potato as the main staple occurred alongside the increasing influence and spread of urban eating habits. These entailed new ways of cooking and eating, such as combining different foods into complex meals instead of preparing simple stews, and the increasing use of individual plates with fork and knife, which supplanted earlier, collective eating from one bowl. Further, increasing meat consumption superseded millet gruel. With respect to cultivation, the wider ecological amplitude of potato, which is able to cope with late frosts, for instance, was another of its advantages that accelerated the decline of millet cultivation and consumption in the 19th century (Wiegelmann 1967, 86-156).

Hardenberg (2021) studied cultural dimensions of millet consumption among the Dongria Kond, an Adivasi tribal group living in the Eastern Ghats mountain range, in India. The Dongria Kond traditionally grow millet and ascribe to it a number of different values and meanings. Millet is considered extremely nutritious; it is given economic value because it is used as a currency in exchange for labour, as a kind of wages; it is also an appropriate gift that strengthens social relationships; finally, it serves as a suitable offering in religious contexts. Many of these cultural ascriptions were transferred to rice, which became a cash crop after it had been introduced in the region as a substitute for millet as part of the programme run by development aid organisations. Only recently have millets been promoted as the 'Forgotten Food for the Future' by the 'Smart Food Initiative' of the ICRISAT, as explained by Stefania Grando at our workshop. For people living in Africa and India, the re-introduction of millet growing is part of a programme aimed at furthering sustainable agriculture.

This promotion of a 'forgotten' crop leads to a politically driven transformation of the role of the hill tribes in northern India, formerly perceived as poor people who had to produce rice to survive, but now becoming custodians of endangered millet species thanks to their traditional knowledge of millet cultivation. This strengthens the cultural identity of the Dongria Kond, and they are now re-instating their traditional lifeways. If the practice of exchange of millets traditionally served to consolidate social bonds, it now also has the role of preserving and enhancing the biodiversity of millets.

This tale shows similarities with the study by Erler *et al.* (2020), who explore the fact that, in today's city of Bengaluru, in India, millets are marketed as a superfood made in India, whereby their positive effects on health and their contribution to optimising body weight are emphasised. As a result of this new approach, millets are now shopped for by middle-class people, in organic food shops. This is a noteworthy transformation of attitude since, traditionally, millets had been perceived as inferior crops compared with rice and wheat, representing food of the poor. The new image as superfoods turned millets into a symbol of social distinction. Buying and consuming millet has become a status determinant for the middle class. Although impoverished farmers in India often perceive the consumption of (finger) millet as a consequence of their food scarcity, the members of Bengaluru's middle class consume (a variety of) millets in order to secure their social standing.

These and similar ethnological studies provide examples of changes in culinary practices being deeply intertwined with social transformations – a perspective difficult to explore for prehistory. Although the superseding of millet by potato in the 19th century was stimulated by the wider ecological plasticity of the latter, it was underpinned by the adaptation of rural populations to bourgeois customs and morals and lifestyles, which found its expression in new culinary practices. The examples from India show how the consumption of millet creates, fosters or transforms individual and/or communal identity depending on the habitus and the socio-political context. These changes are in this case almost completely independent from any environmental affordances or constraints. This observation becomes highly relevant when we try to understand causes and consequences of the fast acceptance of broomcorn millet as a new staple crop in Bronze Age Europe.

Millets in the frame of research of the CRC 1266 'Scales of Transformation'

The spread of millet cultivation is one of the central themes of the subproject 'Dynamics of Plant Economies in Ancient Societies' in the research programme CRC 1266 'Scales of Transformation – Human-Environmental Interaction in Prehistoric and Archaic Societies' at Kiel University, which investigates transformational processes in a wide array of societal formations and environmental settings (Müller and Kirleis 2019). The project is investigating the role of millet in the substantial and enduring reorganisation of socio-environmental interaction in prehistoric Europe. It searches for patterns and indicators in crop cultivation and food consumption that reveal the importance of this new resource in the wider processes of cultural and environmental transformation.

In order to place the research and discussions on a firm spatiotemporal footing, the project executed a large, continental-scale radiocarbon dating programme targeting the 'earliest' millet grains in Europe. The dating results proved an earlier assumption (*e.g.* Hunt *et al.* 2008) that broomcorn millet arrived in Europe in the Bronze Age (Filipović *et al.* 2020). The workshop 'Millet and what else? The wider context of the adoption of millet cultivation in Europe', held in Kiel in November 2019, marked the closing of the 'Millet Dating Programme' and celebrated this major collaborative work of the European archaeobotanical community (Fig. 4). It also provided a roadmap for future research and collaborations, and this book is a step in that direction.

More than 20 invited workshop participants – archaeobotanists, zooarchaeologists, isotope and biomarker specialists, and ethnographers – presented and discussed dietary, economic and cultural aspects of the period in which the new crop was introduced in Europe, *i.e.* the Middle Bronze Age and the Late Bronze Age, the methods used in archaeology to track and reconstruct the growing and consumption of millet, and the growing and consumption of millet today or in the recent past. The workshop was organised in three sessions.

In the first session, titled 'Innovations in the Bronze Age subsistence economy – regional perspectives from Ukraine to France', the presenters addressed a series of questions suggested by the workshop organisers:

- Why did broomcorn millet spread in the 2nd millennium BCE, and why then? What were the pre-conditions (social, environmental, technological)? Did millet arrive as both human and animal (*e.g.* chicken) food?
- What was food production (plant and animal) in Europe like before and after the arrival of millet? What was the role of gathered resources?
- Once adopted, how, when and where was millet cultivated, processed, stored, consumed?
- What else changed at the time? What was the role of millet in these changes?

In the second session, titled 'Beyond seeds: Isotopic and biomolecular evidence of millet cultivation and consumption', participants presented new, state-of-the-art methods, such as stable isotope and biomolecular analyses, which detect millet cultivation, cooking and consumption directly in the soil, ceramic vessels and consumers' tissue, while also pointing to a specific yield-securing/improving cultivation practice, *i.e.* manuring.

In session 3, titled 'Growing and eating millet: Insights from ethnography, agronomy and experimentation', participants shared observations of recent or present-day millet cultivation, processing, storing and uses (as food or fodder); the agricultural routine and amount of labour required in millet cultivation; and the economic and nutritional status of millet in relation to other crops.

The workshop programme and the abstracts are available at https://www.sfb1266.uni-kiel.de/en/events/sessions-workshops/millet-and-what-else-the-wider-context-of-the-adoption-of-millet-cultivation-in-europe

WEDNESDAY, 27th NOVEMBER 2019

08:00 – 08:30	***Arrival of participants to the venue***
08:30 – 09:00	Welcome & Opening talk Wiebke Kirleis & Dragana Filipović (CAU Kiel)
	SESSION 1: Innovations in Bronze Age subsistence economy – regional perspectives from Ukraine to France **Session chairs:** Wiebke Kirleis & Marta Dal Corso (CAU Kiel), Almuth Alsleben (Akademie der Wissenschaften und der Literatur, Mainz), Susanne Jahns (Brandenburgisches Landesamt für Denkmalpflege und Archäologisches Landesmuseum, Zossen)
09:00 – 09:20	**Millet finds in the territory of Ukraine** Galyna Pashkevych (NASU, Kiev), Marta Dal Corso & Wiebke Kirleis (CAU Kiel)
09:20 – 09:40	**Chasing Chinese millets in Ukraine using seed impressions in pottery** Eiko Endo (Meiji University, Tokyo)
09:40 – 10:00	**Millet cultivation in the Belarus and the Baltic States** Giedrė Motuzaitė Matuzevičiūtė & Mindaugas Grikpėdis (Vilnius University)
10:00 – 10:20	**The Bronze Age in Poland – archaeological and environmental traces of subsistence strategies** Aldona Mueller–Bieniek (Polish Academy of Sciences, Warsaw) et al.
10:20 – 10:40	**Timing the introduction of *Panicum miliaceum* to the Middle Danube Region – dual evidence** Mária Hajnalová (Constantine the Philosopher University, Nitra) & Peter Barta (Comenius University, Bratislava)
10:40 – 11:10	**COFFEE BREAK**
11:10 – 11:30	**Bronze Age agricultural changes in the Czech Republic** Adéla Pokorná, Petr Kočár & Tereza Šálková (Czech Academy of Sciences, Prague)
11:30 – 11:50	**Millets in Bulgaria – diachronic overview of their role in the subsistence and critical review of the archaeological finds** Elena Marinova (State Office for Cultural Heritage Baden–Württemberg, Hemmenhofen), Ivanka Hristova (Umeå University) & Delphine Fremondeau (University of Leuven)
11:50 – 12:10	**Archaeobotany in Romania – investigations in the Late Bronze Age fortification Corneşti–Iarcuri** Astrid Stobbe, Christoph Herbig & Maren Gumnior (Johann Wolfgang Goethe-Universität, Frankfurt am Main)
12:10 – 12:30	**Before and after millet in Slovenia, south of the Alps to the Balkans** Tjaša Tolar (ZRC SAZU, Ljubljana)
12:30 – 14:00	**LUNCH BREAK**
14:00 – 14:20	**The successful spread of millets in Northern Italy** Mauro Rottoli & Barbara Proserpio (Musei Civici, Como)
14:20 – 14:40	**On the „early“ evidence of broomcorn millet in central Germany, primarily Saxony–Anhalt** Monika Hellmund (Landesamt für Denkmalpflege und Archäologie Sachsen-Anhalt, Halle)
14:40 – 15:00	**Millets in Bronze Age agriculture and food consumption in Northeastern France** Françoise Toulemonde (AASPE National Museum for Natural History/CNRS Paris) & Julian Wiethold (INRAP, Metz) et al.
15:00 – 15:20	**The start of millet cultivation in Iberia** Hans-Peter Stika (University of Hohenheim, Stuttgart)
15:20 – 15:40	**Weedy millets and millet weeds** Helmut Kroll (Kiel)
15:40 – 16:00	**COFFEE BREAK**
16:00 – 16:20	**Ukrainian dishes from millet** Galyna Pashkevych (NASU, Kiev)
16:20 – 16:50	**Novelties in animal herding and consumption in Bronze Age Europe** László Bartosiewicz (Stockholm University)
16:50 – 17:20	**DISCUSSION**
17:30 – 19:00	**KEYNOTE LECTURE** **Change in the later second millennium BC: plants, pots, and people** Anthony Harding (University of Exeter)
19:00	**WORKSHOP DINNER**

THURSDAY, 28th NOVEMBER 2019

08:30 – 09:00	***Arrival of participants to the venue***
	SESSION 2: Beyond seeds: Isotopic and biomolecular evidence of millet cultivation and consumption **Session chairs:** Lorenz Schwark & John Meadows (CAU Kiel)
09:00 – 09:20	**Miliacin in palaeosoils and sediments, a powerful biomarker for telling stories about broomcorn millet** Blandine Courel (Université de Strasbourg & The British Museum), Pierre Adam (Université de Strasbourg), Philippe Schaeffer (Université de Strasbourg), Jérémy Jacob (Université d'Orléan & LSCE Gif-sur-Yvette)
09:20 – 09:40	**Molecular and isotopic identification of millet in prehistoric pottery: New results from Bruszczewo, Poland** Edward Standall (The British Museum & University of York), Carl Heron (The British Museum), Oliver Craig (University of York), Jutta Kneisel, Wiebke Kirleis & Johannes Müller (CAU Kiel), Janusz Czebreszuk (Adam Mickiewicz University, Poznań)
09:40 – 10:00	**Towards the quantification of millet in ancient diets using stable isotopes** Oliver Craig (University of York)
10:00 – 10:20	**Detecting the manuring of millet in the past** Amy Styring (University of Oxford)
10:20 – 10:40	**Early integration of pastoralism and millet cultivation in Bronze Age Eurasia** Taylor Hermes (CAU Kiel)
10:40 – 11:10	**COFFEE BREAK**
11:10 – 11:30	**Chicken feed: tracking the introduction and incorporation of new plants and animals** Naomi Sykes (University of Exeter) & Holly Miller (University of Nottingham)
	SESSION 3: Growing and eating millet: Insights from ethnography, agronomy and experimentation **Session chair:** Anna Maria Mercuri (University of Modena and Reggio Emilia)
11:30 – 11:50	**Traditional millet growing in NW Iberia: from the ethnographic insights to the archaeobotanical implications** Andrés Teira-Brión (University of Santiago de Compostela)
11:50 – 12:10	**Looking Away from Europe: A Wider Perspective on Millets in Dry Lands** Marco Madella & Carla Lancelotti (Universitat Pompeu Fabra, Barcelona)
12:10 – 12:30	**Proso millet: cultivation, agronomic practices, and uses** Stefania Grando (International Crops Research Institute for the Semi-Arid Tropics)
12:30 – 13:00	**DISCUSSION & CLOSING REMARKS**
13:00 – 14:00	**LUNCH**

Figure 4. Programme of the millet-themed workshop in Kiel, November 2019.

This volume

Some of the knowledge on millet presented at the workshop is compiled in these proceedings. One of the aims of this volume is to illuminate the wider context of the spread and acceptance of millet in parts of Europe: agricultural, social, technological, environmental, architectural, culinary, ritual and symbolic. The papers do so by re-iterating the importance of looking beyond the list of crops when studying the history of food and food production. The broader-based approach advocated here extends to the methodologies of millet-related research, whereby sophisticated techniques and non-conventional proxies are crucial, but the information they offer must be checked against the results produced by other approaches, as a two-way control. To this point, we note that radiocarbon dating of millet grains has clearly demonstrated the importance of applying direct and adequate methods, which go as far as dismantling old narratives, but that the dates alone cannot tell the story of the agricultural change, its causes and ramifications.

The papers here 'put flesh on the bones'. They examine the cultural and environmental circumstances surrounding the start of millet cultivation in Europe. They present novel methods to investigate the production and use of millet on the past. They showcase rare examples of recent and modern-day growing of millets in Europe.

The book is organised in two sections: the first, 'Innovations in the Bronze Age subsistence economy: regional perspectives from Ukraine to France', includes nine contributions that describe the social, technological, economic, dietary and natural environment in different regions in Europe at the time of the establishment of millet cultivation. The second section, 'Approaching millet cultivation and consumption through high-end microscopy, chemistry and ethnography', presents some new, non-carpological methods of tracing the cultivation and consumption of millets in the past – using high-resolution microscopic analysis of millet grain impressions and casts, as well as biomolecular and isotopic studies. It also emphasises the ethnographic route to understanding millet agriculture, where the living agronomic knowledge illuminates past practices. Below we provide sneak-peeks into the contributions.

Innovations in the Bronze Age subsistence economy: Regional perspectives from Ukraine to France

The paper by **Galina Pashkevich** critically approaches the research history on finds of broomcorn millet in the Ukraine, the region with the earliest dating of millet on its westwards shift to Europe in the 17th century BCE. Prominent finds of millet from the main periods of prehistory and history are listed here, some previously mentioned only in the literature written in Russian or Ukrainian. The paper further describes ancient millet cuisine based on written sources and discusses the sociocultural relevance of millet dishes in Ukraine. It is accompanied by two recipes for millet dishes that allow the reader to improve their own cooking practices and widen their culinary horizon.

Sofia Filatova explores the environmental, cultural and archaeobotanical context of the introduction of broomcorn millet in Bronze Age Hungary. She summarises the settlement history of the 3rd and 2nd millennium BCE, changes in which seem to reflect the apparently fluctuating population density and possible diachronic shifts in food economy between more and less labour-intensive productions. The author then conducts an evaluation of the existing quantitative archaeobotanical data for Bronze Age sites in Hungary, acknowledging that the field and analytical methodologies have varied among sites and among specialists. Using standardised values for the numerous crops recorded at Bronze Age sites, the author shows how the range and quantities of crops varied among cultures and changed over time. As is clear from this overview, broomcorn millet arrived in the Carpathian Basin at a time of cultural transformation – from Middle to Late Bronze Age and the spread of the Tumulus culture – and a time of changing climatic conditions and vegetation cover, from more to less humid and from less to more open, respectively.

Laszlo Bartosiewicz describes the dynamics of animal herding and use during the Bronze Age, primarily in the Carpathian Basin, but also in neighbouring regions, especially those to the east of the Basin, pointing out regional variations in the uses of domesticates. He offers a crisp summary of the general chronological and environmental background to the Bronze Age, noting in particular the predominance in central Europe of a cooler and increasingly humid climate by the middle of the Subboreal, the period encompassing the Bronze Age. For the Carpathian Basin, he gives an overview of the representation of the major animal species in the Bronze Age, emphasising the high variability in this within and between settlement types and the general importance of cattle as a source of both meat and secondary products. The author also documents the sharply rising rate of use/importance through time of caprines *vs.* pigs in the region and reviews the evidence suggesting the production of wool as a factor driving this trend. The contribution benefits from the bonus commentaries on the (early) finds of chicken, specialised antler working in the Bronze Age, and the curious finds of perforated hare and dog metapodia at a few Bronze Age sites in Hungary. A prominent place is given to the discussion of the appearance and role of horse, and how the animal's mobility enabled a greater degree of movement on the part of humans. The author illustrates the 'special status' of horses with examples of horse burials in the West Asian steppe.

Kelly Reed, Jacqueline Balen, Ivan Drnić, Sara Essert, Hrvoje Kalafatić, Marija Mihaljević and **Emily Zavodny** provide an overview of the archaeobotanical records of millet and the stable isotopic evidence of millet consumption by humans and/or animals in Croatia. They offer more detail about the archaeological sites and contexts yielding the grains of broomcorn and foxtail millet that were dated within the 'Millet Dating Programme'. They observe that the data on the Bronze Age plant economy and diet, and changes in these, in Croatia are still very sparse but that the available evidence clearly points to the Middle to Late Bronze Age as the period when crop cultivation began to rely on broomcorn millet and, later on, a few other crops not known in previous periods. As one possible reason for the diversification of crop growing, they suggest risk buffering, which is particularly relevant in agriculturally marginal environments, where a wider range of crops ensured a regular food supply.

The paper by **Tjaša Tolar** and **Primož Pavlin** builds a picture of prehistoric crop cultivation and wild plant gathering in Slovenia, from the thus far earliest crop traces in the region, registered at Eneolithic sites, through to the Early Iron Age. Prior to presenting the evidence of plant production and consumption, they introduce us to the region and its later prehistory, emphasising key developments in technologies of material production (*e.g.* copper and bronze metallurgy). They also summarise the characteristics of burial ritual, settlements and houses, emphasising the fortified nature of the habitations in the Late Bronze Age and Early Iron Age, including the sites from which the dated broomcorn millet grains derived. This comprehensive contribution also includes an overview of finds of harvesting tools, which takes us back in time to the early days of wild grass cutting in the Natufian culture of prehistoric southwest Asia. In Slovenia, flint pieces used as implements in sickles are known from the Late Neolithic, whereas the Bronze Age was the time of metal sickles, commonly found in hoards of metal objects, suggesting that they were highly valued.

In her paper, **Monika Hellmund** revisits a number of reportedly Neolithic broomcorn millet finds in central Germany and, using the radiocarbon dates, in many cases obtained directly on the millet grains, demonstrates how all of them are later intrusions, many from the Late Bronze and Early Iron Age. Along the way, she takes us through the exceptionally rich archive of prehistoric millet finds in the German state of Saxony-Anhalt, including many cases of lumps of fused grains (millet 'porridge') or otherwise large deposits. She also looks beyond the borders of Saxony-Anhalt and discusses some of the 'early' millet finds in the neighbouring German states, emphasising again the insecure temporal attribution of these finds in the absence of direct radiocarbon dates. This critical and detailed overview emphasises the importance of accurate chronological determination of archaeobotanical finds, since broader narratives on crop introductions and agricultural innovations directly depend on accurately establishing their timing. In addition to scrutinising the finds of broomcorn millet in the study region and adjacent areas, Hellmund puts another late addition to the crop spectrum in focus – faba bean (*Vicia faba*). She observes the coinciding temporal and contextual occurrence of the two crops in the Late Bronze Age and the Early Iron Age in central Germany and argues for their importance in both the mundane and the ritual spheres.

Françoise Toulemonde, Julian Wiethold, Emmanuelle Bonnaire, Geneviève Daoulas, Marie Derreumaux, Frédérique Durand, Bénédicte Pradat, Oriane Rousselet, Caroline Schaal and **Véronique Zech-Matterne** provide an in-depth overview of the spread of early millet in northeastern France in the Late Bronze Age, from the 14th century BCE onwards, that is based on an impressive compilation of new and already published archaeobotanical data and new radiocarbon dates. It is interesting to learn that the establishment of millet cultivation in this region coincides with an increase in human population size and with human settlements expanding into previously unexploited environments. The widening of the crop spectrum in northeastern France in the Bronze Age extends beyond the integration of millet and includes the newcomers faba bean and gold-of-pleasure (*Camelina sativa*). Further, new farming strategies emerge involving a dynamic agropastoral economy. In addition to the socio-economic relevance of millet, the authors stress the sociocultural dimensions of millet consumption in the Bronze Age, since it occurs in collective feasting sites as well as in funerary contexts.

In an ambitious integration of off-site and on-site palaeo-environmental, archaeobotanical and archaeological evidence, **Ingo Feeser, Stefanie Schaefer-Di Maida, Stefan Dreibrodt, Jutta Kneisel** and **Dragana Filipović** chart the process of cultural and environmental development before and during the last centuries of the 2nd millennium BCE in northern Germany. Their focus is on a long-lived burial site in Schleswig-Holstein, Mang de Bargen, where they found evidence of changing landscape and intensifying agricultural and ritual use of the land, all culminating around the 12th century BCE, which is when broomcorn millet was introduced in north-central Europe and when a new cultural phenomenon, the Urnfield culture, spread across the region. The authors conclude that the shifts they see in the local vegetation composition resulted from abrupt, concurrent and considerable changes in local funerary, settlement and agricultural activities during the 13th to 11th centuries BCE. They then look at the evidence from the wider region around the site and beyond it, from Schleswig-Holstein; they find that the environmental and cultural transformation took place at all three scales observed – from local to regional to supra-regional.

Approaching millet cultivation and consumption through high-end microscopy, chemistry and ethnography

The paper by **Edward Standall, Oliver Craig** and **Carl Heron** shifts our focus from the growing of millet to its processing for food or drink. The authors describe novel methods – biomarker and carbon and nitrogen stable isotope analyses – applied in the identification of millet in organic residues. As an illustration, they summarise examples of the studies that detected the diagnostic biomolecule miliacin in ceramic vessels: in charred surface deposits (so-called foodcrusts) and/or absorbed into the ceramic fabric. This molecule is retained after the processing of millet or millet-containing foods, in the pots. Besides highlighting the advantages, the authors, importantly, outline the limitations of these new approaches and provide guidance for their future development and application.

In the contribution by **Marta Dal Corso, Marco Zanon, Carl Heron, Mauro Rottoli, Michele Cupitò, Elisa Dalla Longa** and **Wiebke Kirleis** broomcorn millet has been attested by the biomarker miliacin in the archaeological sediments at the Terramare culture site of Fondo Paviani (ca. 1350-1100 BCE), in the Po River valley, northern Italy. This molecule is typical of *Panicum miliaceum* and it was absent in the other modern panicoid grasses analysed for reference. The study presents the results of investigation of on-site sediments and, together with the available archaeobotanical and isotopic records, inserts them into the picture of millet consumption and cultivation during the Late Bronze Age in the Po Valley.

Eiko Endo describes in detail the method she applies in the analysis of plant impressions within the fabric of pottery, which has proved highly efficient and reliable in her work in Japan, but also in Ukraine. In her paper, she gives details on the analytical procedure, which allows her to identify the impressions down to species as well as to plant part (*e.g.* grain *vs.* chaff). As an illustration of the application of this method, she summarises the study she conducted on a pottery assemblage from a large number of prehistoric and historic sites in the Japanese archipelago. She also lists the types of questions one can ask based on the record of impressions, such as those related to formation processes and the use of crop-processing by-products. The paper highlights the potential benefit of this method for the study of crop cultivation and use in general, and of millets in particular. Particularly promising is the application at sites or in regions and periods where plant impressions are the major or the only recovered source of information on plant use.

Andrés Teira-Brión's ethnographic study presents the living tradition of broomcorn and foxtail millet cultivation in northwestern Spain and northern Portugal, both regions of high rainfall. Earlier ethnographic work in this area, in which the author participated, documented millet-growing, -processing and -preparation procedures. In this paper, the author emphasises variations in these practices between neighbouring regions. For instance, in the relatively low-lying Galicia and Minho regions, the farmers' focus is on broomcorn millet, which they use as both food and fodder. In mountainous Asturias, foxtail millet is grown as green fodder, whereas the occasional broomcorn millet in foxtail millet fields is a tolerated weed. But the author does not just describe these general observations. He looks at a much broader socio-economic context – the place of millet cultivation in agricultural systems, which, as he emphasises, are built around, and shaped by, much more than a presence/absence of a crop. Land ownership and inheritance rules, the organisation of production, the structure of community, the balance between arable and pastoral farming or a focus on one of the two, production for own needs and/or market, flexibility of the agrarian cycle – all these and other aspects play a role in agricultural decision making, change, adaptation and adoption. The author urges us to consider the broader economic and social contexts of agriculture in general and millet growing in particular before coming to conclusions about millet as a highly desired 'enabler crop'. This contribution reminds us of the possibilities and limitations of the use of ethnological analogies to inform archaeological interpretations and the danger of directly superimposing present-day perceptions and knowledge onto the past.

Wiebke Kirleis and **Marta Dal Corso** present an interesting example of highly specialised handicraft – broom production – reliant on millet cultivation, in this case of the species *Sorghum technicum.* Their ethnographic observations emphasise how rare this handicraft is in Europe, as it is nowadays practised in Moldova and northern Serbia, but hardly anywhere else. The richly illustrated paper presents the *chaîne opératoire* of the almost-extinct practice, covering the production steps from harvesting the plants to tying the brooms. This contribution shifts the attention to the non-food purposes of millet cultivation, highlighting the place of millet and millet-related activities in the production of objects for everyday use and the craft associated with the use of millet beyond solely foodstuff.

Acknowledgements

The work on broomcorn millet conducted within the CRC 1266 is one more 'panicle' in the global field of millet research. Besides the three of us, many collaborators and colleagues have helped this panicle to grow and the grains to ripen. Some of our associates were directly involved, throughout the research process or at some of its stages, and others contributed with their insights, opinions or practical help. A heartfelt thank-you to all, those named below and those who remain unnamed.

A core group at Kiel included our colleagues within the CRC 1266, above all our key collaborator, John Meadows. Another group, variously linked with the CRC 1266, working both at Kiel and elsewhere, included all of our co-authors on the millet papers that have been published or are forthcoming. Many of them joined us at the workshop in Kiel, and we are delighted that we could host them. We are also lucky that a number of other colleagues accepted our invitation to the workshop and made the event all the more diversified; we are grateful for their interest and enthusiasm.

Both the Millet Dating Programme and the workshop relied immensely on the organisational and technical support of the staff and students at the Institute for Prehistoric and Protohistoric Archaeology at Kiel University, which hosts the CRC 1266. Key help was provided by Tanja Reiser, Yasmin Dannath, Anna Carina Lange, Ralf Opitz, Carsten Reckweg and Janina Stampe. Tomasz Goslar, at the Poznan Radiocarbon Laboratory, facilitated radiocarbon dating of most of the samples included in the programme and provided all the necessary information and details. Christian Hamann, at Kiel, oversaw millet dating done at the Leibniz-Laboratory and provided some crucial advice.

The preparation of the proceedings was possible thanks to the eagerness, time and effort of the authors of the papers included here. We are thrilled and grateful that they responded to our call for contributions. A group of colleagues gave advice or acted as reviewers for this book, and we are very much indebted to them for their readiness to join our team.

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SECTION 1: INNOVATIONS IN THE BRONZE AGE SUBSISTENCE ECONOMY: REGIONAL PERSPECTIVES FROM UKRAINE TO FRANCE

The (pre)history of common millet (*Panicum miliaceum*) in Ukraine and its place in the traditional cuisine

Galyna Pashkevych

Abstract

The generally high scientific interest in the Tripolye prehistoric culture of Ukraine peaked several years ago. Conferences were held and many relevant publications appeared at the time. There were journalists at these conferences and, wishing to entertain the conference participants, they prepared a *kulish* meal. In their opinion, kulish was a typical Tripolye dish. However, the archaeobotanical evidence shows that this is not the case, because the main ingredient in this traditional dish is millet (*Panicum miliaceum*) and the association of millet with the Tripolye period is wrong. Millet appeared in Ukraine much later than this culture. The history of the emergence of millet on the territory of Ukraine has been unravelled thanks to archaeobotanical and other research, the results of which are summarised here.

Introduction

The wide array of cultivated plants and the traditional methods of their cultivation, processing and dietary use are a part of human culture and reflect the talent, intellect and diligence of many generations. There has, therefore, been growing awareness of the need to study and preserve the heritage of culinary knowledge and practices. This has recently started to manifest itself in the increased attention being paid to ancient crop varieties and other plants as sources of products for healthy nutrition and wellbeing.

Archaeobotanical materials are an important source of information on the history of the origin, distribution and use of plants. One of the plants that has attracted the interest of both archaeobotanists and laypersons is common/broomcorn/proso millet (*Panicum miliaceum*). The cultivation and consumption of this cereal has a long tradition in Ukraine. This paper revisits the 'early' finds of millet in Ukraine in light of the recent determinations of the precise age of these finds. It then moves through time and presents some of the records of millet from the classical antiquity and medieval periods, after which it turns to the recent and modern-day role of millet in the region.

The 'early' finds of common millet in Ukraine

The Tripolye culture extended over great parts of the modern forest-steppe zone in Ukraine, in the area between the Prut and Dnieper rivers. Calibrated ^{14}C dates indicate that the Tripolye culture covered the period from the 5th to the 3rd millennium BCE (*e.g.* Müller *et al.* 2016). The major cereals grown by these groups were the hulled wheats einkorn (*Triticum monococcum*) and emmer (*T. dicoccum*); barley (*Hordeum vulgare*) was a minor crop. The list of cultivated plants from this period further includes pea (*Pisum sativum*), bitter vetch (*Vicia ervilia*), lentil (*Lens culinaris*) and flax *(Linum usitatissimum*) (Янушевич 1976, 1980; Пашкевич 1980, 1989, 1990a, 1993, 2000a, 2011; Pashkevich/Pashkevych 2003, 2005, 2012; 2016; Пашкевич and Відейко 2006; Kirleis and Dal Corso 2016).

For the territory of present-day Ukraine and Moldova, the presence of millet on Neolithic and Eneolithic sites was previously reported as involving rare, single impressions of grain in pottery or daub (Янушевич 1976; Pashkevych 2012). Yanushevich notes that some impressions said to be millet grains in pottery and daub from the settlements of the Bugo-Dniester culture and the early phase of the Tripolye culture are not very clear and that some of them probably are of the weedy species *Setaria glauca*, *Setaria viridis* or *Echinochloa crus-galli* (Янушевич 1976, 153). Impressions of what seems to be millet grain were also detected in the clay materials of the middle and late phases of the Tripolye culture, where it was reported that they preserved morphological features of the grains (Pashkevych 2012).

Neolithic and Eneolithic records of millet are known not only from Ukraine, but also from central and western Europe. Detailed lists of these 'oldest' finds of millet grains in Europe are given by Zohary and Hopf (2000, 83-85) and Hunt *et al.* (2008), the latter already critically asking when millet actually arrived in Europe. This issue was pursued by Motuzaite-Matuzeviciute *et al.* (2013) who, through radiocarbon dating some of the 'Neolithic' millet grains from Europe, demonstrated that they date much later. This raised suspicion about the age of other such 'early' millet finds on the continent and emphasised the importance of obtaining reliable dates in order to answer the question of when millet arrived. With the completion of a much larger scale Millet Dating Programme at Kiel University, it is now clear that millet became a staple crop in Europe only in the 2nd millennium BCE and that the millet finds from earlier archaeological contexts represent later intrusions (Filipović *et al.* 2020).

Before the start of archaeobotanical analysis in Ukraine, the determination of archaeological plant remains was based on the knowledge of archaeologists, which was insufficient, and on some general assumptions. For example, *Setaria* was referred to as 'millet', but without specifying whether it was foxtail (*italica*) or some other *Setaria* species. For instance, at the Tripolye settlement site of Grebeni (excavated from 1961-1963 by S.N. Bibikov) yielded a vessel filled with grains, which was stored in the site's archive under the label 'millet'. Analysis under a microscope revealed that these were instead grains of the weedy species *Setaria glauca* (Пашкевич 1991). One plant of this species produces about 6000 grains and, when they are ripe, shatters them rapidly and infests the soil. *S. glauca* seeds do not lag much behind common millet in terms of their nutritional value and can be used as food (Рева М.Л. and Рева Н.Н. 1976). The grains found in the vessel may have been collected and kept in the pot for some kind of use.

In the 20th century, archaeobotanists rarely used scanning electron microscopy, and the radiocarbon dating technique was much less precise than nowadays. Results obtained with conventional microscopy and non-AMS radiocarbon dating can, therefore, benefit from a revision. An excellent example is the recent re-examination of the plant impressions on figurines of the Usatovo culture of prehistoric Ukraine. This study was carried out as part of the research on the timing and pace of the movement of millets from China to Europe. Archaeobotanical studies of Usatovo culture materials were carried out by N. Kuzminova (Кузьминова and Петренко 1989), who identified impressions of millet grains on 70 anthropomorphic clay figurines. Re-analysis of these impressions was recently conducted using a scanning electron microscope, and this re-analysis showed that none of these impressions bear morphological features of common millet (An *et al.* 2018).

Another example is the radiocarbon dating of charred grains of common millet from the territory of Ukraine, performed jointly with archaeobotanists from Kiel University (Filipović *et al.* 2020; Dal Corso *et al.* 2022). The results revealed that common millet first appeared in Ukraine in the last quarter of the 17th century BCE; the dated grains from the Bronze Age settlement at the site of Vinogradniy Sad, in southeastern Ukraine are, for now, the earliest finds of common millet in Europe. Perhaps Ukraine was the gateway through which millet entered Europe on its westward journey from the areas of origin in China.

Finds of common millet from the Bronze Age to early modern times in Ukraine

For most of its duration, the Bronze Age in Europe (ca. 3000-500 BCE) coincided with the Subboreal climatic period. Under the impact of climatic deterioration, with frequent droughts and cold spells, significant changes took place in the economy, social organisation and material culture of the populations of central and eastern Europe. For instance, the Tripolye culture disappeared at the time of a dry Subboreal phase.

According to the radiocarbon AMS-dates, millet grains from Vinogradniy Sad, a settlement of the Bronze Age Sabatinovka culture, date from the period 1631-1455 BCE (Filipović *et al.* 2020; Dal Corso *et al.* 2022). This settlement was excavated at the end of the 1980s; soil samples were taken from the cultural layers and wet sieved, and charred plant remains were extracted and archived. The crop assemblage from Vinogradniy Sad is composed mainly of hulled wheat, naked barley and common millet (Пашкевич and Костильов 1992). The data from this and other sites of the Sabatinovka culture show that barley, common millet and emmer were the principal crops of the Bronze Age (Pashkevich 2003). The Bronze Age economy in the steppe and forest-steppe zone of Ukraine was based on stock breeding and agriculture. Archaeobotanical records show that agriculture gained in economic importance during the Middle Bronze Age and Late Bronze Age (Пашкевич and Шовкопляс 2012).

As shown by the radiocarbon dating, by the beginning of the 12th century BCE, common millet was being grown throughout Europe, including in its northern part. In Ukraine, millet grains from the Belozerska culture settlement of Dikiy Sad, located in the town of Nikolaev, gave the following radiocarbon dates: 1214-1001 BCE and 1209-979 BCE (Filipović *et al.* 2020; Dal Corso *et al.* 2022). The settlement itself dates to the end of the Bronze Age. Archaeobotanical analysis of the pit fills and layers within structures documented the presence of barley, common millet, free-threshing wheats and hulled wheats, as well as seeds of crop weeds (Горбенко and Пашкевич 2010).

From the Bronze Age onwards, common millet frequently occurs in large quantities throughout Ukraine, in both the steppe and the forest-steppe zones, and even in the forested areas. In particular, it seems to have had great importance in the Iron Age in the forest-steppe zone. In *The Histories*, Book IV, Ch. 18 and 75-76, Herodotus writes about the use of common millet and hemp by the Scythians (Godley 1920). Hulled wheats (principally emmer) and hulled barley, along with common millet, dominated the food production of the Scythians in the forest-steppe zone (Janushevich 1981; Янушевич 1986; Пашкевич 1991, 2001; Пашкевич and Горбаненко 2019). Charred grains of common millet were recovered at the sites of Ivane-Puste and Zalissya, in the western part of this zone (Пашкевич 1991). Crop cultivation became prominent in the predominantly pastoral food economy of the Scythians in the steppe zone in the period 500-400 BCE, when these groups occupied the lower Dnieper region. The crops they cultivated were barley and millet and, to a lesser extent, emmer (Pashkevich 1984; Гаврилюк and Пашкевич 1991; Пашкевич 2000b). The composition of plant assemblages, the types of tools and some ethnographic data offer a basis for the reconstruction of the nature of crop cultivation. It seems that, at this time, parts of the population shifted their economic base more to farming. The need for winter fodder for the herds led to a focus on certain crops, primarily common millet and barley that have traditionally been known as forage plants. Apparently, crop cultivation emerged as a key subsistence strategy of the Scythians in the steppe zone due to the need for animal fodder (Dal Corso *et al.* 2022).

There were Early Iron Age settlements in the northern Black Sea region that were located in similar environments, but their economies were different. Most obviously, the great importance of bread wheat is a distinctive feature of the ancient Greek towns in the North Pontic; besides bread wheat, hulled barley was also very common here. Free-threshing wheat arrived in the northern Black Sea region with the Greek colonists from Miletus, in Asia Minor, and, in the course of time, was integrated into agricultural production over the entire territory of modern Ukraine. It is evident that the Greek settlers brought new food production strategies and used the crops known from their homeland. Hulled wheats were of less significance, whereas a range of pulses were grown, including bitter vetch, pea, lentil and chickpea (Янушевич 1976, 1986; Janushevich and Nikolaenko 1979; Janushevich 1989; Пашкевич 1990b, 2002, 2004, 2005, 2006, 2016).

The significance of hulled wheats among the plants constituting food for the residents of the ancient Greek city of Chersonesos, on the Crimean Peninsula, may have been connected with an economic downturn. Grain reserves stored in individual homesteads were intended only for consumption and not for sale. The importance of crafts increased and the inhabitants of Chersonesos recovered the lost trade income by selling their handicrafts to the groups living in the hilly regions (Сорочан *et al.* 2001), where a different set of grain crops was cultivated to that in the *chora* of Chersonesos; the dominant ones where hulled wheats, rye and common millet.

The importance of millet in the Greek colonies of the northern Black Sea region increased in the first centuries CE, when contacts and mixing with the local population became reflected in the crop spectrum of the Greek communities, which now also included hulled wheats and barley. These crops, which had long been locally grown, were well adapted to the climatic and soil conditions of the region. The last centuries of the 1st millennium BCE and the first centuries CE were the time when millet was widespread in eastern and central Europe. Charred grains and their impressions from this period were found at sites in Slovakia, Germany and Poland.

Over a long period, millet was the main grain crop of the Slavic tribes in Ukraine, starting from the 3rd century BCE and continuing up to 7th century CE. At some of the sites, it makes up almost 60% of the plant assemblage (Пашкевич 1988a, b; Горбаненко and Пашкевич 2010; Пашкевич and Горбаненко 2010).

The Rus' people of early medieval eastern Europe grew bread wheat, rye and common millet. The associated archaeobotanical samples date from the 9th to the 14th centuries CE and were collected from such places as old Rus' towns, fortified villages and military camps; they vary in volume from a few grams to several kilograms (Пашкевич 2010; Козловська *et al.* 2012). The significant finds come from the period spanning the 11th to 13th centuries CE, from the territory of ancient Kyiv, where archaeological work has been going on for more than 100 years. During the excavations of 1907-1908, charred grains of rye, millet and free-threshing wheat were most commonly found in the Rus' structures. In some areas wheat prevailed, in others millet (Пашкевич 2010).

In the 18th and 19th centuries CE, Russia occupied first place in the world for the cultivation of common millet, as highlighted by the words of the famous botanists who travelled through the Russian Federation at the time. The well-known scientist Piotr Zhukovsky stated that millet arrived in Europe from East Asia together with nomadic tribes.

> '*Of the cereals, millet is probably the most ancient food plant in China. All of the most ancient traces of Chinese history from around 2700 BCE testify to this. Even younger evidence, dating back to the Yin era (XVIII-XII BCE), speaks of the leading significance of millet*'[1] (Жуковский 1964, 229-230).

According to N.I. Vavilov, common millet was the favourite cereal of the nomads in Eurasia, and it was with these tribes that he associated the appearance of millet in Europe.

> '*Millet can be sown very late, at different periods, and does not bind the nomads. Sowing* […] *requires very few grains; millet is extremely transportable, unusually drought resistant, it grows even on sandy soils* […] *and therefore is still an indispensable attribute of the nomadic economy of the semi-desert regions of Asia and the southeast of the European part of the Russian Federation*'[2] (Вавилов 1987, 65).

In the selected works by N.I. Vavilov, various forms of economy among the Afghan tribes are described: '*Even nomads were engaged in agriculture, especially during long migrations from the south of the country to the north*' (Вавилов 1959, 105-106). The advantage of sowing millet is also emphasised:

> '*A small amount of grains per hectare is needed for sowing and, at the same time,* [it is] *undemanding in terms of conditions. Therefore, millet is a good companion of nomadic and semi-nomadic tribes*'[3] (Вавилов 1959, 262-264).

Some insights on the role of millet in ancient and traditional cuisines

Millet is one of the most important grain crops. The grains removed from the glumes (groats) are called *psheno* in Ukrainian. It has a high protein content (12-14%) and a low percentage of fat (1-3.5%), *e.g.* lower than that of oat groats. Millet boils quickly and absorbs water easily (Вавилов *et al*. 1986, 143-152). Unlike buckwheat and oat groats, millet has little fibre; vitamin PP; and microelements such as copper, nickel, manganese and zinc. The proteins it contains are quickly oxidised leading the groats to become bitter. Other parts of plant, *i.e.* straw and chaff, are used as hay or green fodder.

The first written evidence for the use of common millet is found in the works of the ancient Roman author Columella:

> '*Bread is made from millet, which can be eaten with pleasure while it is still warm. From the mogar [or foxtail millet,* Setaria italica*], when crushed and freed from the brans, as well as from the millet, porridge is obtained in any quantity; it is quite tasty, especially with milk*'[4] (after Сергеенко 1970, 14).

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1 Translated by the author.
2 Translated by the author.
3 Translated by the author.
4 Translated by the author.

Pliny the Elder reported in his *Natural History*, Book XVIII:

> '*Millet flourishes particularly well in Campania, where it is used for making a white porridge; it also makes extremely sweet bread. Moreover, the Sarmatian tribes live chiefly on millet porridge, and even on raw meal, mixed with mare's milk or with blood taken from the veins in a horse's leg. Millet and barley are the only grains known to the Ethiopians*' (Rackham 1938, 253).

Common millet and foxtail millet (or *mogar*) are mentioned by other classical sources too. According to the ancient Greek authors, in the 1st century CE, millet and mogar were the main crops. Strabo named millet as one of the main crops in the typical Campanian crop rotation. At the same time, he pointed to its reliability: '*… the most reliable protection against hunger, because millet is stable in any weather and there is never a shortage of it*'[5] (cited in Кузищин 1966, 111-113). Herodotus (485-425 BCE), in his Book IV, Ch. 17, mentioned consumption of lentil and millet among the Scythians who inhabited the Dnieper and Bug basins (Godley 1920). Xenophon (434-359 BCE), in Anabasis, Book 1, Ch. 22, describes how, in a campaign through Cilicia, he encountered fields sown with barley, wheat and millet (Brownson *et al*. 1922).

From an agronomic point of view, this cultivar is more thermophilic than other cereals and survives higher temperatures than do winter rye, wheat and oat. Unlike other cereals, millet is almost indifferent to the sowing time. It gives an equally good yield whether sown in early or late spring, or in the middle of summer. This has an advantage because, in the event of bad winter or spring weather affecting the wheat harvest, millet comes to the rescue. According to Columella's calculations for millet, on average, the number of grains needed for sowing is 20 times lower than for wheat and 40 times lower than for emmer (after Сергеенко 1970, 149).

Today, millet is grown mostly in the Middle East, central Asia and India. In the past few decades, millet production has also been started in some American and European countries. In Ukraine, in contrast, the cultivation of millet has been drastically reduced in recent years, despite millet being a well-known and widespread crop here until the 21st century. Various dishes were made from it – porridge, soup and even a drink called *buza*, which contains 4-6% alcohol.

In the recent history of Ukraine, a range of millet-based dishes are found in the cuisine of the Zaporozhye Cossacks. This was a military organisation in the steppe zone of Ukraine, formed in the 16th century CE from the local Slavonic tribes and nomads. Their life was on the road, and so they prepared food on an open fire, in big copper or iron pots. Porridges were widespread, prepared from millet or buckwheat. The millet porridge had different names and ingredients: *teterya* was a combination of millet and sour rye dough, fat, milk or fish; *bratko* was a simple porridge made purely of millet. A more liquid millet dish was called *kandiour*. The Ukrainians also eat millet porridge with pieces of pumpkin. Sometimes they wrap millet porridge in cabbage leaves; cover the rolls with sour cream, spices and tomato sauce; and then boil for several minutes. This last dish is called *golubcy*.

Kulish is the most famous millet-based traditional Ukrainian dish, still popular today. Interestingly, the word 'kulish' is of Hungarian origin (*köles*=millet). Kulish is normally eaten for lunch in the field or for dinner at home. It is prepared on an open fire. Fat (*salo*), millet, onions, carrot, salt and pepper are the basic ingredients (Fig. 1). Potato was added in the 20th century CE. Kulish with meat is especially tasty, and the dish is also sometimes cooked with fish or mushrooms (*Хименко* 1960, 110; Шалімов and Шадура 1981, 39). In ancient times, when the ingredients were deficient, kulish was also made with underground plant parts (bulbs or tubers, *e.g.* of *Typha*), which are rich in starch.

5 Translated by the author.

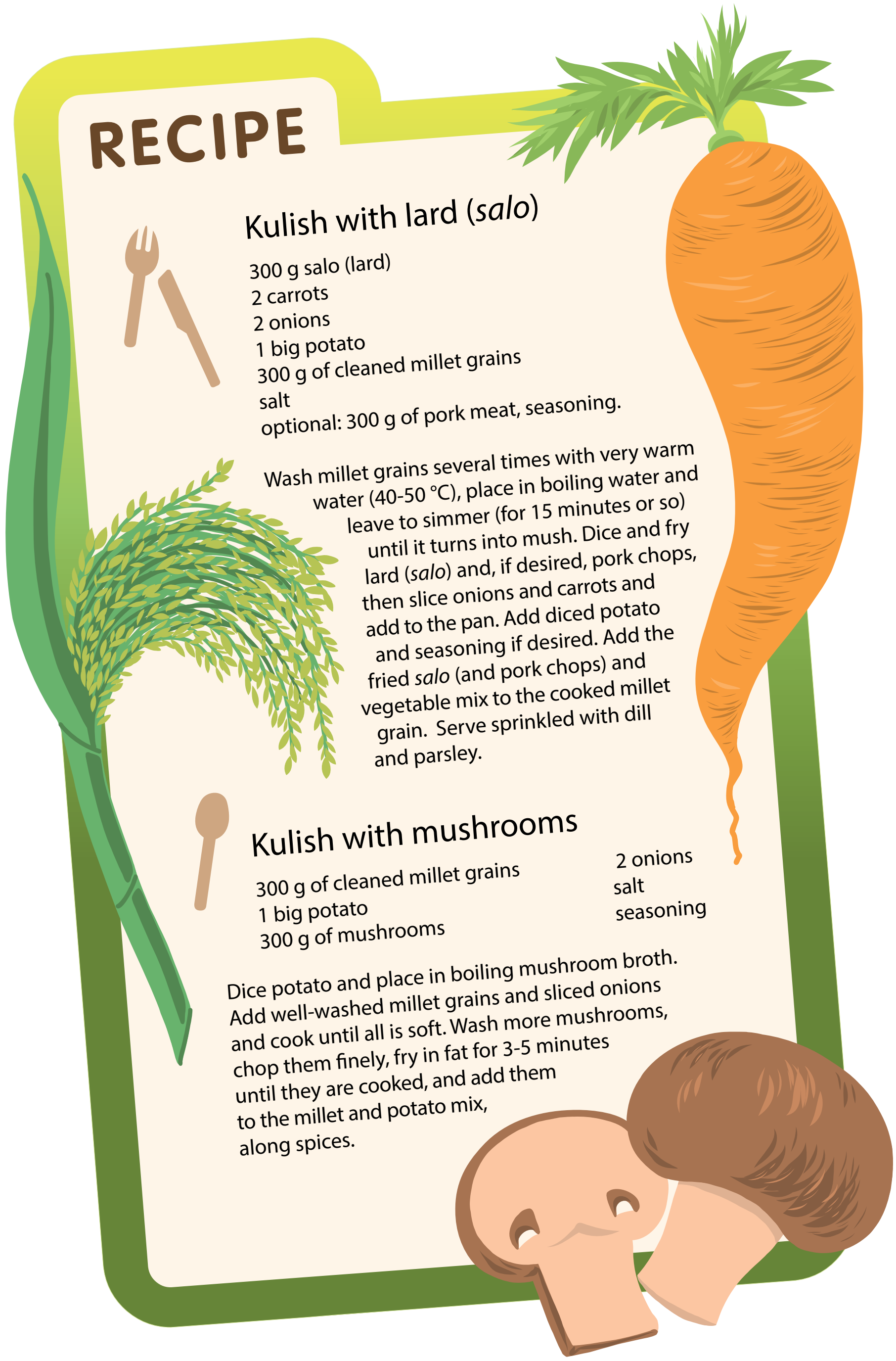

Figure 1. Two common recipes for Ukrainian kulish (suggested by Galyna Pashkevych; figure by Anna Carina Lange).

Conclusions

For a long time, it was thought that the earliest finds of ancient millet grains on the territory of modern Ukraine dated to the Neolithic. However, modern research methods have shown that the earliest millet grains known from Ukraine are no older than the Bronze Age. These small grains often move within and between archaeological layers, as they find their way through cracks, root channels, and rodent burrows or are carried by insects and rodents, ending up as younger intrusions in older layers. This is particularly evident at multi-period sites.

From the Bronze Age to the present day, common millet has been one of the main cultivated plants in the territory of Ukraine, associated both with agriculturalists and mobile pastoralists, such as the Scythians, who lived in villages and towns, and with nomads, such as the Cossacks. Pliny, Columella and other classical authors indicated the varied uses of common millet in ancient cuisines. This diversity was preserved over centuries and millennia, and the Cossacks of the Zaporizhzhya cooked various dishes from millet. The most popular dish was a porridge called kulish. Kulish recipes have survived to this day and are commonly used in Ukrainian cuisine.

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Bronze Age plant spectra in Hungary before and after the introduction of millet cultivation

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Abstract

The current paper provides an overview of the plant spectra from archaeological sites dating to the Bronze Age in Hungary, and seeks to identify changes and continuities therein before and after the establishment of broomcorn millet as a crop. The overview includes a discussion of the general trends that have been identified in the Bronze Age habitation and environment in the region, as well as a quantitative consideration of macro-botanical data from 52 Bronze Age sites in Hungary. The results confirm the introduction of millet cultivation in Hungary during the Late Bronze Age and further demonstrate the diverse spectra of plants within individual settlements of all three phases of the Bronze Age.

Introduction

Macro-botanical finds of broomcorn millet (*Panicum miliaceum*) in modern-day Hungary have been reported dating as early as the Neolithic (6th millennium BCE; Gyulai 2014, 32). Recent AMS-dating of charred broomcorn millet has, however, revealed that the earliest evidence of millet in Hungary dates to the 15th century cal BCE (the onset of the Late Bronze Age), indicating the redeposition of the small grains from younger to older archaeological layers (Filipović *et al.* 2020, 6, Table 2). Isotopic studies of human bone samples from the Great Hungarian Plain dating from the Neolithic to the Bronze Age have, furthermore, revealed an increase in C4 plant dietary input from the Late Bronze Age onwards, suggesting the inclusion of millet in the diet of humans and/or animals (Gamarra *et al.* 2018, 12-13). The Bronze Age has also been distinguished as the time when millet cultivation was introduced into other regions of Europe (Filipović *et al.* 2020, 13).

The current paper provides an overview of the spectra of plants from archaeological sites dating to the Bronze Age in Hungary, and seeks to identify changes and continuities therein before and after the establishment of broomcorn millet as a crop. The paper starts with brief discussion on the general trends identified in Bronze Age habitation and environment, in order to contextualise the situation in which millet appeared in the region. This is followed by an introduction to the plant spectra based on macro-botanical studies from Bronze Age settlements throughout Hungary. The paper concludes with a consideration of the patterns that could be distinguished from the assemblages. Note that part of the information presented below applies to the Carpathian Basin as a whole, in which Hungary is situated.

Hungarian Bronze Age chronology and society

The Hungarian chronology of the Bronze Age was established by the 1980s (Fischl *et al.* 2015, 505) and an important part of it is based on Istvan Bóna's (1975) analysis of material from more than 1200 archaeological sites (Bóna 1975, 13). Although it has been further elaborated and refined since, its foundation has remained unaltered and it is still in use today (Fischl *et al.* 2015, 505). The Bronze Age in Hungary is divided into three main phases (Early, Middle and Late), and together these cover a period that starts in the second half of the 3rd millennium BCE and ends at the beginning of the 1st millennium BCE (Table 1).

A diverse array of communities, or archaeologically determined groups, inhabited the Carpathian Basin during the Bronze Age, and they are distinguished based on ceramic styles, burial customs and types of settlement. Traditionally, the areas occupied by different archaeological groups have been defined on the basis of uniformity in material culture, thereby forming 'cultural territories' throughout the Carpathian Basin (*e.g.* Bóna 1992, 16-17). Although this view has been criticised due to the underlying assumption that there exists a direct relationship between ethnicity and material culture, the traditional definition of Bronze Age groups and their related territories remain in use within Hungarian archaeology (Kienlin 2012, 2015, 36; Staniuk 2020, 38).

Starting with the transition to the Early Bronze Age (2800/2700 cal BCE), a group known as Makó-Kosihy-Čaka inhabited areas in northern, central and eastern Hungary, occupying small campsites as well as larger settlements (Kulcsár 2009, 14-16, 64). A few centuries later (from ca. 2600/2500 cal BCE), a variety of groups become visible in the archaeological record of the Carpathian Basin, including Bell Beaker groups inhabiting the area north of Budapest and Nagyrév groups first settling on the western bank of the river Danube (for a more elaborate description, see Fischl *et al.* 2015, 505-509). Some of these groups vanished in the course of the Early Bronze Age (*e.g.* the Bell Beaker groups), while others persisted and laid the foundations for subsequent Middle Bronze Age groups (Kienlin 2015, 33). Of special importance are Nagyrév groups, who in some cases constructed their houses one on top of the other in succession, creating superposed building horizons eventually leading to the formation of tells, which were occasionally fortified. This practice spread along the Danube and the Tisza, and to the northern and eastern parts of the Carpathian Basin (Fischl *et al.* 2015, 513). The occupation of tells is one of the defining features of the Early and Middle Bronze Age in central and eastern Hungary, although only small parts of the inhabited regions actually contained tells (Gogâltan 2008, 40; Kienlin 2015, 34). Tell-like, mound-like and flat settlements were inhabited alongside tells, while in Transdanubia (western Hungary) tells never appeared and settlements were occupied for shorter periods (Fischl *et al.* 2015, 514).

During the Middle Bronze Age (2000/1900-1500/1450 cal BCE), a number of tells that had been established in the Early Bronze Age were continuously inhabited by the succeeding Middle Bronze Age groups (*e.g.* Vatya groups on the Nagyrév tells). This continuity in occupation is attributed to population concentration and/or growth, which is also reflected in the increase in the number and size of settlements

Bronze Age phase	Date (cal BCE)	Important characteristics
Late Bronze Age II	1250/1150-800/750	Entire Carpathian Basin occupied by local groups of the Urnfield culture; settlements include campsites, hamlets and fortified hilltop settlements; bronze metallurgy becomes widespread.
Late Bronze Age I	1500/1450-1250/1150	Entire Carpathian Basin occupied by the Tumulus culture; settlements are more dispersed and sizes decrease compared with previous phase.
Middle Bronze Age	2000/1900-1500/1450	Continuity of tell occupation in the central and eastern Carpathian Basin by a variety of communities; settlements increase in size and number.
Early Bronze Age	2600/2500-2000/1950	Appearance of a variety of communities; onset of development of tells in the central and eastern Carpathian Basin.
Copper Age/Early Bronze Age	2800/2700-2600/2500	Transitional phase: Early Bronze Age settlements ranging from larger, more permanent sites to small, temporary campsites.

Table 1. Chronology of the Hungarian Bronze Age and summarised characteristics based on the information provided in the text. Dates after Fischl et al. (2015, 504-505, Table 1a, b).

(Szeverényi and Kulcsár 2012, 292; Fischl *et al.* 2015, 513). In some cases, (fortified) tells are surrounded by smaller settlements and a hierarchical relationship has been proposed, whereby tells, occupied by an elite, acted as primary centres and controlled movement and communication in the surroundings (Gogâltan 2008, 53; Earle and Kolb 2010, 72-73). This is, however, not the case in all regions of the Carpathian Basin (*e.g.* Szeverényi and Kulcsár 2012, 336) and because very few 'satellite settlements' have been systematically excavated, this hierarchical relationship remains speculative (Kienlin 2012, 282; Jaeger 2016, 69; Staniuk 2020, 43).

The end of the Middle Bronze Age is marked by the gradual abandonment of tells and by the burial of bronze hoards, the latter practice happening during what is known as the Koszider horizon (Poroszlai 2003, 155; Jaeger 2016, 99-100). Although this practice was initially interpreted as a rapid event stimulated by a violent invasion by the Tumulus people from the west, the absence of evidence for settlement destruction and the increasing evidence for gradual settlement abandonment, both prior to and after the Koszider horizon, have altered this view (Fischl *et al.* 2013, 358; Vicze 2013, 15; Jaeger 2016, 99-100; Duffy *et al.* 2019).

During the first part of the Late Bronze Age (1500/1450-1200/1150 cal BCE), the open, more dispersed and generally smaller settlements of the Tumulus groups came to dominate the landscape (Sánta 2010, 257). These groups occupied the entire region of the Carpathian Basin and are especially known for their distinctive burials, in kurgans or tumuli (Csányi 2003, 162). There is no consensus on what may have caused the sudden decline in number and size of settlements, but explanations that have been put forward include a shift from intensive to extensive agricultural practices, with a more pronounced reliance on animal husbandry (Sánta 2010, 522), and a reduction in agricultural yields due to (a) climatic deterioration, (b) scarcity in available arable land, and/or (c) exhaustion of the cultivated soil (Gyulai 1993, 19; Reményi 2012, 281; Fischl *et al.* 2013, 366).

The final phase of the Late Bronze Age (1250/1150-800/750 cal BCE) witnessed another major change in occupation. The Carpathian Basin was now inhabited by a range of local Urnfield groups, such as the Gáva in the east and the Piliny and Kyjatice in the west (Marková and Ilon 2013, 827). These groups occupied a variety of (marginal) landscapes, ranging from the plains to the mountains, and their settlements included large, fortified hilltop settlements and small hamlets and campsites (Szábo 2003, 162-164; Marková and Ilon 2013, 827-828). The Urnfield groups are especially known for their burial rite, which took the form of cremations in urns, and for their extensive development of bronze metallurgy and trade. The bronze metallurgy was characterised by a variety of tools that were no longer solely prestige items, but became objects of common use (Szábo 2003, 164; Marková and Ilon 2013, 827).

Bronze Age environment

The Bronze Age in Hungary coincides with the Subboreal biozone, which spans the Late Copper Age to the start of the Iron Age (ca. 3600/3500-900/800 cal BCE; Somogyi 1987, 30). In contrast to the preceding Atlantic phase, which witnessed the Holocene climatic optimum, the Subboreal is distinguished by cooler summer temperatures and high levels of humidity (Kordos 1987, 13-14, Figs. 2, 3). Stable hydrogen, oxygen and carbon isotope data obtained from cave stalagmites in southern Hungary and from bivalve shells from Lake Balaton in western Hungary reflect a short-term humid phase during the first part of the Middle Bronze Age, with a subsequent increase in humidity during the second part of the Middle Bronze Age. After the humidity peak, precipitation decreased and gave way to drier and warmer summer temperatures during the second phase of the Late Bronze Age. These conditions have been interpreted to reflect a period of fluctuating humidity but with a relatively mild climate, suitable for arable farming (Demény *et al.* 2019).

Despite the mosaic-like character of the vegetation that prevailed in Hungary during the Bronze Age, a few general commonalities can be observed. Although the exact combination of taxa varied locally, the arboreal pollen in the records in northeastern, central and western Hungary show a strong presence of species indicative of mixed oak forests (*e.g.* species of oak (*Quercus* sp.), elm (*Ulmus* sp.) and lime (*Tilia* sp.)) throughout the entire period and an increase in hornbeam (*Carpinus* sp.) and beech (*Betula* sp.) towards the Late Bronze Age (Sümegi and Bodor 2000, 89; Juhász 2007a, 34, 2007b, 47-49; Juhász and Szegvári 2007, 324; Magyari *et al.* 2010, 926-927; Náfrádi *et al.* 2011, 363). The increasing presence of hornbeam and beech can be seen as an indicator for more arid and humid conditions, respectively (Magyari *et al.* 2010, 927), but their combined presence can more likely be interpreted as a reflection of woodland clearance. The exploitation of oak, elm and lime for the construction of houses and fortifications during the Bronze Age would have promoted the spread of hornbeam and beech (Sümegi and Bodor 2000, 89; Náfrádi *et al.* 2011, 361). At least part of the mixed oak forest that prevailed in Hungary during the Bronze Age was in the form of a forest-steppe vegetation, the so-called Pannonian steppe, which existed throughout the semi-arid regions of the Carpathian Basin during most of the Holocene (Nagy-Bodor *et al.* 2000, 121; Sümegi *et al.* 2012, 17). Over the long term, the exploitation of oak, elm and lime caused thinning of the forest, blurring the boundaries between closed woodlands, gallery (riverine) forests and forest-steppe, and an increase in grasslands, eventually resulting in an expansion of the forest-steppe (Sümegi *et al.* 2012, 18).

From the second half of the Middle Bronze Age onwards, anthropogenic indicators, such as plantain (*Plantago* sp.) and dock (*Rumex* sp.), are more pronounced in the pollen record than before and suggest disturbance through pastoral activities and arable agriculture (Sümegi and Bodor 2000, 87; Juhász 2007a, 34, 2007b, 47-49; Juhász and Szegvári 2007, 324; Magyari *et al.* 2010, 926-927; Náfrádi *et al.* 2011, 362, Fig. 3; Knipl and Sümegi 2012, 444). This is in line with the archaeological evidence presented above that indicates flourishing of communities and a population growth within the Carpathian Basin from the Middle Bronze Age onwards.

Macro-botanical finds of the Bronze Age in Hungary

The material

Macro-botanical material retrieved from Bronze Age settlements in Hungary has been intensively studied during two phases: in the 1960s-1970s and in the 1990s-2000s (Gyulai 2010, Appendix Bronze Age data). An extensive compilation of macro-botanical data in Hungary was published by Gyulai in 2010, and this publication forms the main source of information in the current contribution. Gyulai's data have been supplemented by recent macro-botanical studies of Tarhos Gyepesi Átkelő (Tarhos 26; Békés County, Hungary) by Duffy (2010, 275, Table 9.1); Százhalombatta-Földvár (Pest County, Hungary) by Stika and Heiss (2013, 79-80, Table 1); and Kakucs-Turján (Pest County, Hungary) by the present author (Filatova 2020).

The data compiled by Gyulai have a few drawbacks that need to be addressed. First, as is inevitable with macro-botanical studies that span several decades, the sampling strategies applied to retrieve the remains were not uniform. Whereas some sites have been sampled systematically, most have not, and there is therefore a discrepancy in the reliability of the data (*e.g.* Gyulai 2010, 100). These data are nevertheless of great value to our understanding of the diversity of plant spectra of the Bronze Age, especially when viewed on a regional scale.

Second, the methods of quantification in Gyulai's compilation vary. Most of the remains have been recorded in absolute quantities, but records also include semi-quantitative estimates (*e.g.* x, xx, xxx) and quantifications in weight and volume. In order to include the entire body of data, these quantifications were converted into absolute numbers according to the guidelines shown in Tables 2 and 3. The semi-quantitative ranges were converted into the median values of those ranges. The conversions of weight and volume into numbers were calculated based on 100 remains of the same species from the Early and Middle Bronze Age settlement of Kakucs-Turján in central Hungary. Exceptions are grass pea (*Lathyrus sativus*), club wheat (*Triticum aestivum* ssp. *compactum*) and millet (*Panicum miliaceum*), which either were not identified in the samples of Kakucs-Turján or were only represented by a few grains/seeds per sample. Grass pea was estimated as equal to the weight and volume of pea (*Pisum sativum*), and club wheat as falling between the weight and volume of barley (*Hordeum vulgare*) and einkorn (*Triticum monococcum* ssp. *monococcum*). The volume and weight of 100 grains of millet were measured based on the same finds from the Byzantine site of Caričin Grad (Lebane municipality, Serbia; Reuter in press), which were readily available for measurement in the archaeobotanical laboratory at Kiel University. Despite the fact that the converted values probably diverge from the actual values, they have the advantage that they

Scientific name	Weight (g)	Volume (ml)	Common name
Hordeum vulgare	1.1	3.5	Barley
Panicum miliaceum	0.1	0.5	Broomcorn millet
Triticum monococcum ssp. *monococcum*	0.9	3	Einkorn
Triticum turdigum ssp. *dicoccon*	1	3.25	Emmer
Triticum aestivum ssp. *compactum*	1	3.25	Club wheat
Lathyrus sativus	2.6	5.5	Grass pea
Lens culinaris	0.7	1.5	Lentil
Pisum sativum	2.6	5.5	Pea

Table 2. Weights and volumes of grains and seeds from Kakucs-Turján and Caričin Grad used to convert weights and volumes into absolute quantities in the dataset compiled by Gyulai (2010). The weights and volumes are given per 100 grains or seeds. Due to the unavailability of the sufficient amount of material, the weight and volume of grass pea is estimated as equal to that of pea and the weight and volume of club wheat as falling between the weight and volume of einkorn and barley. The volume and weight of millet grains is based on the volume and weight 100 millet grains from Caričin Grad (Reuter in press).

Category	Original quantity	New quantity
x	1-10	5.5
xx	10-100	55
xxx	100-1000	550
xxxx	1000-10,000	5500

Table 3. Absolute quantities used as a basis for conversion of the semi-quantitative indications in the dataset compiled by Gyulai (2010).

Site	Phase*	Taxon	Plant part	Preservation	Original quantification	Adapted quantification
Tiszaalpár-Várdomb	MBA	*Hordeum vulgare* subsp. *hexastichum*	Grain	Charred	10 g + 59	968
Tiszaalpár-Várdomb	MBA	*Hordeum vulgare* subsp.. *tetrastichon*	Grain	Charred	14 g + 540	1813
Tiszaalpár-Várdomb	MBA	*Hordeum vulgare* var. *nudum*	Grain	Charred	5.5 g	500
Tiszaalpár-Várdomb	MBA	*Hordeum vulgare*	Grain	Charred	93.4 g + 3960	12,451
Tiszaalpár-Várdomb	MBA	*Lathyrus sativus*	Seed	Charred	101 g + 744	4629
Tiszaalpár-Várdomb	MBA	*Lens culinaris*	Seed	Charred	20.6 g + 3253	2943
Tiszaalpár-Várdomb	MBA	*Triticum aestivum* ssp. *compactum*	Grain	Charred	11 g + 35	1135
Tiszaalpár-Várdomb	MBA	*Triticum monococcum*	Grain	Charred	71.4 g + 3930	11,863
Tiszaalpár-Várdomb	MBA	*Triticum dicoccon*	Grain	Charred	23.9 g + 372	1107
Tiszaalpár-Várdomb	MBA	*Triticum* spec.	Grain	Charred	722 g + 1988	2710
Százhalombatta-Téglagyár	MBA	*Triticum monococcum*	Grain	Charred	480 cm^3 +592	16,592
Százhalombatta-Téglagyár	MBA	*Triticum dicoccon*	Grain	Charred	500 cm^3 + 32	15,417
Pákozd-Várhegy	MBA	*Pisum sativum*	Seed	Charred	80 cm^3	1455
Pákozd-Várhegy	MBA	*Triticum monococcum*	Grain	Charred	40 cm^3 + 104	1437
Mende-Leányvár	MBA	*Hordeum vulgare*	Grain	Charred	20 cm^3 (=20 ml)	100
Mende-Leányvár	MBA	*Hordeum vulgare* subsp. *distichon*	Grain	Charred	20 cm^3 (=20 ml)	100
Mende-Leányvár	MBA	*Triticum monococcum*	Grain	Charred	520 cm^3	17,333
Mende-Leányvár	MBA	*Triticum dicoccon*	Grain	Charred	1000 cm^3	30,769
Jászdózsa-Kápolnahalom	MBA	*Triticum dicoccon*	Grain	Charred	4 cl	123
Balatonboglár-Szárszó	MBA	*Triticum monococcum*	Grain	Charred	20 cl	6666
Balatonboglár-Szárszó	MBA	*Triticum dicoccon*	Grain	Charred	50 cl	15,385
Poroszló-Aponhát	LBA	*Panicum miliaceum*	Grain	Charred	20 cl	4000

Table 4. List of sites and taxa from the dataset published by Gyulai (2010), originally recorded in weights or volumes and converted for the current overview based on the values in Table 2. The names of the sites and taxa represent the original names reported by Gyulai, although some have been adapted in the current study.
** MBA=Middle Bronze Age; LBA=Late Bronze Age.*

allow for the inclusion of all data known from the Bronze Age in Hungary and therefore the potential error created by the conversion is considered acceptable. The converted values per site included in the dataset are given in Tables 4 and 5.

Furthermore, the Bronze Age chronology used by Gyulai in his database does not correspond to the chronological framework suggested more recently for Hungary. The dates have therefore been adjusted according to the data provided by Fischl *et al.* (2015, 504-505, Tables 1a-b). In a few cases, the classification of archaeological groups likewise deviated from recent classifications; where necessary, these were adjusted according to information extracted from Figler *et al.* (1997), Horváth (2005), Kulcsár (2009), Fülöp (2017), Filatova (2020) and the Hungarian National Museum Archaeology Database (2020).

Lastly, Gyulai's data are presented based on summarised remains per site and there are no contextual data that indicate the number of remains per archaeological context per site. Although this does not form a major drawback in the current paper,

Site	Taxon	Plant part	Phase	Preservation	Original quantification	Adapted quantification
Poroszló-Aponhát	*Triticum aestivum* ssp. *spelta*	Grain	LBA	Charred	xxx	550
Poroszló-Aponhát	*Triticum aestivum* ssp. *spelta*	Spikelet fork	LBA	Charred	x	5.5
Poroszló-Aponhát	*Triticum monococcum*	Spikelet fork	LBA	Charred	x	5.5
Poroszló-Aponhát	*Triticum turgidum* ssp. *dicoccon*	Spikelet fork	LBA	Charred	x	5.5
Tószeg-Laposhalom	*Atriplex patula*	Seed	MBA	Charred	x	5.5
Tószeg-Laposhalom	*Cicer arietinum*	Seed	MBA	Charred	x	5.5
Tószeg-Laposhalom	*Equisetum arvense*	Stem	MBA	Charred	x	5.5
Tószeg-Laposhalom	*Hordeum vulgare*	Grain	MBA	Charred	xxx	550
Tószeg-Laposhalom	*Hordeum vulgare* ssp. *distichum*	Grain	MBA	Charred	xxx	550
Tószeg-Laposhalom	*Lathyrus sativus*	Seed	MBA	Charred	x	5.5
Tószeg-Laposhalom	*Lens culinaris*	Seed	MBA	Charred	x	5.5
Tószeg-Laposhalom	*Pisum sativum*	Seed	MBA	Charred	x	5.5
Tószeg-Laposhalom	*Pyrus* sp.	Seed	MBA	Charred	x	5.5
Tószeg-Laposhalom	*Triticum aestivum* ssp. *vulgare*	Grain	MBA	Charred	x	5.5
Tószeg-Laposhalom	*Triticum monococcum*	Grain	MBA	Charred	x	5.5
Tószeg-Laposhalom	*Vicia angustifolia*	Seed	MBA	Charred	x	5.5
Tiszafüred-Ásotthalom	*Panicum miliaceum*	Grain	MBA	Charred	xxx	550
Tiszaalpár-Várdomb	*Triticum monococcum*	Grain	MBA	Charred	xx	55
Szihalom-Földvár	*Cucumis* sp.	Seed	MBA	Charred	x	5.5
Szihalom-Földvár	*Panicum miliaceum*	Grain	MBA	Charred	x	5.5
Százhalombatta-Téglagyár	*Hordeum vulgare* ssp. *distichum*	Grain	MBA	Charred	xx	55
Százhalombatta-Téglagyár	*Triticum monococcum*	Spikelet fork	MBA	Charred	x	5.5
Solymár-Várhegy	*Hordeum vulgare*	Grain	MBA	Charred	x	5.5
Mende-Leányvár	*Triticum dicoccon*	Spikelet fork	MBA	Charred	xx	55
Mende-Leányvár	*Triticum monococcum*	Spikelet fork	MBA	Charred	xx	55
Jászdózsa-Kápolnahalom	*Triticum turgidum* ssp. *dicoccon*	Spikelet forks	MBA	Charred	x	5.5
Felsődobsza-Várdomb	*Hordeum vulgare var. nudum*	Grain	MBA	Charred	x	5.5
Felsődobsza-Várdomb	*Lens culinaris*	Seed	MBA	Charred	x	5.5
Felsődobsza-Várdomb	*Triticum aestivum* ssp. *vulgare*	Grain	MBA	Charred	x+9	14.5
Felsődobsza-Várdomb	*Triticum monococcum*	Grain	MBA	Charred	x+4	9
Felsődobsza-Várdomb	*Triticum vulgare antiquorum*	Grain	MBA	Charred	x	5.5
Dunaújváros-Kosziderpadlás	*Hordeum vulgare polystichum (H. tetrastichum+H. hexastichum)* var. *nudum*	Grain	MBA	Charred	x	5.5
Dömsöd-Apaj	*Bromus* sp.	Grain	MBA	Charred	x	5.5
Dömsöd-Apaj	*Hordeum vulgare*	Grain	MBA	Charred	x	5.5
Dömsöd-Apaj	*Triticum monococcum*	Spikelet fork	MBA	Charred	x	5.5
Dömsöd-Apaj	*Triticum turgidum* ssp. *dicoccon*	Spikelet fork	MBA	Charred	x	5.5

Table 5. List of sites and taxa from the dataset published by Gyulai (2010) that were originally recorded as semi-quantitative values and were converted for the current overview based on the values in Table 3. The names of the sites and taxa represent the original names reported by Gyulai, although some of these have been adapted in the current study.

Site	Taxon	Plant part	Phase	Preservation	Original quantification	Adapted quantification
Békés-Várdomb	*Agrostemma githago*	Seed	MBA	Charred	x	5.5
Békés-Várdomb	*Calystegia* sp.	Seed	MBA	Charred	x	5.5
Békés-Várdomb	*Hordeum vulgare*	Grain	MBA	Charred	x	5.5
Békés-Várdomb	*Melampyrum* sp.	Seed	MBA	Charred	x	5.5
Békés-Várdomb	*Quercus* sp.	Glans	MBA	Charred	x	5.5
Békés-Várdomb	*Triticum monococcum*	Grain	MBA	Charred	x	5.5
Baracs-Bottyánsánc	*Hordeum vulgare polystichum (H. tetrastichum+H. hexastichum)*	Grain	MBA	Charred	x	5.5
Baracs-Bottyánsánc	*Triticum monococcum*	Grain	MBA	Charred	x	5.5
Ároktő-Dongóhalom	*Secale cereale*	Grain	MBA	Charred	xx	55
Ároktő-Dongóhalom	*Triticum aestivum* ssp. *vulgare*	Grain	MBA	Charred	x	5.5
Pécs-Nagyárpád	*Agrimonia eupatoria*	Glans	EBA	Charred	x	5.5
Pécs-Nagyárpád	*Agropyron repens*	Grain	EBA	Charred	x	5.5
Pécs-Nagyárpád	*Bromus tectorum*	Grain	EBA	Charred	x	5.5
Pécs-Nagyárpád	*Camelina sativa*	Seed	EBA	Charred	x	5.5
Pécs-Nagyárpád	*Centaurea* sp.	Achenium	EBA	Charred	x	5.5
Pécs-Nagyárpád	*Convolvulus arvensis*	Seed	EBA	Charred	x	5.5
Pécs-Nagyárpád	*Datura stramonium*	Seed	EBA	Charred	x	5.5
Pécs-Nagyárpád	*Hordeum vulgare*	Grain	EBA	Charred	x	5.5
Pécs-Nagyárpád	*Lens culinaris*	Seed	EBA	Charred	x	5.5
Pécs-Nagyárpád	*Lolium* sp.	Grain	EBA	Charred	x	5.5
Pécs-Nagyárpád	*Malva* sp.	Seed	EBA	Charred	x	5.5
Pécs-Nagyárpád	*Pisum sativum* ssp. *microspermum*	Seed	EBA	Charred	x	5.5
Pécs-Nagyárpád	*Rumex acetosella*	Glans	EBA	Charred	x	5.5
Pécs-Nagyárpád	*Rumex crispus*	Glans	EBA	Charred	x	5.5
Pécs-Nagyárpád	*Rumex* sp.	Glans	EBA	Charred	x	5.5
Pécs-Nagyárpád	*Triticum aestivum* ssp. *compactum*	Grain	EBA	Charred	x	5.5
Pécs-Nagyárpád	*Verbascum* sp.	Seed	EBA	Charred	x	5.5

Table 5. continued.

since it represents a regional overview, it prohibits the calculation of more nuanced values, such as relative frequencies of plant remains expressed as percentages of the total number of samples.

The resulting data comprise a total of 52 sites (Fig. 1, Table 6) dating to the Early (n=12), Middle (n=25) and Late (n=15) Bronze Age. The majority of the finds consist of charred macro-botanical remains, although a few sites also include waterlogged finds (designated with a (w)). For practical reasons, species of cereals and pulses (*e.g. Triticum* sp. and cf. *Vicia faba*) have been merged into the categories of 'Cerealia indet.' and 'Leguminosae sativae indet.'.

Table 6 (right and overleaf). Overview of the archaeological sites of the Bronze Age in Hungary that have been included in the current contribution. The assignations of the sites to archaeological groups partially rely on the data in Figler et al. 1997; Horváth 2005; Kulcsár 2009; Fülöp 2017; Filatova 2020; Hungarian National Museum Archaeology Database 2020. Note that the database in Gyulai (2010) included Százhalombatta-Földvár and Százhalombatta-Téglagyár as separate entries. According to the Hungarian National Museum Archaeology Database (2020), the latter is a synonym of the former; the two sets of data have therefore been merged here under the name Százhalombatta-Földvár.

	Site	Archaeological group	Number of samples	Total number of remains
Late Bronze Age (n=15)	Mosonmagyaróvár-Németbánya	Unknown	1	21
	Lébény-Billedomb	Unknown	2	1875
	Győr-Szabadrétdomb	Unknown	4	13
	Százhalombatta-Földvár	Urnfield	2	851
	Sopron-Krautacker 1	Urnfield	1	37
	Gór-Kápolnadomb	Urnfield	16	20,420
	Budapest, Albertfalva-Kitérő út	Urnfield	4	780
	Polgár 31	Tumulus	6	393
	Mosonmagyaróvár-Németdűlő (w)	Tumulus	1	1232
	Isztimér-Csőszpuszta	Tumulus	Unknown	264
	Dunakeszi-Székesdűlő (Auchan) (w)	Tumulus	35	1692
	Börcs-Paphomlok	Tumulus	10	354
	Balatonmagyaród-Hídvégpuszta	Tumulus	1	2304
	Ludas, Varjú-dűlő	Kyjatice	231	4928
	Poroszló-Aponhát	Gáva	2	9214.5
Middle Bronze Age (n=25)	Balatonboglár-Szárszó	Unknown	Unknown	22,078
	Tiszaalpár-Várdomb (w)	Vatya	43	42,444
	Százhalombatta-Földvár	Vatya	257	55,031.5
	Solymár-Várhegy	Vatya	1	5.5
	Pákozd-Várhegy	Vatya	Unknown	2953
	Mende-Leányvár (w)	Vatya	4	46,501
	Kakucs-Turján	Vatya	369	81,447.5
	Dömsöd-Apaj	Vatya	Unknown	22
	Cegléd 4/1	Vatya	1	26
	Budapest, Bocskai-Fehérvári úti aluljáró	Vatya	6	408
	Ménfőcsanak-Szeles (w)	Transdanubian Encrusted Pottery	32	298
	Túrkeve-Terehalom	Otomani	4	75,315
	Tarhos Gyepesi Átkelő (Tarhos 26)	Otomani	10	150
	Békés-Várdomb	Otomani	Unknown	38.5
	Dunaújváros-Koszíderpadlás	Nagyrév/Vatya	1	479.5
	Bölcske-Vörösgyír (w)	Nagyrév/Vatya	Unknown	38,030.5
	Baracs-Bottyánsánc	Nagyrév/Vatya	1	921
	Budapest, Csepel-Szennyvíz telep (w)	Nagyrév/MBA	13	74
	Tószeg-Laposhalom	Nagyrév/Hatvan	Unknown	17,764
	Süttő-Hosszúvölgy	Magyarád	1	157
	Tiszafüred-Ásotthalom	Hatvan/Füzesabony	Unknown	1650
	Szihalom-Földvár	Hatvan/Füzesabony	1	16.5
	Jászdózsa-Kápolnahalom	Füzesabony	Unknown	168.5
	Felsődobsza-Várdomb	Füzesabony	Unknown	112.5
	Ároktő-Dongóhalom	Füzesabony	1	275.5

	Site	Archaeological group	Number of samples	Total number of remains
Early Bronze Age (n=12)	Budapest, Corvin tér	Unknown	2	66
	Pécs-Nagyárpád	Somogyvár-Vinkovci	9	422.5
	Kakucs-Turján	Nagyrév	28	3676
	Mosonszentmiklós-Pálmajor	Makó-Kosihy-Čaka	6	19
	Kiskundorozsma (M5 45, 26/59)	Makó-Kosihy-Čaka	27	1
	Endrőd 161	Makó-Kosihy-Čaka	6	87.5
	Biatorbágy-Hosszúrét	Makó-Kosihy-Čaka	4	34
	Szigetszentmiklós-Vízmű	Bell Beaker	10	88
	Dunakeszi-Székesdűlő (w)	Bell Beaker	16	372
	Budapest, Csepel-Hollandi u.	Bell Beaker	6	132
	Budapest, Albertfalva -Hunyadi J. U	Bell Beaker	37	2700
	Budakalász M0 motorway, 12	Bell Beaker	51	69

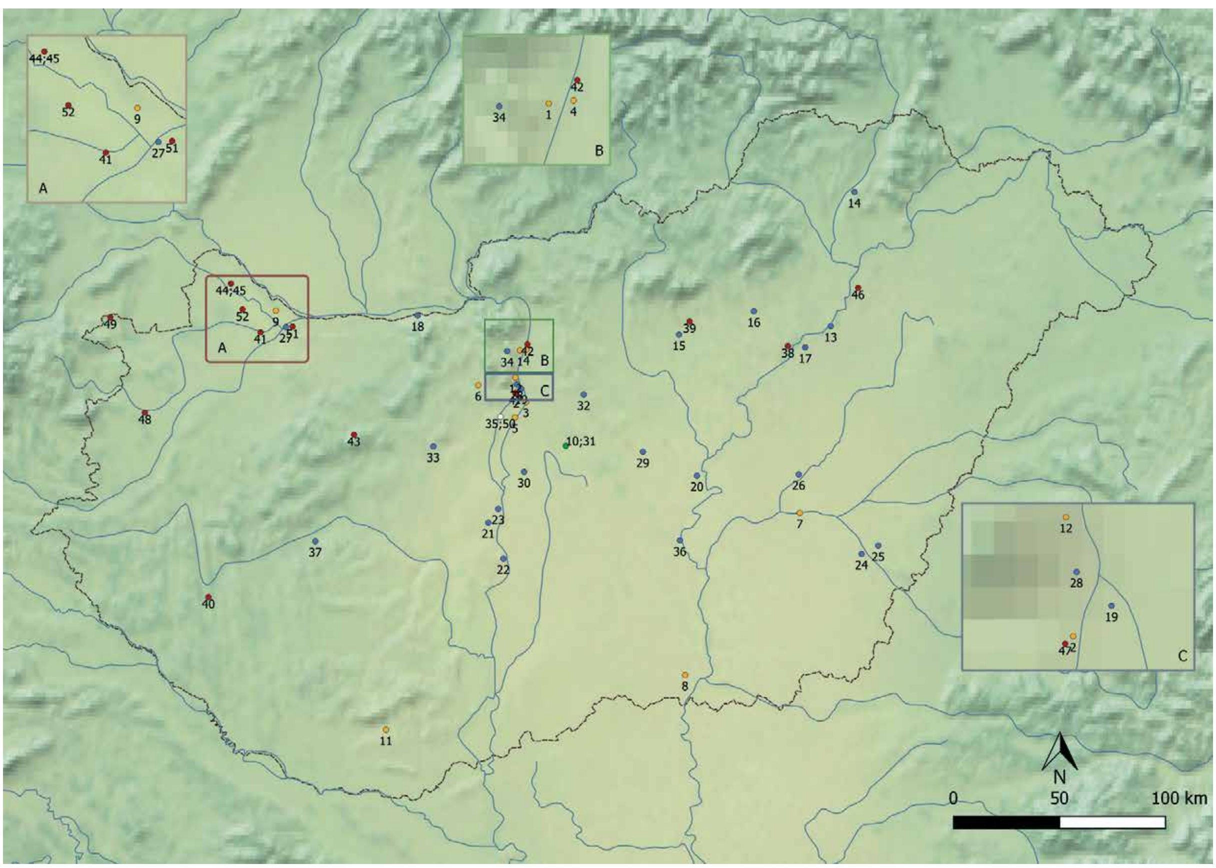

Figure 1. Distribution of the Bronze Age settlements in Hungary included in the current overview. The majority of the sites are plotted based on estimations of their locations because the exact coordinates of the sites are not available to the author. **Early Bronze Age (yellow):** *1. Budakalász M0 motorway, 12; 2. Budapest, Albertfalva-Hunyadi J. U; 3. Budapest, Csepel-Hollandi u.; 4. Dunakeszi-Székesdűlő; 5. Szigetszentmiklós-Vízmű; 6. Biatorbágy-Hosszúrét; 7. Endrőd 161; 8. Kiskundorozsma (M5 45, 26/59); 9. Mosonszentmiklós-Pálmajor; 11. Pécs-Nagyárpád; 12. Budapest, Corvin tér.* **Early and Middle Bronze Age (green)***: 10/31. Kakucs-Turján.* **Middle Bronze Age (blue)***: 13. Ároktő-Dongóhalom; 14. Felsődobsza-Várdomb; 15. Jászdózsa-Kápolnahalom; 16. Szihalom-Földvár; 17. Tiszafüred-Ásotthalom; 18. Süttő-Hosszúvölgy; 19. Budapest, Csepel-Szennyvíz telep; 20. Tószeg-Laposhalom; 21. Baracs-Bottyánsánc; 22. Bölcske-Vörösgyír; 23. Dunaújváros-Kosziderpadlás; 24. Békés-Várdomb; 25. Tarhos Gyepesi Átkelő (Tarhos 26); 26. Túrkeve-Terehalom; 27. Ménfőcsanak-Szeles; 28. Budapest, Bocskai-Fehérvári úti aluljáró; 29. Cegléd 4/1; 30. Dömsöd-Apaj; 32. Mende-Leányvár; 33. Pákozd-Várhegy; 34. Solymár-Várhegy; 36. Tiszaalpár-Várdomb; 37. Balatonboglár-Szárszó.* **Middle and Late Bronze Age (white)***: 35/50. Százhalombatta-Földvár.* **Late Bronze Age (red)***: 38. Poroszló-Aponhát; 39. Ludas, Varjú-dűlő; 40. Balatonmagyaród-Hídvégpuszta; 41. Börcs-Paphomlok; 42. Dunakeszi-Székesdűlő (Auchan); 43. Isztimér-Csőszpuszta; 44/45. Mosonmagyaróvár-Németbánya; 46. Polgár site 31; 47. Budapest, Albertfalva-Kitérő út; 48. Gór-Kápolnadomb; 49. Sopron-Krautacker site 1; 51. Győr-Szabadrétdomb; 52. Lébény-Billedomb (Basemap: Stamen Design; Map data: Open Street Map 2018).*

The plant spectra

For practical reasons, the crops and gathered plants have been summarised per phase and archaeological group in Table 7. As this does not provide an insight into the diversity of plants at individual settlements, the absolute quantities and relative frequencies of taxa have been presented according to plant groups per settlement in Figures 2 and 3. Cereals prevail among the macro-botanical finds from the Early Bronze Age, while other plant groups occur in modest amounts. The most common cereal taxa vary per archaeological group: barley was most prominent at Bell Beaker and Makó-Kosihy-Čaka group sites, while einkorn was of greater importance at Nagyrév and Somogyvár-Vinkovci group sites. The absolute quantities and relative frequencies of taxa[1] show a relatively uniform picture, with some expected variations in the frequencies of taxa per site. It is noteworthy that there is a great diversity of weeds and wild plants (see Table 7), which can be seen as an indication of the presence of products and by-products of harvested crops. Grains of millet have been identified in small amounts in two Bell Beaker settlements and one Makó-Kosihy-Čaka settlement.

Middle Bronze Age macro-botanical assemblages show a greater diversity compared with the previous phase. Cereals prevail among most of the groups distinguished archaeologically, followed by pulses, oil and fibre crops, and gathered plants. The most important taxa represented in different archaeological groups are either einkorn or barley among the cereals, lentil (*Lens culinaris*) and bitter vetch (*Vicia ervilia*) of the pulses, and safflower (*Carthamus tinctorius*) and flax/linseed (*Linum usitatissimum*) among oil and fibre crops. There are, however, several exceptions. At first glance, one of these seem to be sites of the Otomani communities, where gathered plants make up the largest proportion of finds. This can be attributed to the settlement site of Túrkeve-Terehalom, where an unusually large amount of cleaned white goosefoot (*Chenopodium album*) fruits has been interpreted as gathered and consumed by the inhabitants (Gyulai 2010, 104). Another exception are some Hatvan/Füzesabony settlements, where the only macro-botanical finds were millet grains. Lastly, several settlements include a larger proportion of wild than cultivated plants (Ároktő-Dongóhalom, Borsod-Abaúj-Zemplén County; Budapest, Csepel-Szennyvíztelep telep, Pest County; and Cegléd 4/1, Pest County), while others include a larger proportion of pulses than cereals (Kakucs-Turján and Pákozd-Várhegy, Fejér County).

Similar to the plant spectra of the Middle Bronze Age, those of the Late Bronze Age are also varied. Cereals are the most common finds at the majority of the settlements, and whereas during the previous phases the cereal finds include large proportions of barley and einkorn, during the Late Bronze Age the most important cereals were spelt (*Triticum aestivum* ssp. *spelta*), emmer (*Triticum turgidum* ssp. *dicoccon*) and millet. Millet prevails in the Gáva and the three Tumulus community settlements; the plant spectra of the Tumulus groups also include a variety of pulses and a large proportion of wild plants and weeds. The latter is especially a reflection of the large assemblages of waterlogged remains of wild plants and weeds from the Tumulus community settlements of Dunakeszi-Székesdűlő (Auchan; Pest County) and Mosonmagyaróvár-Németdűlő (Győr-Moson-Sopron County). Except for cultivated millet, wild species of Panicoideae (*e.g. Digitaria ischaemum* and *Echinochloa crus-galli*) are identified in larger quantities, adding to the variety of taxa in Late Bronze Age assemblages.

1 In this paper, frequency of taxa denotes the number of different taxa within each plant category (cereals, pulses, *etc.*) expressed as percentage of the total number of taxa per site. As context-based data are unavailable to the author, the calculation of taxa frequency expressed as percentage of the total number of samples was not possible.

		Period	(Transition to) Early Bronze Age (2800/2700-2000/1900 cal. BCE)							
		Archaeological group	Bell Beaker		Makó-Kosihy-Čaka		Nagyrév	Somogyvár-Vinkovci	Unknown	
		No. of sites	5		4		1	1	1	
		No. of samples	120		43		28	9	2	
Scientific name	Plant part	Preservation	Count	No. of occurring sites	Count	No. of occurring sites	Count	Count	Count	Common name
Cereals										
Hordeum vulgare (undiff.)	Grain	Charred					92.0			Barley
Hordeum vulgare (h)	Grain	Charred	1256.0	5.0	68.0	3.0	35.0	5.5	44.0	Hulled barley
Hordeum vulgare (n)	Grain	Charred	17.0	4.0						Naked barley
Hordeum vulgare	Rachis fragment	Charred	10.0	1.0			9.0			Barley
Hordeum vulgare	Rachis fragment	Waterlogged								Barley
Secale cereale	Grain	Charred	1.0	1.0						Rye
Triticum aestivum ssp. *compactum*	Grain	Charred	1.0	1.0				5.5		Club wheat
Triticum aestivum	Grain	Charred	3.0	2.0	5.0	2.0			10.0	Common wheat
Triticum aestivum	Rachis fragment	Charred							1.0	Common wheat
Triticum aestivum ssp. *spelta*	Grain	Charred	1.0	1.0						Spelt
Triticum aestivum ssp. *spelta*	Spikelet fork	Charred								Spelt
Triticum aestivum/durum	Grain	Charred								Free-threshing wheat
Triticum aestivum/durum	Spikelet fork	Charred								Free-threshing wheat
Triticum monococcum	Grain	Charred	84.0	3.0			848.5	238.0		Einkorn
Triticum monococcum	Spikelet fork	Charred	593.0	3.0			1992.0			Einkorn
Triticum monococcum/dicoccum	Grain	Charred								Hulled wheat
Triticum monococcum/dicoccum	Spikelet fork	Charred	19.0	2.0			2.5			Hulled wheat
Triticum turdigum ssp. *dicoccon*	Grain	Charred	101.0	5.0	4.0	1.0	77.0	82.0	10.0	Emmer

Table 7 (a, b, c). Overview of the macro-botanical assemblages in Bronze Age Hungary per archaeological group. Compilation of macro-botanical data after Gyulai (2010, Appendix Bronze Age data), Duffy (2010, 275, Table 9.1), Stika and Heiss (2013, 79-80, Table 1) and Filatova (2020).

		Period	(Transition to) Early Bronze Age (2800/2700-2000/1900 cal. BCE)							
		Archaeological group	Bell Beaker		Makó-Kosihy-Čaka		Nagyrév	Somogyvár-Vinkovci	Unknown	
		No. of sites	5		4		1	1	1	
		No. of samples	120		43		28	9	2	
Scientific name	Plant part	Preservation	Count	No. of occurring sites	Count	No. of occurring sites	Count	Count	Count	Common name
Triticum turdigum ssp. *dicoccon*	Spikelet fork	Charred	126.0	4.0	6.0	2.0				Emmer
Triticum turdigum ssp. *dicoccon*	Spikelet fork	Waterlogged								Emmer
Triticum turgidum ssp. *durum*	Rachis fragment	Charred								Macaroni wheat
Triticum timopheevii	Spikelet fork	Charred								New Type Glume (NTG) wheat
Triticum sp.	Grain	Charred								Wheat species
Cerealia indet	Grain	Charred	271.0	2.0	25.0	2.0	283.0			Indeterminate cereals
Cerealia indet	Spikelet fork	Charred								Indeterminate cereals
Millet										
Panicum miliaceum	Grain	Charred	9.0	2.0	1.0	1.0				Broomcorn millet
Panicum miliaceum	Grain	Waterlogged								Broomcorn millet
Pulses										
Cicer arietinum	Seed	Charred								Chick-pea
Lathyrus sativus	Seed	Charred								Grass pea
Lens culinaris	Seed	Charred	1.0	1.0			186.0	5.5		Lentil
Pisum sativum	Seed	Charred	1.0	1.0	26.5	2.0		5.5		Pea
Vicia ervilia	Seed	Charred					1.0			Bitter vetch
Vicia faba	Seed	Charred	1.0	1.0						Broad bean
Vicia sativa	Seed	Charred								Common vetch
Leguminosae sativae indet	Seed	Charred								Indeterminate pulses

Table 7a. continued.

		Period	(Transition to) Early Bronze Age (2800/2700-2000/1900 cal. BCE)							
		Archaeological group	Bell Beaker		Makó-Kosihy-Čaka		Nagyrév	Somogyvár-Vinkovci	Unknown	
		No. of sites	5		4		1	1	1	
		No. of samples	120		43		28	9	2	
Scientific name	Plant part	Preservation	Count	No. of occurring sites	Count	No. of occurring sites	Count	Count	Count	Common name
Oil, fibre and dye crops										
Camelina sativa	Seed	Charred						5.5		Gold-of-pleasure
Carthamus tinctorius	Achenium	Charred								Safflower
Linum usitatissimum	Seed	Charred					4.0			Flax/linseed
Linum usitatissimum	Seed	Waterlogged								Flax/linseed
Linum usitatissimum	Fruit + perianth	Charred								Flax/linseed
Papaver somniferum	Seed	Charred								Opium poppy
Gathered plants										
Chenopodium album	Fruit	Charred								White goosefoot
Cornus mas	Fruit endocarp	Charred					0.5			Cornelian cherry
Cornus mas	Fruit endocarp	Waterlogged								Cornelian cherry
Corylus avellana	Fruit	Charred					4.0			Common hazel
Crataegus monogyna	Fruit	Waterlogged								Common hawthorn
Fragaria vesca	Fruitlet	Charred								Wild strawberry
Malus silvestris	Seed	Charred								Crab apple
Malus silvestris	Seed	Waterlogged								Crab apple
Malus silvestris	Seed	Mineralized								Crab apple
Malus silvestris	Fruit	Charred								Crab apple
Malus silvestris	Fruit	Waterlogged	8.0	1.0						Crab apple
Portulaca oleracea	Fruit	Charred								Common purslane
Prunus spinosa	Fruit endocarp	Charred								Blackthorn
Prunus sp.	Fruit endocarp	Charred								Prunus species

Table 7a. continued.

		Period	(Transition to) Early Bronze Age (2800/2700-2000/1900 cal. BCE)							
		Archaeological group	Bell Beaker		Makó-Kosihy-Čaka		Nagyrév	Somogyvár-Vinkovci	Unknown	
		No. of sites	5		4		1	1	1	
		No. of samples	120		43		28	9	2	
Scientific name	Plant part	Preservation	Count	No. of occurring sites	Count	No. of occurring sites	Count	Count	Count	Common name
Pyrus sp.	Seed	Charred								Pear
Quercus sp.	Fruitlet	Charred								Oak
Rubus caesius	Fruitlet	Charred								Blackberry
Rubus caesius	Fruitlet	Waterlogged								Blackberry
Rubus sp.	Fruitlet	Charred								
Sambucus ebulus	Fruit endocarp	Charred	1.0	1.0						Danewort
Sambucus ebulus	Fruit endocarp	Waterlogged								Danewort
Sambucus nigra	Fruit endocarp	Charred								Elder
Sambucus nigra	Fruit endocarp	Waterlogged								Elder
Sambucus sp.	Fruit endocarp	Wateröpgged								Sambucus species
Valerianella dentata	Fruit	Charred								Narrowfruit cornsalad
Vitis vinifera	Seed	Charred								Grape vine
Vitis vinifera	Seed	Waterlogged								Grape vine
Panicoideae										
Digitaria ischaemum	Fruit	Charred	4.0	2.0						Smooth crabgrass
Digitaria sanguinalis	Fruit	Charred								Hairy crabgrass
Echinochloa crus-galli	Fruit	Waterlogged								Cockspur
Echinochloa crus-galli	Fruit	Charred	1.0	1.0						Cockspur
Setaria lutescens	Fruit	Charred								Yellow foxtail
Setaria viridis	Fruit	Charred								Yellow foxtail
Setaria viridis	Fruit	Waterlogged								Green foxtail
Setaria sp.	Fruit	Charred								Foxtail grasses
Wild plants and weeds (combined)			843.0	5.0	5.0	3.0	141.5	75.0	1.0	

Table 7a. continued.

		Period	Middle Bronze Age (2000/1900-1500/1450 cal. BCE)						Middle Bronze Age (2000/1900-1500/1450 cal. BCE)								
		Archaeological group	Füzesabony		Hatvan / Füzesabony		Magyarád	Nagyrév/ MBA	Nagyrév / Vatya		Otomani		Transdanubian Encrusted Pottery	Vatya		Unknown	
		No. of sites	3		2		1	1	4		3		1	9		1	
		No. of samples	>1		>1		1	13	>2		>14		32	424		unknown	
Scientific name	Plant part	Preservation	Count	No. of occurring sites	Count	No. of occurring sites	Count	Count	Count	No. of occurring sites	Count	No. of occurring sites	Count	Count	No. of occurring sites	Count	Common name
Cereals																	
Hordeum vulgare (undiff.)	Grain	Charred												3039.5	2.0		Barley
Hordeum vulgare (h)	Grain	Charred	51.0	2.0			1.0	3.0	11671.5	4.0	11.5	3.0	74.0	22521.0	8.0		Hulled barley
Hordeum vulgare (n)	Grain	Charred	5.5	1.0					14300.5	3.0			1.0	566.0	4.0		Naked barley
Hordeum vulgare	Rachis fragment	Charred							2.0	1.0				257.0	2.0		Barley
Hordeum vulgare	Rachis fragment	Waterlogged															Barley
Secale cereale	Grain	Charred	110.0	1.0									2.0	8.0	1.0		Rye
Triticum aestivum ssp. *compactum*	Grain	Charred					15.0							1135.0	1.0		Club wheat
Triticum aestivum	Grain	Charred	25.0	2.0					11.0	2.0	49.0	1.0	3.0	186.0	2.0		Common wheat
Triticum aestivum	Rachis fragment	Charred															Common wheat
Triticum aestivum ssp. *spelta*	Grain	Charred							33.0	1.0	12.0	1.0	7.0	77.0	1.0		Spelt
Triticum aestivum ssp. *spelta*	Spikelet fork	Charred												5.5	2.0		Spelt
Triticum aestivum/ durum	Grain	Charred	14.5	1.0										58.0	2.0		Free-threshing wheat
Triticum aestivum/ durum	Spikelet fork	Charred															Free-threshing wheat
Triticum monococcum	Grain	Charred	29.5	2.0			141.0		20834.0	3.0	196.5	2.0	55.0	64630.5	6.0	6666.0	Einkorn
Triticum monococcum	Spikelet fork	Charred							103.0	3.0	20.0	1.0		2730.0	6.0		Einkorn
Triticum monococcum/ dicoccum	Grain	Charred												191.0	2.0		Hulled wheat
Triticum monococcum/ dicoccum	Spikelet fork	Charred												6510.0	2.0		Hulled wheat
Triticum turdigum ssp. *dicoccon*	Grain	Charred	135.0	2.0				2.0	1414.0	4.0	161.0	2.0	47.0	49899.0	6.0	15385.0	Emmer
Triticum turdigum ssp. *dicoccon*	Spikelet fork	Charred	5.5	1.0					43.0	1.0	40.0	1.0		210.5	6.0		Emmer
Triticum turdigum ssp. *dicoccon*	Spikelet fork	Waterlogged						8.0									Emmer
Triticum turgidum ssp. *durum*	Rachis fragment	Charred												1.0	1.0		Macaroni wheat

Table 7b.

		Period	Middle Bronze Age (2000/1900-1500/1450 cal. BCE)								Middle Bronze Age (2000/1900-1500/1450 cal. BCE)						
		Archaeological group	Füzesabony		Hatvan / Füzesabony		Magyarád	Nagyrév/ MBA	Nagyrév / Vatya		Otomani		Transdanubian Encrusted Pottery	Vatya		Unknown	
		No. of sites	3		2		1	1	4		3		1	9		1	
		No. of samples	>1		>1		1	13	>2		>14		32	424		unknown	
Scientific name	Plant part	Preservation	Count	No. of occurring sites	Count	No. of occurring sites	Count	Count	Count	No. of occurring sites	Count	No. of occurring sites	Count	Count	No. of occurring sites	Count	Common name
Triticum timopheevii	Spikelet fork	Charred												249.0	1.0		New Type Glume (NTG) wheat
Triticum sp.	Grain	Charred															Wheat species
Cerealia indet	Grain	Charred			550.0			8.0	2261.0	2.0	39.5	3.0	1.0	11792.0	4.0		Indeterminate cereals
Cerealia indet	Spikelet fork	Charred									47.0	2.0		235.0	1.0		Indeterminate cereals
Millet																	
Panicum miliaceum	Grain	Charred			555.5				8.0	2.0			2.0	60.0	2.0		Broomcorn millet
Panicum miliaceum	Grain	Waterlogged															Broomcorn millet
Pulses																	
Cicer arietinum	Seed	Charred							5.5	1.0							Chick-pea
Lathyrus sativus	Seed	Charred							5.5	1.0				4677.5	2.0		Grass pea
Lens culinaris	Seed	Charred	5.5	1.0				1.0	4706.5	3.0	53.0	1.0		46607.5	5.0		Lentil
Pisum sativum	Seed	Charred							16.5	2.0	103.0	1.0		9404.5	5.0		Pea
Vicia ervilia	Seed	Charred							537.0	2.0	220.0	1.0		469.5	3.0		Bitter vetch
Vicia faba	Seed	Charred							19.0	1.0				123.0	3.0		Broad bean
Vicia sativa	Seed	Charred							4.0	1.0				5.5	1.0		Common vetch
Leguminosae sativae indet	Seed	Charred												128.5	1.0		Indeterminate pulses
Oil, fibre and dye crops																	
Camelina sativa	Seed	Charred												11.0	1.0		Gold-of-pleasure
Carthamus tinctorius	Achenium	Charred									1246.0	1.0					Safflower
Linum usitatissimum	Seed	Charred												31.0	3.0		Flax/linseed
Linum usitatissimum	Seed	Waterlogged												3.0	1.0		Flax/linseed
Linum usitatissimum	Fruit + perianth	Charred												1.0	1.0		Flax/linseed
Papaver somniferum	Seed	Charred															Opium poppy
Gathered plants																	
Chenopodium album	Fruit	Charred									36609.0	1.0					White goosefoot
Cornus mas	Fruit endocarp	Charred	12.0	1.0					2.0	1.0	2.0	1.0		46.0	2.0		Cornelian cherry
Cornus mas	Fruit endocarp	Waterlogged															Cornelian cherry
Corylus avellana	Fruit	Charred												35.0	1.0		Common hazel
Crataegus monogyna	Fruit	Waterlogged							1.0	1.0							Common hawthorn

Table 7b (continued).

		Period	Middle Bronze Age (2000/1900-1500/1450 cal. BCE)						Middle Bronze Age (2000/1900-1500/1450 cal. BCE)								
		Archaeological group	Füzesabony		Hatvan / Füzesabony		Magyarád	Nagyrév/ MBA	Nagyrév / Vatya		Otomani		Transdanubian Encrusted Pottery	Vatya		Unknown	
		No. of sites	3		2		1	1	4		3		1	9		1	
		No. of samples	>1		>1		1	13	>2		>14		32	424		unknown	
Scientific name	Plant part	Preservation	Count	No. of occurring sites	Count	No. of occurring sites	Count	Count	Count	No. of occurring sites	Count	No. of occurring sites	Count	Count	No. of occurring sites	Count	Common name
Fragaria vesca	Fruitlet	Charred												4.0	1.0		Wild strawberry
Malus silvestris	Seed	Charred												6.0	1.0		Crab apple
Malus silvestris	Seed	Waterlogged															Crab apple
Malus silvestris	Seed	Mineralized											1.0				Crab apple
Malus silvestris	Fruit	Charred															Crab apple
Malus silvestris	Fruit	Waterlogged											1.0				Crab apple
Portulaca oleracea	Fruit	Charred												124.0	1.0		Common purslane
Prunus spinosa	Fruit endocarp	Charred							5.0	1.0			1.0	7.0	2.0	1.0	Blackthorn
Prunus sp.	Fruit endocarp	Charred												8.0	1.0		Prunus species
Pyrus sp.	Seed	Charred							5.5	1.0							Pear
Quercus sp.	Fruitlet	Charred							1.0	1.0	5.5	1.0	62.0	8.0	2.0		Oak
Rubus caesius	Fruitlet	Charred												1.0	1.0		Blackberry
Rubus caesius	Fruitlet	Waterlogged															Blackberry
Rubus sp.	Fruitlet	Charred	3.0	1.0										17.0	2.0		
Sambucus ebulus	Fruit endocarp	Charred	1.0	1.0										11.0	2.0		Danewort
Sambucus ebulus	Fruit endocarp	Waterlogged											24.0				Danewort
Sambucus nigra	Fruit endocarp	Charred												4.0	2.0		Elder
Sambucus nigra	Fruit endocarp	Waterlogged															Elder
Sambucus sp.	Fruit endocarp	Wateröpgged															Sambucus species
Valerianella dentata	Fruit	Charred												25.0	1.0		Narrowfruit cornsalad
Vitis vinifera	Seed	Charred												2.0	1.0		Grape vine
Vitis vinifera	Seed	Waterlogged															Grape vine
Panicoideae																	
Digitaria ischaemum	Fruit	Charred												1.0	1.0		Smooth crabgrass
Digitaria sanguinalis	Fruit	Charred															Hairy crabgrass
Echinochloa crus-galli	Fruit	Waterlogged															Cockspur
Echinochloa crus-galli	Fruit	Charred															Cockspur
Setaria lutescens	Fruit	Charred															Yellow foxtail
Setaria viridis	Fruit	Charred												2.0	1.0		Yellow foxtail
Setaria viridis	Fruit	Waterlogged															Green foxtail
Setaria sp.	Fruit	Charred							1.0	1.0				1.0	1.0		Foxtail grasses
Wild plants and weeds (combined)			159.0	1.0	5.5			52.0	1196.5	4.0	36688.5	2.0	15.0	2658.5	8.0	26.0	

Table 7b (continued).

		Period	Late Bronze Age (1500/1450-800/750 cal. BC)				Late Bronze Age (1500/1450-800/750 cal. BC)				
		Archaeological group	Gáva	Kyjatice	Tumulus		Urnfield		Unknown		
		No. of sites	1	1	6		4		3		
		No. of samples	2	231	>53		23		7		
Scientific name	Plant part	Preservation	Count	Count	Count	No. of occur-ring sites	Count	No. of occurring sites	Count	No. of occurring sites	Common name
Cereals											
Hordeum vulgare (undiff.)	Grain	Charred					10.0	1.0			Barley
Hordeum vulgare (h)	Grain	Charred	265.0	101.0	143.0	5.0	724.0	4.0	212.0	2.0	Hulled barley
Hordeum vulgare (n)	Grain	Charred		16.0	2.0	2.0	1.0	1.0	2.0	2.0	Naked barley
Hordeum vulgare	Rachis fragment	Charred			1.0	1.0	3.0	1.0			Barley
Hordeum vulgare	Rachis fragment	Waterlogged			2.0	1.0					Barley
Secale cereale	Grain	Charred		20.0	1.0	1.0	5.0	2.0			Rye
Triticum aestivum ssp. *compactum*	Grain	Charred		8.0			4.0	2.0			Club wheat
Triticum aestivum	Grain	Charred		19.0	7.0	2.0	16.0	2.0	14.0	1.0	Common wheat
Triticum aestivum	Rachis fragment	Charred		1.0							Common wheat
Triticum aestivum ssp. *spelta*	Grain	Charred	550.0	162.0	1.0	1.0	1618.0	3.0	6.0	1.0	Spelt
Triticum aestivum ssp. *spelta*	Spikelet fork	Charred	5.5	14.0			1108.0	2.0	2.0	1.0	Spelt
Triticum aestivum/durum	Grain	Charred			4.0	1.0					Free-threshing wheat
Triticum aestivum/durum	Spikelet fork	Charred					375.0	1.0			Free-threshing wheat
Triticum monococcum	Grain	Charred	69.0	282.0	2.0	2.0	4299.0	3.0			Einkorn
Triticum monococcum	Spikelet fork	Charred	5.5	11.0	1.0	1.0	35.0	2.0			Einkorn
Triticum monococcum/dicoccum	Grain	Charred		25.0							Hulled wheat
Triticum monococcum/dicoccum	Spikelet fork	Charred					230.0	1.0			Hulled wheat
Triticum turdigum ssp. *dicoccon*	Grain	Charred	25.0	35813.0	9.0	4.0	7185.0	4.0	6.0	1.0	Emmer
Triticum turdigum ssp. *dicoccon*	Spikelet fork	Charred	5.5	320.0	13.0	3.0	1000.0	2.0	5.0	2.0	Emmer
Triticum turdigum ssp. *dicoccon*	Spikelet fork	Waterlogged			28.0	2.0					Emmer
Triticum turgidum ssp. *durum*	Rachis fragment	Charred									Macaroni wheat

Table 7c.

		Period	Late Bronze Age (1500/1450-800/750 cal. BC)				Late Bronze Age (1500/1450-800/750 cal. BC)				
		Archaeological group	Gáva	Kyjatice	Tumulus		Urnfield		Unknown		
		No. of sites	1	1	6		4		3		
		No. of samples	2	231	>53		23		7		
Scientific name	Plant part	Preservation	Count	Count	Count	No. of occurring sites	Count	No. of occurring sites	Count	No. of occurring sites	Common name
Triticum timopheevii	Spikelet fork	Charred					32.0	1.0			New Type Glume (NTG) wheat
Triticum sp.	Grain	Charred									Wheat species
Cerealia indet	Grain	Charred		6017.0	25.0	2.0	2608.0	3.0	4.0	1.0	Indeterminate cereals
Cerealia indet	Spikelet fork	Charred			1.0	1.0					Indeterminate cereals
Millet											
Panicum miliaceum	Grain	Charred	4000.0	775.0	811.0	5.0	291.0	3.0	784.0	2.0	Broomcorn millet
Panicum miliaceum	Grain	Waterlogged			67.0	2.0					Broomcorn millet
Pulses											
Cicer arietinum	Seed	Charred									Chick-pea
Lathyrus sativus	Seed	Charred			37.0	1.0					Grass pea
Lens culinaris	Seed	Charred	40.0	32.0	9.0	3.0	61.0	4.0			Lentil
Pisum sativum	Seed	Charred		134.0	678.0	1.0	9.0	2.0			Pea
Vicia ervilia	Seed	Charred		990.0	261.0	1.0					Bitter vetch
Vicia faba	Seed	Charred		2.0							Broad bean
Vicia sativa	Seed	Charred									Common vetch
Leguminosae sativae indet	Seed	Charred					2.0	1.0			Indeterminate pulses
Oil, fibre and dye crops											
Camelina sativa	Seed	Charred					359.0	1.0			Gold-of-pleasure
Carthamus tinctorius	Achenium	Charred									Safflower
Linum usitatissimum	Seed	Charred									Flax/linseed
Linum usitatissimum	Seed	Waterlogged									Flax/linseed
Linum usitatissimum	Fruit + perianth	Charred									Flax/linseed

Table 7c (continued).

		Period	Late Bronze Age (1500/1450-800/750 cal. BC)				Late Bronze Age (1500/1450-800/750 cal. BC)				
		Archaeological group	Gáva	Kyjatice	Tumulus		Urnfield		Unknown		
		No. of sites	1	1	6		4		3		
		No. of samples	2	231	>53		23		7		
Scientific name	Plant part	Preservation	Count	Count	Count	No. of occurring sites	Count	No. of occurring sites	Count	No. of occurring sites	Common name
Papaver somniferum	Seed	Charred		7.0							Opium poppy
Gathered plants											
Chenopodium album	Fruit	Charred									White goosefoot
Cornus mas	Fruit endocarp	Charred			1.0	1.0					Cornelian cherry
Cornus mas	Fruit endocarp	Waterlogged			3.0	1.0					Cornelian cherry
Corylus avellana	Fruit	Charred			2.0	1.0					Common hazel
Crataegus monogyna	Fruit	Waterlogged									Common hawthorn
Fragaria vesca	Fruitlet	Charred									Wild strawberry
Malus silvestris	Seed	Charred			1.0	1.0			1.0	1.0	Crab apple
Malus silvestris	Seed	Waterlogged			2.0	2.0					Crab apple
Malus silvestris	Seed	Mineralized									Crab apple
Malus silvestris	Fruit	Charred		12.0							Crab apple
Malus silvestris	Fruit	Waterlogged									Crab apple
Portulaca oleracea	Fruit	Charred									Common purslane
Prunus spinosa	Fruit endocarp	Charred									Blackthorn
Prunus sp.	Fruit endocarp	Charred									Prunus species
Pyrus sp.	Seed	Charred									Pear
Quercus sp.	Fruitlet	Charred		2993.0							Oak
Rubus caesius	Fruitlet	Charred									Blackberry
Rubus caesius	Fruitlet	Waterlogged			15.0	2.0					Blackberry
Rubus sp.	Fruitlet	Charred									
Sambucus ebulus	Fruit endocarp	Charred		264.0	1.0	1.0					Danewort

Table 7c (continued).

		Period	Late Bronze Age (1500/1450-800/750 cal. BC)				Late Bronze Age (1500/1450-800/750 cal. BC)				
		Archaeological group	Gáva	Kyjatice	Tumulus		Urnfield		Unknown		
		No. of sites	1	1	6		4		3		
		No. of samples	2	231	>53		23		7		
Scientific name	Plant part	Preservation	Count	Count	Count	No. of occurring sites	Count	No. of occurring sites	Count	No. of occurring sites	Common name
Sambucus ebulus	Fruit endocarp	Waterlogged			28.0	2.0					Danewort
Sambucus nigra	Fruit endocarp	Charred		2.0							Elder
Sambucus nigra	Fruit endocarp	Waterlogged					2.0	1.0			Elder
Sambucus sp.	Fruit endocarp	Wateröpgged			30.0	1.0					Sambucus species
Valerianella dentata	Fruit	Charred									Narrowfruit cornsalad
Vitis vinifera	Seed	Charred		2.0							Grape vine
Vitis vinifera	Seed	Waterlogged			5.0	2.0	1.0	1.0			Grape vine
Panicoideae											
Digitaria ischaemum	Fruit	Charred		2.0	3.0	2.0			22.0	1.0	Smooth crabgrass
Digitaria sanguinalis	Fruit	Charred		24.0			1.0	1.0	2.0	1.0	Hairy crabgrass
Echinochloa crus-galli	Fruit	Waterlogged			2.0	1.0					Cockspur
Echinochloa crus-galli	Fruit	Charred		26.0	1.0	1.0	2.0	1.0			Cockspur
Setaria lutescens	Fruit	Charred		2.0			41.0	1.0			Yellow foxtail
Setaria viridis	Fruit	Charred									Yellow foxtail
Setaria viridis	Fruit	Waterlogged					1.0	1.0			Green foxtail
Setaria sp.	Fruit	Charred		26.0	4.0	2.0	2.0	1.0			Foxtail grasses
Wild plants and weeds (combined)			249.0	403.0	3160.0	6.0	1772.0	3.0	65.0	3.0	

Table 7c (continued).

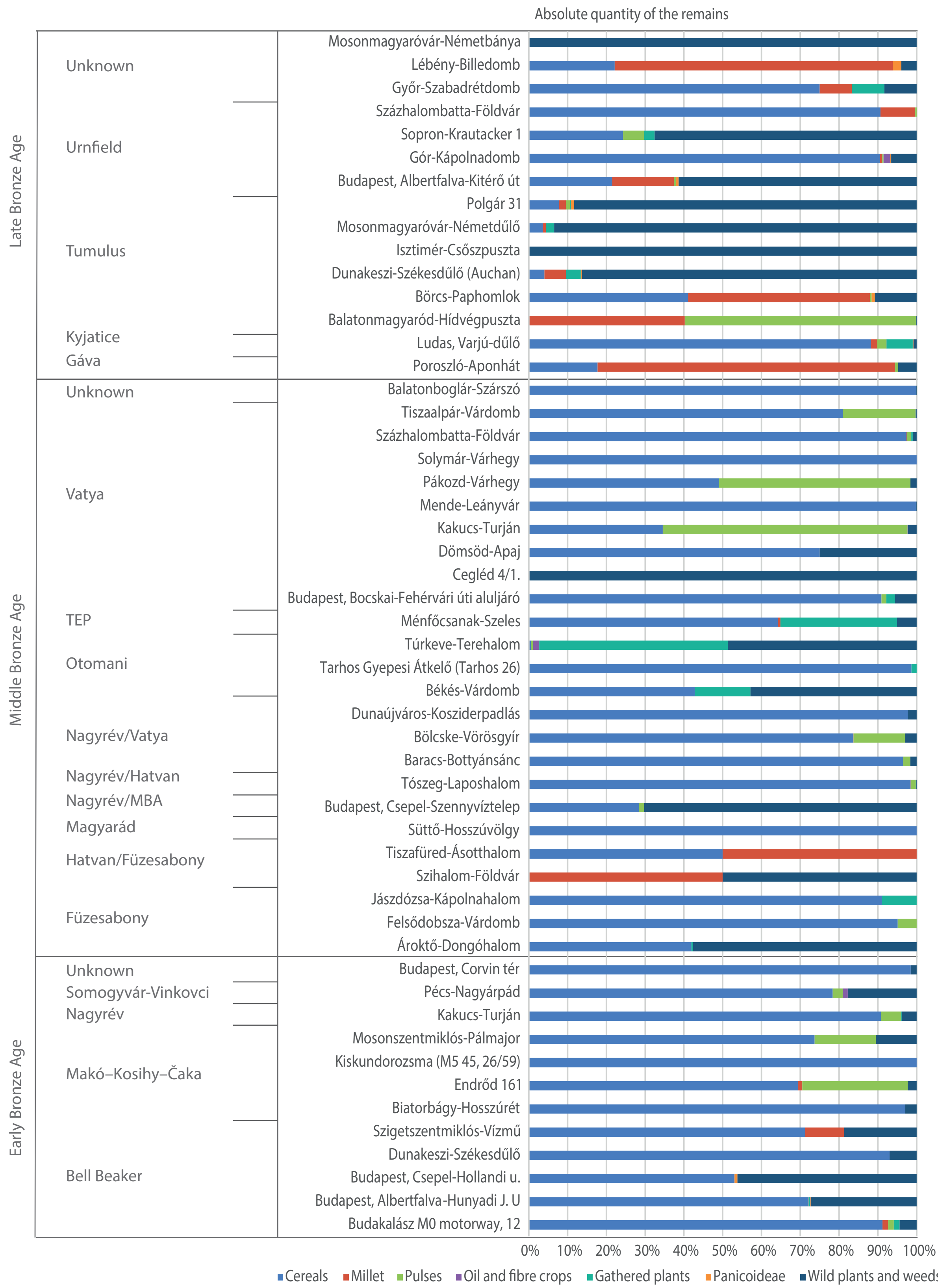

Figure 2. Absolute quantities (%) of plant groups plotted per phase, archaeological group and archaeological site.

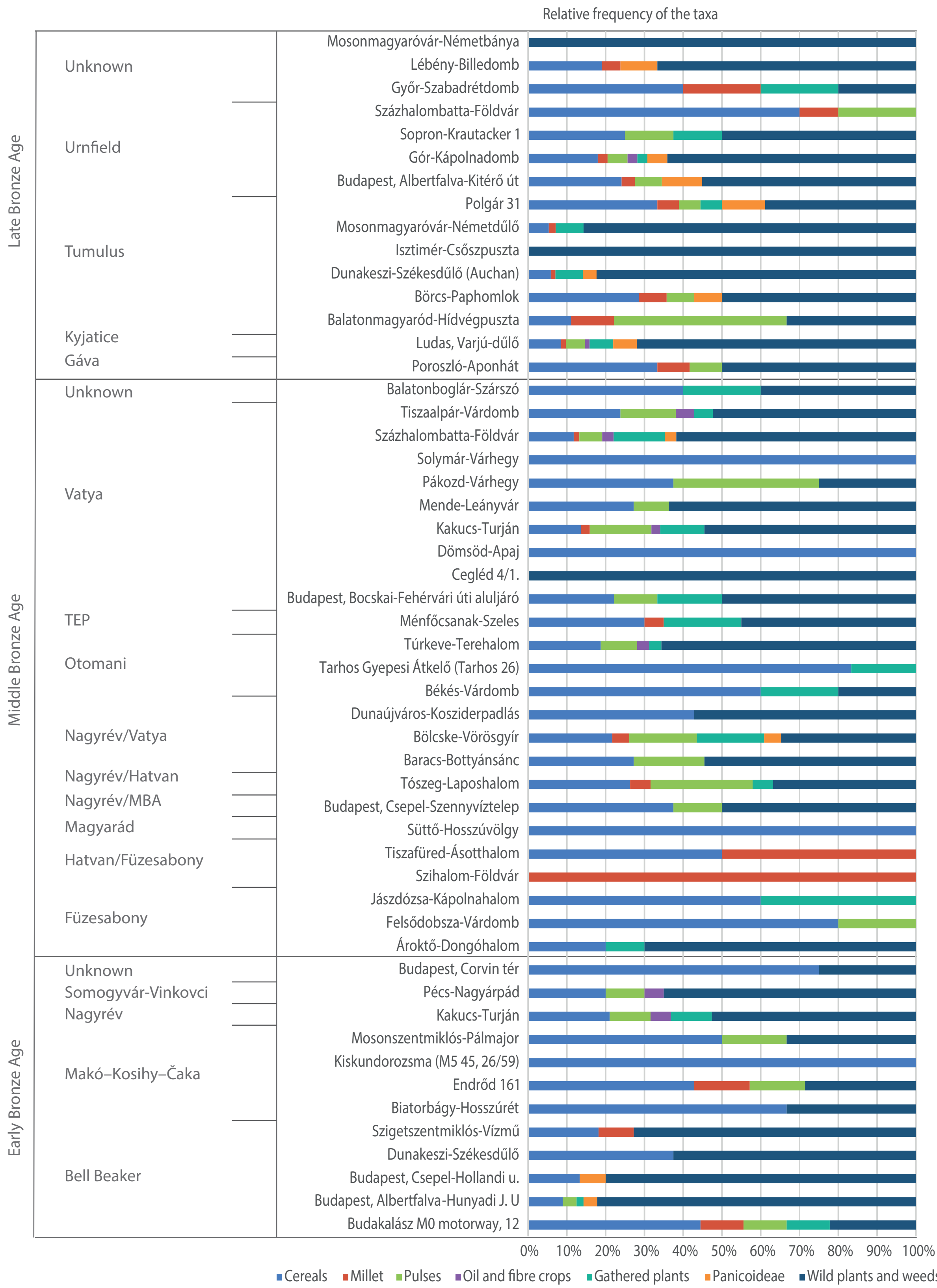

Figure 3. Frequencies of taxa (%) plotted per phase, archaeological group and archaeological site.

Considerations of the introduction of millet in Hungary

Within the Bronze Age as a whole, a diversity has been observed in the macro-botanical assemblages of all three phases, with site-specific variations in the predominant plant groups and taxa. The most important observations with respect to changes in the assemblages concern the diversification of the plant spectra from the Middle Bronze Age onwards and the shift in the major cereal taxa during the Late Bronze Age, including the more prominent role of millet. The pollen record supports the intensification in agricultural activity, showing increased signs of human disturbance from the Middle Bronze Age onwards. It must be noted that at least part of the (increasing) diversity in the assemblages reflects differences in preservation (*i.e.* charred *vs.* waterlogged), sampling strategies, and the number of samples and settlements that have been studied per phase and archaeological group.

According to the published data (Figs. 2 and 3, Table 7), there are finds of millet from all three phases of the Bronze Age. However, the results of the radiocarbon dating of individual charred millet grains demonstrate that the earliest of these grains originate from the mid-15th century BCE and thus from the onset of the Late Bronze Age in Hungary (Filipović *et al.* 2020, 6). For the remainder of the early finds of millet in the Bronze Age, it is likely that these also originate from this later phase, as has been demonstrated for the entire Carpathian Basin by Filipović *et al.* (2020).

In general, macro-botanical assemblages from Hungary confirm the introduction of millet as a staple crop during the Late Bronze Age, as the crop then occurs in higher frequency and greater quantity than before and is the predominant cereal taxon at several settlement sites. It is interesting to note the related increase in the frequency and quantity of weedy species of Panicoideae, which have been observed to co-occur with grains of millet in several macro-botanical studies (*e.g.* Motuzaitė-Matuzeviciute *et al.* 2012; Stobbe *et al.* 2019). These weedy species have been suggested to have been a source of nutrition prior to the introduction of cultivated millet into Europe (Kroll 2017).

The earliest definite indications for cultivation of millet in Hungary seem to be related to the occurrence of the Tumulus community during the first part of the Late Bronze Age. As described above, Sánta (2010, 522) suggested that the more dispersed and generally smaller settlements of the Tumulus community could possibly be related to a shift from the intensive agricultural practices of the Middle Bronze Age (*i.e.* high input of labour within a restricted plot of land located close to the settlement; Bogaard 2005, 180; Jones 2005, 165; Van der Veen 2005, 159) to extensive agricultural practices (*i.e.* low input of labour on large fields located farther from the settlements; Bogaard 2005, 179; Van der Veen 2005, 159) and a greater reliance on animal husbandry. This hypothesis is especially interesting because it proposes a relationship between Tumulus groups, millet cultivation and animal husbandry, a characteristic that is also attributed to central Asian pastoralists who practised low-investment millet cultivation and are believed to have contributed to the spread of the crop from East Asia into mainland Europe (Spengler 2019, 74), although Tumulus groups migrated from the west to the east of Europe (*e.g.* Csányi 2003). Defining cultivation intensity, however, requires a more detailed set of data than has been presented in the current contribution (*e.g.* analysis of individual samples based on weed assemblages; Charles and Jones 1997; Charles *et al.* 2002) and, to my knowledge, no macro-botanical studies of Late Bronze Age assemblages from Hungary have attempted such a reconstruction. Furthermore, as has also been emphasised by Bartosiewicz (this volume) for the zooarchaeological remains, there exists a diversity in the plant spectra and this diversity seems to be more strongly related to local factors than to 'generalised cultural habits'. Although all Tumulus group settlements in Hungary contain finds of cultivated millet, it does not prevail at every settlement; at the Tumulus sites of Isztimér-Csőszpuszta (Fejér County), Mosonmagyaróvár-Németdűlő and Polgár 31 (Hajdú-Bihar County), other cereals were more prominent than millet (Fig. 2). This topic requires the support of more systematic studies; the suggestion of Sánta (2010) remains an interesting hypothesis until those become available.

The environmental records obtained from stable isotopes in cave stalagmites and bivalve shells in western and southern Hungary indicate that the humidity peak characterising the Middle Bronze Age gave way to a drier and warmer climate during the Late Bronze Age (Demény *et al.* 2019). Although millet is known to tolerate low amounts of water (Filipović *et al.* 2020), it is, in my opinion, doubtful that its introduction is related to this relatively subtle climatic shift. The climatic deterioration suggested as part of the explanation for the change in settlement patterns at the beginning of the Late Bronze Age (Fischl *et al.* 2013) may be based on the data whose interpretations have changed. Namely, the more recent studies by Demény *et al.* (2019) indicate an opposite situation: the entire Bronze Age is characterised as mild and suitable for arable agriculture (Demény *et al.* 2019, 13, Fig. 9). Climatic conditions may, however, have varied locally in the Carpathian Basin, which today is still known for the mosaic-like character of its climate and geology (Sümegi and Bodor 2000, 84; Nagy-Bodor *et al.* 2000, 121; Mezősi 2017). From the data at hand, it is unclear whether potential local climatic deterioration may have caused the movement of people throughout Hungary and whether this coincided with the introduction of millet cultivation.

Regardless of the exact circumstances in which millet cultivation was introduced, it would certainly have been an advantageous addition to the plant economies of the groups that cultivated the crop, especially due to its tolerance of a variety of growing conditions and its short growing season (Filipović *et al.* 2020, 1). It is beyond the scope of this paper to address whether the cultivation of millet could have favoured the general developments of Late Bronze Age society in Hungary. The potential relationship between the inclusion of millet into the diet, the widespread bronze metallurgy of the Urnfield groups and the distribution of their settlements into marginal areas, such as mountain ranges, may be a topic of interest for future, more elaborate considerations of the macro-botanical and archaeological archives of these groups.

For now, it can be concluded that the macro-botanical assemblages and the pollen records indicate increasing agricultural activity in Hungary from the Middle Bonze Age onwards. The continuity in the main cereals cultivated during the Early and Middle Bronze Age terminated during the Late Bronze Age, when a different set of main cereals appears, including millet. It is unlikely that the appearance of millet is related to unfavourable climatic conditions, especially since the recently studied isotopic records have shown the opposite. The circumstances of the introduction of millet into Hungary and the likely advantages that this had for the Bronze Age groups remains a topic for future investigations.

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Bronze Age novelties in animal exploitation in the Carpathian Basin in a European context

László Bartosiewicz

Abstract

Bronze Age animal exploitation was very diverse in Europe due to broad chronological boundaries and extensive adaptations to local geographical and socio-economic environments. Demographic changes and the emergence of settlements with high concentrations of increasingly stratified human populations stimulated the diversification of animal-related resources beyond mundane meat consumption. This is directly reflected in ordinary food refuse brought to light at settlement excavations. Subsistence hunting had lost its significance compared with the preceding Neolithic, while domestic animals gained in importance not only as a source of meat: the use of renewable, 'secondary' animal products also became widespread. Innovations such as dairying, wool production and using cattle for draught had already developed earlier. However, the roles of these resources in local economies stabilised during the Bronze Age. Quantitative comparisons between animal remains and macro-botanical finds are made difficult by taphonomic and methodological differences. Reconstructions of mobility, as reflected in archaeozoological assemblages, may be profitably compared with occurrences of millet, a special crop of short growing season and also a C4 plant, detectable by means of stable isotope analysis in both human and animal diets.

Introduction

The study of animal and plant remains began at prehistoric pile-dwellings in Switzerland, where both were preserved in remarkable quantities (Rütimeyer 1861; Heer 1866). Archaeobotany and archaeozoology are disciplines that cross-cut cultural and temporal divisions in archaeology. However, deposition, preservation, sampling, and recovery biases affect plant and animal assemblages differently, making the integrated quantitative analysis of botanical and zoological finds difficult. Raw abundance data cannot be compared directly, methods of standardising joint datasets are only possible in projects where the finds are collected in a systematically coordinated manner with integrated analyses in mind. Major syntheses are prone to inter-observer bias even in archaeozoology itself. Re-analysing published data is difficult due to uncertain identifications (*e.g.* distinctions between bones of sheep and goat) and inconsistent reporting of potentially shed antler – a renewable wild animal product – and its unclear relation to hunting (Bartosiewicz 2005, 51). In spite of all these difficulties, however, close cooperation between experts has always produced valuable results (*e.g.* Gross *et al.* 1990; Schibler *et al.* 1997; VanDerwarker 2010; Jacomet and Schibler 2015; Bleicher *et al.* 2018).

The Bronze Age (BA) in Europe has conventionally been dated to between the mid-3rd and early 1st millennium BCE. If we imagine this interval in terms of CE dates, the challenge in this chapter would be similar to characterising animal keeping 'during Christianity', beginning with the fall of the Roman Empire up until today. Although the impacts of technical innovation and religion on daily life should not be confused, the length of this timespan is thought-provoking. A notable difference highlighted by this sketchy analogy is the meagre body of written sources regarding prehistory against which animal remains can be interpreted. Although in southwestern Asia, Egypt, and – exceptionally in Europe – Greece there are contemporaneous texts referring to animals, such evidence is unknown from all other parts of Europe. Therefore, the continent's BA animal exploitation cannot be appraised in such cognitive terms as linguistic, religious or 'ethnic' identities. In spite of the complexity of the Eurasian BA, the focus on millet in this volume makes it easier to single out characteristic phenomena in animal exploitation potentially relevant to the spread of this crop.

Keeping domesticates was firmly established by the BA in most of Europe: stocks could be increased without additional domestication (Bökönyi 1971, 647), the protracted 'secondary products revolution' (Sherratt 1983) of inventing sustainable animal products was over. Agriculture also benefited from a valuable secondary product previously neglected in research – manure (Bogaard *et al.* 2013). After 1500 BCE, evidence of manuring is known from northern Europe (De Hingh 2000; Robinson 2003), showing the importance of mixed farming (Wijngaarden-Bakker and Brinkkemper 2005, 496). By the BA, subsistence hunting was abandoned, although it retained some role in meat provisioning in the hilly regions of Austria, Slovakia and western Hungary (Bökönyi 1974, 67; Gál 2017, 64), as well as in the middle Volga River Basin. Here, domestic bovids were introduced along with metallurgy around the turn of the 3rd and 2nd millennia BCE (Matolcsi 1982, 77).

Within this extremely variegated scenario, the title '*Novelties in animal exploitation…*' helps me to focus on a few typical BA developments. There will be an inevitable geographical bias in this brief review. In spite of references to the entire continent and adjacent areas, the data analysed originate from central Europe, especially the Carpathian Basin, where most of my research experience is rooted (Bartosiewicz 2017).

Chronological and environmental framework

There is a south-east-north-west temporal cline in the spread of metallurgy across Europe. The Aegean BA began around 3200 BCE, while at the opposite end of the continent, Oscar Montelius's (1885) chronology for Scandinavia (supported by radiocarbon dating) indicates the beginning around 1700 BCE. In central Europe, recent radiocarbon results often blurred periods in Reinecke's typochronological system, as each region had its own artefact varieties (Kiss *et al.* 2015; Stockhammer *et al.* 2015), and some old and new 'cultures' (defined by stylistic criteria) co-existed, whether for a longer or shorter time (Szabó 2017, 101). Dates proposed for the early (2200-1600 BCE), middle (1700/1600-1300 BCE) and late (1300-800/700 BCE) phases

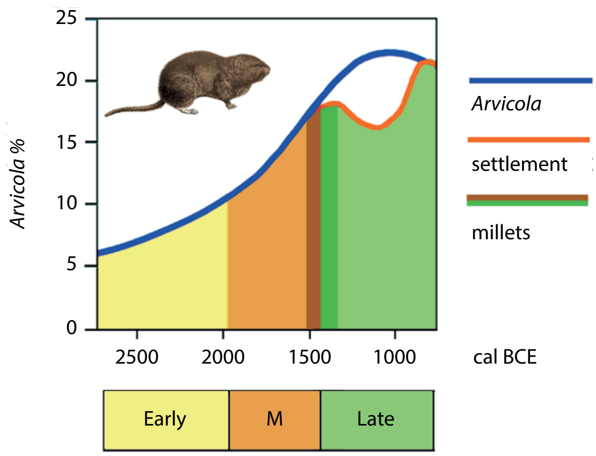

Figure 1. Graph showing humidity (Arvicola %), changes in the altitudes of floodplain occupation (settlement) and AMS-dates for millets during the BA in Hungary. Explanation in the text.

are thus subject to change within a broader geographical context. According to interpretations of the New Kingdom Egyptian texts and other documentary sources (Adams and Cohen 2013), the legendary ‘Sea Peoples’, a little-known confederation of seafaring warriors, ransacked the eastern Mediterranean, contributing to the Late Bronze Age (LBA) collapse (1200-900 BCE) in the region. Meanwhile, this period lasted until approximately 600 BCE in northern Europe.

Climatic oscillations also affected various parts of the continent differently. The BA in central Europe began with a relatively dry period, as observed in the intensive formation of alluvial deposits in Bohemia (Dreslerová 1995). The climate turned cooler and increasingly humid by the middle of the Subboreal period, encompassing the BA in the region (Jäger 1997). The percentage of water vole (*Arvicola amphibius* L., 1758) among rodents in Holocene cave deposits correlates to annual precipitation. Following a lull during the Chalcolithic, this value began to progressively increase around 2200 BCE (Kordos 1977, 225, Fig. 1). Steppe elements of the wild fauna, including Holocene lions, gradually withdrew from the Carpathian Basin (Daróczi-Szabó *et al.* 2020). In Greece, they became extinct during the BA (Thomas 2014).

Topographic surveys show that settlements were moved to high terraces in alluvial areas (Horváth 2000, 150, Fig. 1). Floodplains had been intensively inundated, until alluvial dynamics cut the riverbeds deeper. Consequently, low-lying floodplain areas and emerging islands could be re-occupied toward the LBA. This latter trend, indicated with the orange line in Figure 1, is difficult to quantify relative to the *Arvicola* humidity curve, but the oscillation of hydrological conditions is evident (Horváth 2000, 149). By the time of the LBA, the *Arvicola* humidity curve reached an inflexion point (Kordos 1977, 225). This climatic shift was observed across central Europe (Jäger 1997) and was also seen in other indicators used as a proxy for climatic changes in the northern hemisphere (Gronenborn 2009, 99, Fig. 2).

Gyulai (2014) identified millets at a dozen BA sites in Hungary. Due to their small size, however, these kernels are prone to redeposition, which could be the reason behind their occurrence in ten Neolithic provenances (Gyulai 2014, 32-33). Recently calibrated AMS-dates for millets from Fajsz, Százhalombatta and Pécel point to the end of the MBA-LBA transition in the west of Hungary (1510-1400 cal BCE, p=95.4%; Filipović *et al.* 2020). This is the time of the Tumulus culture, which is seen to have developed locally and then spread from the east toward its heartland in Germany. In any case, millets point to the connections of this culture with the Eurasian steppe, as hypothesised by Anthony (2010, 367).

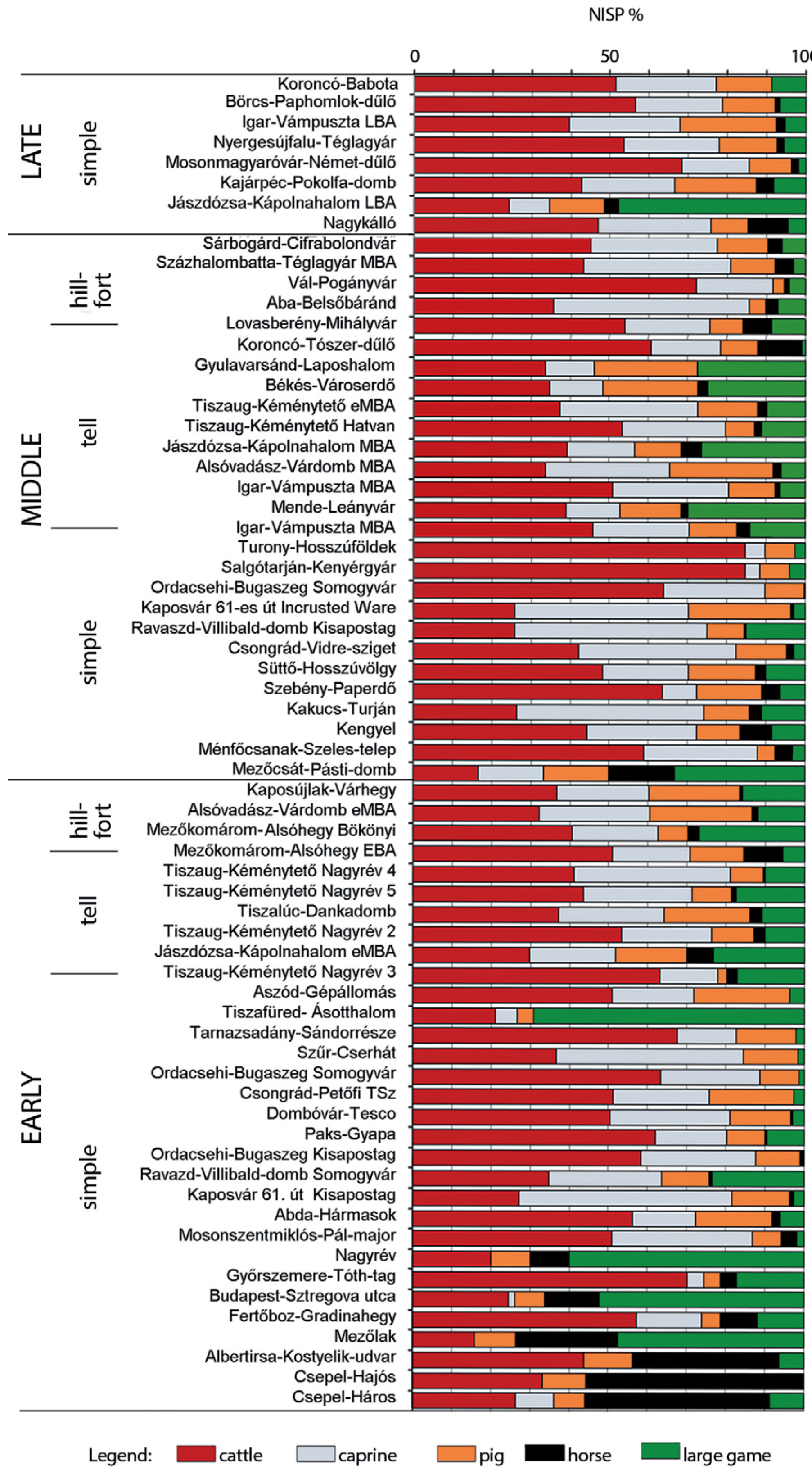

Figure 2. The percentages of livestock and large game in 66 BA archaeozoological assemblages in Hungary based on the number of identifiable specimens (NISP). Sites are grouped by chronological phase and settlement type.

Animal exploitation in general

Recently, the numbers of identifiable specimens (NISP) in 238 BA archaeozoological assemblages from across Europe were summarised (Bartosiewicz 2013a). Their high variability indicates that surplus became an integral economic factor behind the maintenance of increasingly stratified societies in which power relations had to be constantly negotiated both internally and in relation to the outer world. The emphasis on various domesticates and the versatile modes of their exploitation changed over both time and space, in ways that made use of the different properties of each species to different degrees, in accordance with the variegated needs and aspirations of the given community. Within this immense variability, cattle dominate among domestic artiodactyls (on average 49% of NISP) followed by caprines, *i.e.* sheep and goat (31%), and pig (20%). Sixty-six BA assemblages from Hungary (Bökönyi 1974; Choyke 1983, 2000; Bartosiewicz 1996; Choyke and Bartosiewicz 1999, 2000; Gál 2017) showed a higher average contribution by cattle (58%) and smaller relative frequencies of both sheep/goat (24%) and pig (18%). These simple numbers, however, mask considerable diversity both by period and by settlement type (Fig. 2). High variability within individual settlement types also means that there is no demonstrable correlation between settlement type and taxonomic composition. It seems that local environmental conditions had an impact on both animal keeping and the economic role played by hunting. What stands out in this chaotic-looking representation is the general importance of cattle, the role of horse in Early Bronze Age (EBA) meat provisioning and the capricious contribution of large game. Although caprine percentages usually exceed those of pig, great variability is evident in this regard as well. Small altitudinal differences and diverse, mosaic-like habitats in the Carpathian Basin did not limit the keeping of any species: animal husbandry could flexibly adapt to the immediate environment. This is illustrated by the aforementioned high diversity of taxonomic composition seen within settlement types.

The importance of beef in human diets becomes even more evident when bone weights, rather than NISP values, are compared. Cattle remains exceeded 75% of the weight of all bones among several EBA strata of the Jászdózsa-Kápolnahalom tell settlement, Hungary (Bartosiewicz 2016, 306, Fig. 1). In spite of fragmentation, the heavy bones of large ungulates indicate a larger share in meat supplies than their NISP values would indicate. Increased phenotypic diversity in BA cattle shows regional patterns (Bökönyi 1974; Matolcsi 1982, 122; Bopp-Ito *et al.* 2018, 4). The patterns may also be related to various forms of exploitation. Although work-related lesions are fewer in prehistoric cattle than in Roman period and Middle Ages cattle (Bartosiewicz 2006, 261), in northwestern Europe, EBA and MBA plough marks offer evidence of cattle having been used in tillage (Thrane 1990; Tegtmeier 1993).

Horse

BA animal exploitation shows considerable continuity with the Neolithic. The only notable innovation of strategic impact is the emergence and spread of the domestic horse. The status of Holocene equids in Eurasia, however, has long been debated (Duerst 1908; Meadow and Uerpmann 1991). Almost 40 Early and Middle Holocene sites yielded horse remains in Austria, Hungary, Romania, Serbia and Slovakia (Vörös 1981, 1994; Bălăşescu *et al.* 2003; Schmitzberger 2009), and some of these are Neolithic. Bökönyi (1971, 643) considered Chalcolithic horses in Hungary domesticated, while Vörös (1994) argued for the presence of wild horses in the Carpathian Basin. Currently, all such European horses are considered wild (Pruvost *et al.* 2011). Németh *et al.* (2016) assume that the wild horse disappeared from the Carpathian Basin when the Yamnaya culture affected much of Europe around 3000 BCE (Allentoft *et al.* 2015).

Horse bones dominated among the food refuse from the 4th millennium BCE onwards in the steppe region, including deposits at Dereivka (Ukraine) and Botai (Kazakhstan). Mare's milk residue shows that at least some horses at Botai were domesticated around 3500 BCE (Outram *et al.* 2009, 1334). Ludwig *et al.* (2009) suggested that the first domestic horses occurred in Europe during the BA, the time when domestic horse remains were also first identified in the Carpathian Basin, along the Danube, with the onset of the Bell Beaker period (Bökönyi 1974, 242). Bell Beaker pottery is found from the western Mediterranean, across western Europe, all the way to Poland. It became widespread around 2750-2500 BCE and disappeared between 2200 and 1800 BCE. However, its distribution area is not contiguous, possibly resulting from a mobile way of life (Schreiber 1973). Genome-wide analyses of 226 humans associated with the Bell Beaker culture (Olalde *et al.* 2018) displayed only limited genetic affinity between individuals from Iberia and those from central Europe, weakening the argument for inter-regional migration. As shown in Figure 2, EBA horses were an important source of meat in Hungary. Broad anatomical representation and patterns of butchery in Bell Beaker assemblages further illustrate this observation. It has been suggested that Iberian native horses share phylogenetic affinities with a single, 3rd millennium BCE specimen from Hungary (Fages *et al.* 2019). Unfortunately, the exact provenance of this find is not specified within the large city of Dunaújváros, where several BA sites were excavated. In the absence of a precise archaeological context, the possible Iberian connection with a presumed late 3rd millennium BCE 'trade centre' in Hungary cannot be interpreted. Whether there was long-distance exchange of horses during the Bell Beaker period, however, remains a valid question.

Horse flesh consumption became sporadic by the MBA. Once people recognised the high value and strategic importance of horses, their meat must have become more of a luxury than a staple. Horses not only revolutionised herding, warfare and trade; they accelerated information exchange in general. Aside from tripling the speed of human movement (even in canter) (Bartosiewicz 2013a, Fig. 18.2), the physical movement of horses was coupled with their unusual mobility within and among societies: they could be traded, rustled, seized as war booty, or presented as high-status gifts, making the study of their circulation unusually complex.

The first signs of horse's special status were discovered in the Catacomb Grave culture of the Lower Volga region (2500-1200 BCE): the skulls of 40 horses were found in a single structured deposit (Anthony 1997). This special treatment, however, does not yet prove the strategic importance of horse. In western Siberia and the adjacent west Asiatic steppe region, the Andronovo culture is a catch-all term for BA groups (ca. 2300-1000 BCE) who kept cattle and caprines as well as horses. Horses buried at Sintashta, near the Ural Mountains in Russia (ca. 2000-1600 BCE), were laid to rest in a quasi-galloping position. In addition, six two-wheeled chariots dated to ca. 1700-1500 BCE were also recovered at this site (Parzinger 2006, 251-257); the Andronovo culture has been tentatively credited with the invention of spoke-wheeled chariots around 2000 BCE (Anthony and Vinogradov 1995). A recent study of two horse skeletons buried with associated cheek-pieces found at Novoil'inovskiy, Kazakhstan – located between Sintashta and Botai – suggests that horsemanship was firmly established in the region by the LBA (Chechushkova *et al.* 2020). The 1890-1774 cal BCE date of these finds indicates a shift from chariots to horseback riding toward the turn of the 2nd millennium BCE.

Necrotic deformation resulting from chronic inflammation in the diastema of an MBA horse mandible from Polgár-Kenderföld, Hungary (Fig. 3), is consistent with the excessive use of rope bridle (Bartosiewicz 2013b, 134), which is a crude loop used to control mounting. Among archaeological artefacts, bridle cheek-pieces offer convincing evidence of horseback riding. They are lateral elements of snaffle bits that exert pressure into the horse's cheeks and lips (Brownrigg 2006), which became common in the northern Pontic steppe and then extended toward the west during the mid-2nd millennium (Bökönyi 1953; Mozsolics 1960; Pankovskiy 2016). Horseback

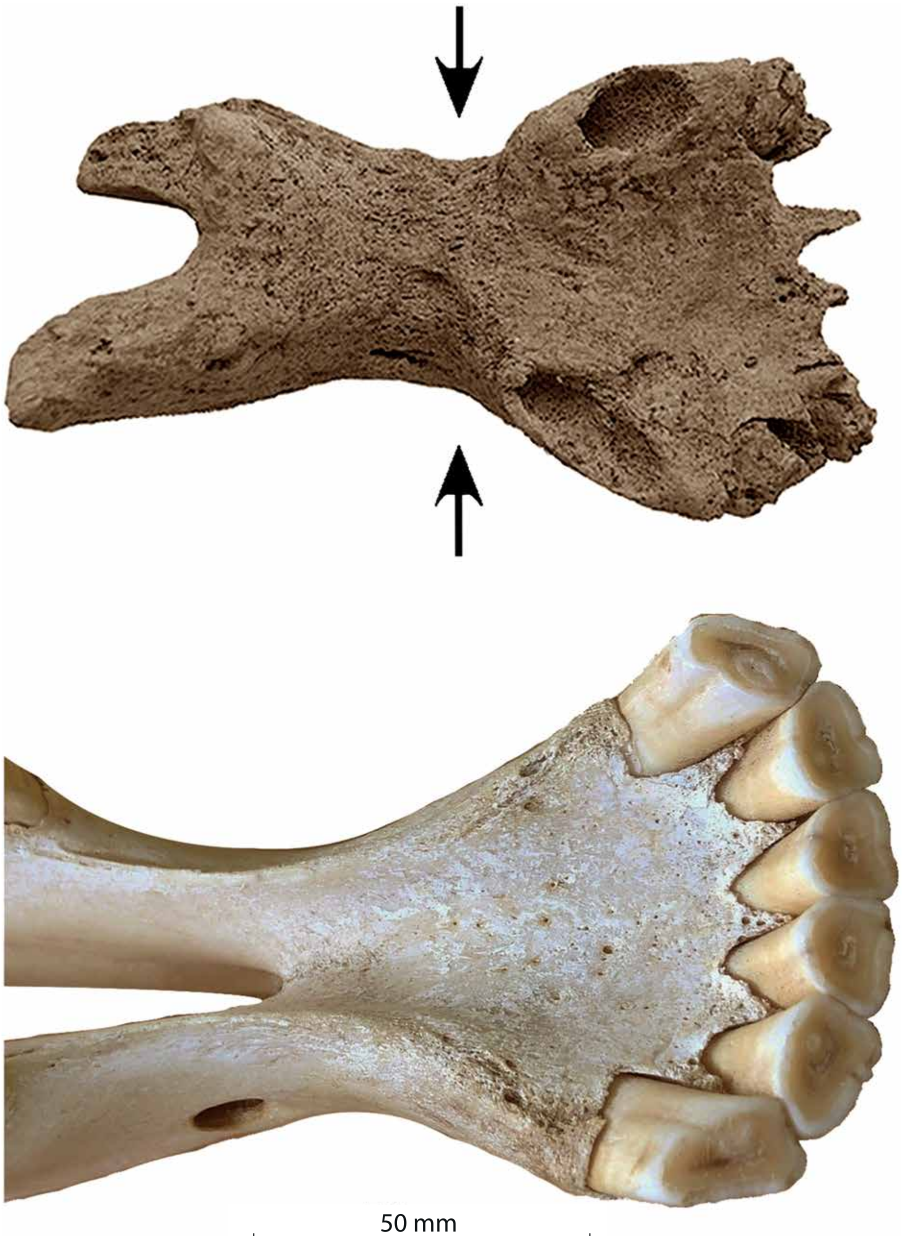

Figure 3. MBA horse mandible oral fragment deformed by traumatic indentations of the diastema (top) and a healthy reference specimen (bottom).

riding played a pivotal role in the Noua-Sabatinivka cultural complex, a tradition seen as an 'eastern intrusion' from the northern Pontic region (Bartosiewicz and Gál 2010a; Boroffka 2013, 889).

Horses thus became a formidable means of cross-regional connectivity, associated with BA socio-economic transformation. Controlling horses created superior military might, a platform in confronting foot soldiers, and horses also became an imposing medium for self-representation for millennia to come (Olsen *et al.* 2006). Among the earliest equestrian peoples in written history are the Cimmerians and the Saka/Scythians mentioned in Assyrian records (Deller 1984). They inhabited the steppe north of the Caucasus and the Black Sea around 1000 BCE. Their first mounted troops were formed when the use of a new type of bridle cheek-piece became common between central Europe and the Caucasus (Olsen *et al.* 2006, 157). Their influence west of eastern Europe is unknown; aside from the circulation of luxury artefacts (weapons, horse tackle, jewellery), their westward movements cannot be confirmed (Metzner-Nebelsick 2000, 165).

Sheep, goat and pig

In southwestern Asia, the Late Chalcolithic-EBA transition is marked by a shift to large-scale caprine herding (Clason and Buitenhuis 1998). Urban centres, palaces and temples often developed on tells, foci of power that ruled extensive hinterlands. Mutton had already attained overwhelming importance in the EBA Late Uruk period (3350-3000 BCE) at Arslantepe, Anatolia (Bartosiewicz 2010, 138), a trend even reflected in the food refuse of individual households (Piccione *et al.* 2015, 16). The concomitant decrease in the share of pig remains is remarkable. Reduced diversity in meat diets may indicate declining self-reliance in the face of increasing centralisation: large caprine herds are easier to inventory and tax than pigs, which would have been easier to keep in individual households. In northeastern Anatolia, the continuing shift from pork to mutton may also be attributable to strengthening relations with steppe regions in Transcaucasia around 3000-2800 BCE, culminating in probable intrusions by mobile pastoralists between 2750-2500 BCE (Siracusano and Bartosiewicz 2012, 114, Fig. 1).

By the Iron Age, the effort to centrally control meat resources may have contributed to pork prohibition in the Biblical Lands (Diener and Robkin 1978, 527). Pig was already poorly represented in the LBA (last third of the 2nd millennium BCE) of Area G at Tel Dor, Israel (Bartosiewicz and Lisk 2018, 283, Fig. 27.2), and was completely absent from Iron Age proveniences in Area D2 (Raban-Gerstel *et al.* 2008, 36, Table 2). Purely ecological explanations are of no help in understanding the origin, presence and change in the status of domestic animals. At Tel Dor, the humid climate of the marshy coastal plain would have been ideal for pig herding, also shown by the presence of wild pig among the remains of game (Raban-Gerstel *et al.* 2008, 38). Sheep also became important in the Balkans, but this trend is less pronounced in the rest of Europe: patterning apparent in southwestern Asia tapers off toward the northwest in increasingly different natural and social environments. When domestic artiodactyls are compared with each other in Hungary, the dominance of cattle is evident, approaching 60% in all phases of the BA (Table 1). Caprine remains identifiable to species show that, in Hungary, the number of bones of sheep is five to six times greater than that of goat among the finds in all periods (Bartosiewicz 1999). Thus, the term caprine may be taken as roughly synonymous with sheep within this context.

Although Table 1 shows parameters obtained for all sites, calculations using 27 assemblages containing at least 500 identifiable specimens shows the same trend: the three BA phases overlap in the top quarter of the ternary diagram in Figure 4, and no statistically significant difference is apparent. Among the large assemblages, only the EBA site of Ravaszd-Villibald-domb (Bartosiewicz 1996) and the MBA assemblages from Kaposvár-Road 61 (Gál 2017, 144) and Kakucs-Turján (Biller 2018, 160) stand out due to low percentages of cattle and relatively high contributions of caprine remains. Meanwhile, sheep and goat are only missing in small datasets along the upper right margin of the diagram: extreme percentages are often a reflection of small assemblage size. In general, the great variability among individual assemblages overshadows minor differences among the mean percentages of phases.

The main trend in Table 1 supports the opinion of Bökönyi (1974, 65) that EBA sheep and goats gained ground at the expense of pigs, although this trend slowed down by the LBA in central Europe. He attributed the decelerating increase in caprine remains to climatic change, pointing out that '*pigs like dampness*', whereas sheep prefer dry grassland habitats. Natural preferences by livestock, however, are known to have been frequently disregarded by their owners. Caprine remains dominated (70-80% of NISP) at the Early Neolithic Körös culture sites in marshland habitats of the Great Hungarian Plain (Bartosiewicz 2012, 198, Table 2). Environmental conditions clearly impacted the health of these herds (Bartosiewicz

Phase	n sites			Cattle %		Caprine %		Pig %	
	<500 NISP	≥ 500 NISP	Total	*mean*	*sd*	*mean*	*sd*	*mean*	*sd*
EBA	21	10	31	**55**	14	**28**	12	**16**	8
MBA	13	13	26	**59**	15	**23**	16	**17**	9
LBA	5	4	9	**57**	9	**25**	5	**18**	7
Pooled	**39**	**27**	**66**	**56**	**14**	**27**	**14**	**17**	**9**

Table 1: Mean values and standard deviations (sd) of percentages of artiodactyl NISP values in the 66 Bronze Age assemblages in Hungary shown in Figure 2.

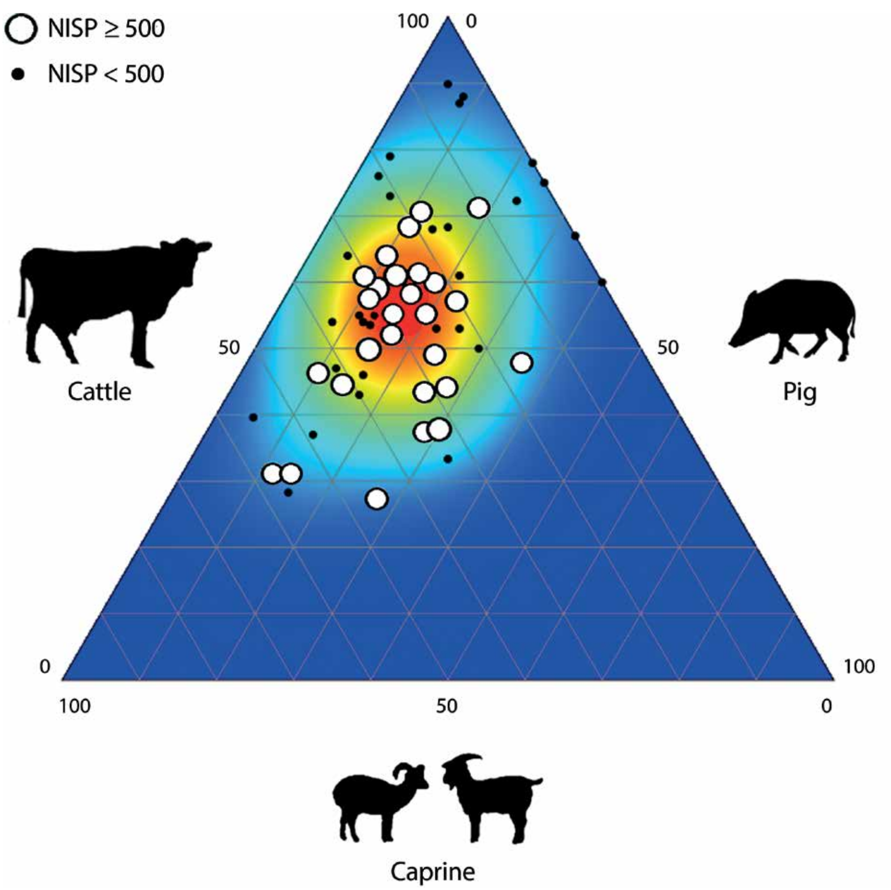

Figure 4. The percentage contribution of domestic artiodactyls to 66 BA assemblages in Hungary. White dots indicate large (NISP≥500) assemblages.

2008). Climatic factors may also have influenced subsequent caprine introductions to Europe (Gronenborn 2009; Grömer and Saliari 2018).

At the tell site of Százhalombatta-Földvár, Hungary, the contribution of sheep rose from below 20% before 2000 BCE to over 40% in subsequent periods (Vretemark 2010). Terramare pile structures in the plains of MBA northern Italy (ca. 1700-1150 BCE) show comparable phenomena (Bernabò-Brea *et al.* 1997). By around 1600/1500-1300 BCE, the contribution of caprines rose to 40% at the Terramare site of Montale (Emilia-Romagna). Studer (1900, 107) noted an increase in BA sheep remains in Switzerland, a trend stronger in the west of the country (Hescheler and Kuhn 1949). Recent studies have shown that the proportion of caprine remains rose from ca. 20% to 30-40% at BA pile-dwellings, at the expense of pig and game. At inland settlements, this increase was 30-70% (Schibler and Studer 1998, 182, Fig. 72). Quantitative increase was accompanied by qualitative changes in sheep populations. By the end of the 3rd millennium BCE, different population types occurred in central Europe, where withers height estimates show considerable regional variation (Bökönyi 1974, 648, Fig. 4; Grömer and Saliari 2018; Schmölcke *et al.* 2018).

A basic form of renewable exploitation shown by longevity is reproduction. Although possibly slaughtered for meat, the lamb is a secondary product of the ewe, the latter potentially having been kept alive until capable of lambing. Reproduction rates differ among domesticates. In contrast to proliferous pigs (four to six piglets per litter), sheep are uniparous. Twin lambing developed only in modern sheep breeds. An effort to maintain and increase flocks thus results in general longevity in females.

Mutton: Proxy for wool production?

According to Leuzinger and Rast-Eicher (2011, 5), an increase in sheep remains may have been a sign of wool production in Switzerland from the Corded Ware culture onwards. Direct evidence, in the form of a small fragment of wool, however, is only available from the BA (Rast-Eicher and Reinhard 1997, 287). Excessive-looking supplies of mutton at BA rural sites in the inner Alpine region (possibly also related to the provisioning of mining sites: Schmölcke *et al.* 2018, 110) clearly illustrate the complex relationships among various sheep products.

Along with regional upsurges in the quantity of caprine remains, age distributions indicative of longevity may support hypotheses concerning renewable animal products, such as wool (Becker *et al.* 2016). At Százhalombatta-Földvár, caprine age distributions indicate a pattern of slaughtering younger individuals before 2000 BCE, whereas the remains of adult and mature individuals dominate in the subsequent Koszider phase of the Vatya culture at the site (1500-1400 BCE) (Vretemark 2010; Vicze 2013). At Kakucs-Turján, on the Great Hungarian Plain, also assigned to the Vatya culture (1900/1800-1700/1600 cal BCE), caprine bones make up half of the 1981 identifiable mammalian bones. However, only 15% of the 747 ageable sheep remains represented fully grown individuals (Biller 2018, 163). This low value is comparable to the BA sheep mortality pattern observed at Arslantepe, where in spite of the massive contribution of mutton to the diet, no marked longevity was observed to support hypotheses concerning specialised wool production (Siracusano and Bartosiewicz 2012, 119-120). According to Ryder (1987, 114), domestic sheep with primitive fleece evolved by about 3000 BCE in southwestern Asia and by 1500 BCE in Europe.

Written sources suggest that wool had an increasing impact on many aspects of life in southwestern Asia. Rare direct evidence of wool manufacturing is preserved only under special circumstances. An early 3rd millennium BCE mixture of sheep wool and camel hair was found in a saline layer at Shahr-I Sokhta, Iran (Compagnoni and Tosi 1978, 97, Fig. 4). In central Europe, remains of woollen textile found in the Hallstatt salt mines, Austria (Grömer 2012), and at Pustopolje, Bosnia and Herzegovina (Marić Baković and Car 2014), were dated to the mid-2nd millennium BCE, the latter being the earliest dyed woollen fabric find in Europe (1520-1510 BCE, 1σ) (Grömer *et al.* 2018, 354). Garments of the salt miners in Hallstatt were nearly all made of wool by between 1460 and 1245 BCE (Grömer 2012; Bender Jørgensen and Rast-Eicher 2016). In spite of the good preservation of organic materials, animal fibres rarely survive in the alkaline deposits at circum-Alpine waterlogged sites (Rast-Eicher and Reinhard 1997). A rare exception is the piece of dyed textile found at the Pfäffikon-Irgenhausen lake dwelling, Switzerland, dated to the EBA-MBA transition (Grömer 2013, 83). In the north, textile finds from the oak-log coffin burials in Denmark (Broholm and Hald 1940; Bergerbrant 2007) date to the mid-2nd millennium BCE as well (Holst *et al.* 2001).

Almost all BA textiles in northern Europe were made of relatively thick wool yarns (Sofaer *et al.* 2013, 479), resulting in coarse and less evenly made fabric, indicative of a different technology to that in regions to the south (Grömer *et al.* 2018, 355). In the absence of finds of wool manufacturing equipment, the question arises of how many of these ca. 1600-1100 BCE wool finds were locally produced. Gleba (2017) suggested that textile working in the European continent differed from that of the Mediterranean region. Her observations are consonant with the hypothesis that wool processing followed distinct regional trajectories (Sabatini 2018) that may be reflected in the great variability of caprine representation in animal bone assemblages.

Mobile pastoralism and millet

Broomcorn millet, a drought-tolerant crop of short growing season and rapid seeding (Nesbitt 2005; Spengler *et al.* 2014), has long been a crop of choice for mobile pastoralists. Around 1600 BCE, BA herders in Inner Asia cultivated domestic wheat and barley of southwestern Asian extraction, as well as broomcorn and foxtail millet originating from China (Hermes *et al.* 2019, 1). From the BA perspective, classical *topoi* concerning nomads may be anachronistic, but they do refer to millet within the important context of mobile pastoralism. Herodotus ([1987] IV: 10-18) described the 5th century BCE Scythians as '*not cultivators but pastoralists*', who also grew millet. Bovid herders likely accelerated the trans-Eurasian transmission of domestic cereals during the EBA (2500-2300 BCE) while exploiting foothill graze between the Iranian Plateau, the Altai Mountains and western China (Hermes *et al.* 2019, 7), contributing to the westward dispersal of millets. The direct role of horses in this process remains a question. Plinius Maior ([1938] XVIII: XXIV, 100), however, lends weight to their association with millet in 77 CE:

'*Sarmatarum quoque gentes hac maxime pulte aluntur et cruda etiam farina, equino lacte vel sanguine e cruris venis admixto. Aethiopes non aliam frugem quam milii hordeique novere*' [Sarmatian tribes live chiefly on millet porridge, and even on the raw meal, mixed with mare's milk or with blood taken from the veins in a horse's leg. Millet and barley are the only grains known to the Ethiopians]. (Rackham 1938, 253).

The coincidental reference to Ethiopia is interesting because East Africa is one of the few places where, until recently, draining blood from live animals has remained a form of secondary exploitation among cattle herders. According to a 13th century CE source (Ligeti 1962), nomadic Mongols also resorted to consuming blood from live camels.

Domestic chicken?

Domestic chicken is a species of East Asian origins, although the northward distribution of its wild ancestor and thus possible places of domestication in Asia are still to be studied (Eda *et al.* 2019, 6). Although a compilation of finds by West and Zhou (1988, 522, Table 2) includes putative Neolithic and Bronze Age specimens from central and southeastern Europe, recently there has been a consensus that these unusually early European occurrences may require verification (Pitt *et al.* 2016, 3). The taphonomic challenge that chicken bones pose is quite similar to that of 'pre-BA' millet finds: small and often fragmented bird remains are prone to post-depositional transport between layers. With the exception of in situ finds or perfectly sealed contexts, their dating by means of stratigraphy is unreliable and needs to be supported using direct radiocarbon measurements.

The main period for domestic chicken dispersion throughout Europe was the Iron Age (Benecke 1993), with the earliest reliable find reported from the Czech Republic. The hillfort on top of the Rubín hill yielded a partial skeleton of an adult individual radiocarbon dated to 720-690 BCE (2σ; Kyselý 2010, 13). This date is consonant with other discoveries of domestic fowl in central Europe attributed to the Hallstatt period C and D phases (ca. 8th century BCE) and the contemporaneous Scythian finds at the settlements of Jászfelsőszentgyörgy (Bökönyi 1974, 371) and Balassagyarmat (Bartosiewicz and Gál 2010b, 116, Table 9.1), in eastern Hungary.

Although verifiable occurrences of domestic chicken post-date the earliest millet finds in Europe, the ‘Scythian connection’ is indicative of the possibility that these birds reached the European continent from the Eurasian steppe region through mediation by mobile pastoralists, whose earlier waves had plausibly played a role in introducing millet through migration and/or trade.

Thoughts on antler manufacture

Following the Neolithic, the quality of bone manufacture began to deteriorate in central Europe, showing strong regional variability attributable to localised traditions manifested in sometimes opportunistic household production (Choyke and Schibler 2007, 58, Fig. 8). Meanwhile, a limited class of high-quality objects, probably made by part-specialists, emerged. Many were made from red deer antler, in spite of the decline in hunting. At the Terramare sites in northern Italy, almost three quarters of MBA osseous objects were carved from antler, often using metal tools (Provenzano 2001). In the Baltic, where red deer antler was difficult to find, skeletal bone was more carefully turned into LBA spearheads, points, buttons and decorated handles (Luik and Maldre 2007).

Many of the artefacts were evidently made of shed antler: the naturally separated antler rose is still visible on typical MBA antler mattocks, *e.g.* on the Great Hungarian Plain and in the Po River valley, Italy (Choyke 1998a, Fig. 2; Provenzano 2001). Antler gathering, rather than hunting, explains the positive correlation (r=0.663) between the relative frequency of manufactured red deer remains and the contribution of this game to the refuse bone assemblages in BA Hungary (Choyke 1984, Table 3). This relationship is far weaker between bone tools and the skeletal remains of livestock among the food remains, where the choice of raw material was more diverse, the manufacturing less planned, and the use of bone frequently opportunistic (Choyke 1998b, 67). The appearance of such mundane bone tools is in stark contrast to sophisticated decorative antler objects, suggesting that the latter may have been manufactured for an emerging elite by artisans possessing specialised skills as well as rare metal tools (Provenzano 2003). Special-purpose antler objects, often parts of complex multi-media artefacts, included harpoons, polished and decorated handles, toggles and pinheads. However, it is horse harness elements, such as bridle cheek-pieces, that are most directly relevant to the spread of horseback riding at the time (Fig. 5).

Due to their function in mobility and the association with elite horsemanship, they were made in part for display, travelled long distances and may have inspired local artisans over broad areas. These objects represent a spectacular intersection among dimensions of raw material, function and relations with animals: before the BA, there were no horses to ride, whereas after the BA, bridles were made of metal; hunting was no longer important, but antler working still flourished.

An odd ‘footnote’

A previously unparalleled type of BA bone object is represented by perforated canid and hare metapodia, usually drilled above the distal articular condyle, in a dorsoplantar direction. They attracted considerable attention in the material from Százhalombatta-Földvár (Choyke 2000, 101). Two such hare metatarsal pendants were found in the EBA Nagyrév culture layer of the tell, while the MBA Vatya culture strata yielded nine such perforated hare metapodia. Two similar pendants were found at the Vatya culture hillfort of Pákozd-Várhegy (Choyke *et al.* 2004, 183, Figs. 8, 18). Vretemark and Sten (2010) contextualised these objects within the skeletal manipulation of dogs at Százhalombatta. Recent finds from the contemporaneous

Figure 5. Examples of MBA red deer antler working from Százhalombatta-Földvár.

Table 2. Perforated small mammal metapodia in burials.

Site	Grave	Century	Metapodium finds	Comment	Source
Tara Su, Kyrgyzstan	18	4th CE	17 small mammal	woman	Кибиров 1959
Kiskőrös-Vágóhíd, Hungary	74	7th-8th CE	11 hare	young girl	Bartosiewicz et al. 2014
Alattyán-Tulát, Hungary	161	7th-8th CE	7 hare, 7 canid, 5 non-identifiable small mammal	-	Bartosiewicz et al. 2014
Kiszombor-E, Hungary	17	7th-8th CE	16 hare	woman	Bálint 1975
Dmitrievka, Ukraine	-	8th-9th CE	9 hare	woman	Pletnyova 1967
Csanytelek-Újhalastó, Hungary	15	6th-4th BCE	2 hare, plus rest of skeleton	woman	Galántha 1981

Vatya culture settlement of Kakucs-Turján (Gál 2018, 124-125, Figs. 9-10) have directed comparable attention to hare. They include 22 hare metapodia and only 4 dog metapodia, as well as 2 hare phalanges. Aside from these three settlements, no BA sites in Hungary have yielded such objects. However, some more recent analogies point to a marked central Asian steppe tradition, as seen in several burials (Table 2). Unfortunately, no parallels to these highly personalised grave goods can be expected from BA Hungary, as cremation prevailed at the time.

The 7th-8th CE finds from the Great Hungarian Plain are associated with the Avars, a population of central Asian origins, whereas the 6th-4th BCE was the time of the Scythian influence in the region. Lending weight to the gendered nature of these objects, Pletnyova (1967, 172) also mentions that hare phalanx pendants are rare and are usually found in association with women.

Discussion and conclusions

The BA witnessed manifold environmental and cultural changes in Eurasia. This often-tumultuous period was characterised by major migrations and even replacements of human populations (Allentoft *et al.* 2015). A century ago, Childe (1925) outlined substantial BA connections between the Near East and southeastern Europe. Amidst conflicting relative chronologies, there are striking stylistic similarities between art in the Mycenaean Greece and the Nordic BA (Kristiansen and Suchowska-Ducke 2015, 363-364). However, the question remains as to which similarities are due to the diffusion of ideas, the distribution of objects, or major human migrations. Similarities between localised phenomena may even be purely coincidental. Although these possibilities are not mutually exclusive, it is difficult to correlate patterning in material culture, including domesticates, with the movement of peoples (Allentoft *et al.* 2015).

Human-driven diffusion is undeniable when domesticates start occurring outside the natural distribution areas of their ancestral forms. Mitochondrial DNA and stable isotopic ratios in animal remains indicate that, around 2700 BCE, domestic caprines of southwest Asian origins were winter-foddered with millet in the Dzhungar Mountains of Kazakhstan (Hermes *et al.* 2019). This discovery already represents a fusion between domesticates originating from two different regions. However, from a European perspective, domestic bovids arrived to the continent millennia before the earliest known occurrence of millet, exposing the complexity of the equation.

The emergence of large BA settlements with high concentrations of people stimulated the diversification of animal resources beyond primary meat consumption. In addition to arable land, extensive pastures were needed for provisioning around large settlements. The increase in caprine remains in various parts of Eurasia may be explained differently depending on time and place: as economic policy, the preservation of breeding stocks, wool production, or even interrelated combinations of these possibilities.

Millets first occurred in Hungary slightly later than in Ukraine and at about the same time as in northern Italy (Filipović *et al.* 2020, 10, Figs. 4-5). Because they were the only C4 crop in Europe prior to the introduction of maize from the New World, millets can be safely detected using dietary stable isotope analyses. Tafuri *et al.* (2009, 150) noted enriched δ^{13}C values in the bones of both humans and livestock from the MBA-LBA (16th-12th centuries BCE) site of Olmo di Nogara and the EBA-MBA site of Sedegliano, in northern Italy. Charred food crusts on shards from Bruszczewo, Poland (Heron *et al.* 2016), differed between the EBA (2100-1650 cal BCE) and LBA-Early Iron Age (1100-800 cal BCE), consistent with the occurrence of residue from a C4 plant. Although the single millet kernel identified among the macro-botanical remains at Kakucs-Turján, Hungary (Filatova *et al.* 2018, 178, Table 1), was unsuitable for direct dating, it would fit this process, especially at a settlement where sheep and goat were heavily represented in the meat diet.

Superficial similarities, however, are easier to spot than substantial differences. Hypothetical connections between BA phenomena outlined in this chapter need to be continuously tested using new data and methods to benefit proper scholarship and understanding of this important period. Co-occurrences or even correlations do not necessarily mean causal relationships. This summary is thus less of a synthesis than a review of ideas worth pursuing in future analyses.

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Unearthing millet in Bronze and Iron Age Croatia

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Abstract

New AMS ^{14}C-dates have been tracking the arrival and spread of millet across prehistoric Europe. They suggest that millet arrived in the Bronze Age at a time when significant socio-economic changes were underway. This paper presents new radiocarbon dates from the region of central and eastern Croatia where grains of both broomcorn (*Panicum miliaceum*) and foxtail millet (*Setaria italica*) were sampled from four prehistoric sites. The radiocarbon dating revealed a date of between the 16th to 12th century cal BCE for two of the sites, corresponding with stable isotope analyses in the region that indicate millet consumption occurred from the mid/late Bronze Age. Overall, the data from Croatia is still relatively sparse, so more information is needed to understand how, when and why millet became incorporated within the local agricultural food system.

Introduction

Croatia has a unique geography within which to explore prehistoric farming, with a coastal zone to the southwest and a continental region to the northeast, separated by the Dinaric Alps (Fig. 1). Within the coastal region, a hotter and drier Mediterranean climate is present and is characterised by a limestone geology that is more rugged and less uniform, with areas containing fertile valleys and mountainous areas covered by thin layers of poor quality soil. Inland Croatia in contrast has a continental climate with greater rainfall and cooler temperatures. As the region moves east it becomes relatively flatter with fertile alluvial plains that are roughly bordered by the Drava River to the north, the Sava to the south and the Danube to the east (Fig. 1). Agriculture arrived in Croatia ca. 6000 cal BCE through two routes; along the coast and through an inland route (*e.g.* Forenbaher and Miracle 2005; Orton *et al.* 2016). The first farmers cultivated einkorn (*Triticum monococcum*), emmer (*Triticum dicoccum*), barley (*Hordeum vulgare*), pea (*Pisum sativum*), lentil (*Lens culinaris*),

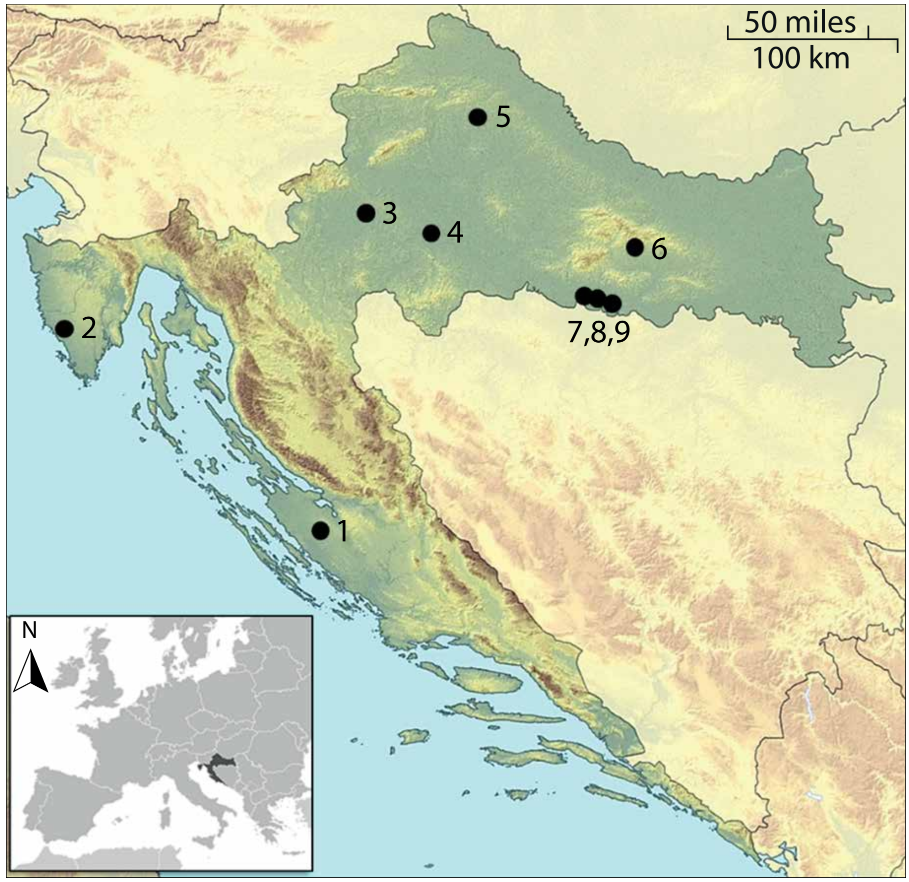

Figure 1. Map of Croatia showing the location of Bronze and Iron Age sites with archaeobotanical remains of millet referred to in this paper 1. Nadin-Gradina 2. Monkodonja 3. Lasinja 4. Sisak-Pogorelac 5. Kalnik-Igrišče 6. Kaptol-Gradići 7. Mačkovac-Crišnjevi 8. Mačkovac-Oštrovi 9. Orubica-Veliki Šeš.

and flax (*Linum usitatissimum*). These main crops dominate assemblages for over three and a half millennia (Reed 2015, 2017). The Bronze Age, however, witnesses the influx of new crops, cereals, pulses and oil plants, in Europe. These crops do not seem to arrive simultaneously in the form of a 'package' but appear at different times during the Bronze Age (Valamoti 2016).

One of these 'new' crops was millet, *i.e.* broomcorn (*Panicum miliaceum*) and foxtail (*Setaria italica*) millet, fast-growing summer annuals. From the archaeobotanical remains in Croatia, we see individual grains of millet appearing in the Neolithic (Reed 2015), small clusters in the Eneolithic (Reed 2017) and large storage deposits in the Late Bronze Age (Mareković *et al.* 2015; Reed *et al.* 2021) and Early Iron Age (Reed and Drnić 2016). From this evidence alone we may surmise an early prehistoric introduction of millet to Croatia but possibly as a weed rather than as a crop. However, studies such as Motuzaite Matuzeviciute *et al.* (2013) and Filipović *et al.* (2018) have shown the importance of dating grains instead of relying on contextual information. Their studies generally showed that many of the millet grains were younger than their contexts, suggesting millet did not arrive in parts of Europe until the Bronze Age, or Late Bronze Age in the case of Germany. These finds highlight the potential for these small grains to move through archaeological contexts. Thus, in recent years singular grains found in contexts dated to before the Bronze Age, when large deposits of grains appear (*e.g.* Stika and Heiss 2013), have been interpreted as intrusive. Isotopic and biomolecular evidence in Europe also suggests that the preparation and consumption of millet only occurred from the Bronze Age onwards (*e.g.* Lightfoot *et al.* 2013; Heron *et al.* 2016).

In comparison to other regions, little is known about the development of agriculture and the introduction of these new species in the Croatian Bronze (ca. 2500 to 900/800 cal BCE) and Iron Age (ca. 900/800 to end of the 1st century BCE) and how agriculture connected with the changing socio-economic environment. Thus, how, when and where millet was introduced to Croatia is still unclear. This paper presents recent AMS-radiocarbon dating of broomcorn and foxtail millet from four prehistoric sites in central and eastern Croatia. These dates were undertaken as part of the Kiel study funded by the German Research Foundation (Deutsche Forschungsgemeinschaft (DFG), Project number 2901391021-SFB 1266), in order to understand the precise chronology and character of the spread of broomcorn millet into Europe and the mechanism for its uptake and final incorporation within food production, diet and the wider socio-economy (Filipović *et al.* 2020).

Evidence of millet cultivation and consumption in prehistoric Croatia

Evidence of broomcorn or foxtail millet in Croatia is rather sporadic at prehistoric sites. Singular finds have been noted from the Neolithic and Eneolithic (Reed 2013), except at the multi-period site of Lasinja where 48 grains of foxtail millet and 6 broomcorn millet grains were identified from an area thought to belong to an Eneolithic settlement (Reed 2017). The site had no other crop remains other than one badly preserved barley grain (cf. *Hordeum vulgare*), with only singular finds of chinese lantern (*Physalis alkekengi*), blackberry (*Rubus* sp.) and elder (*Sambucus ebulus*) and a few weed/wild seeds.

For the Bronze Age only five sites have finds of millet: Monkodonja, Orubica-Veliki Šeš, Mačkovac-Crišnjevi, Mačkovac-Oštrovi and Kalnik-Igrišče. However, Monkodonja, which dates to the Early/Middle Bronze Age (2000-1200 BCE) only had two broomcorn millet grains (Kroll 2015) and Orubica-Veliki Šeš only had one grain (Reed 2013). These few grains have not been dated and so are not considered to indicate crop cultivation at this time. Instead, the most secure finds come from Kalnik-Igrišče where 37,000 broomcorn millet grains have so far been identified within a burnt down building (Mareković *et al.* 2015; Essert 2019). This site is particularly interesting as there are clear storage areas within the building, along with large deposits of other crops including barley, naked wheat (*Triticum aestivum/durum*), emmer (*Triticum dicoccum*), spelt (*Triticum spelta*), broad bean (*Vicia faba*) and lentil (*Lens culinaris*) (Reed *et al.* 2021). At Mačkovac-Crišnjevi, a settlement site, only 10 broomcorn millet grains were identified along with 4 foxtail millet grains. They were generally singular finds in general occupation layers except for one pit where five broomcorn millet grains were recovered. Interestingly, this site also had over 300 oat grains from two general occupation layers. Only one grain of emmer and one of lentil were also identified along with a range of grasses and sedges and other wild/weed species (Reed 2013). At Mačkovac-Oštrovi, a Bronze Age necropolis, 15 broomcorn millet grains were recovered from one of the cremation burials (Reed 2013). No other crops were identified and only three wild/weed seeds were recovered.

In the Iron Age, only three sites have archaeobotanical material published and all of these have yielded broomcorn millet grains to a greater or lesser extent. The first is Nadin-Gradina in Dalmatia, where millet was identified from Iron Age and Roman levels (Nye 1996). Although it is unclear from the publication which samples were dated to the Iron Age, no one sample contained more than 12 broomcorn millet grains and overall, the site yielded only 23 grains. Plant remains collected in 2010 from tumulus 14 at Kaptol-Gradci near Požega date to the Early Iron Age (Hallstatt) (Šaić 2014). In total, 3821 fruits, seeds, chaff and other plant remains were recovered. Here, only six broomcorn millet and one foxtail millet grains were identified. The site was dominated by spelt grain, followed by naked wheat and emmer. Other samples have been collected at the site, but millet was not identified

	Site name	Monkodonja	Mačkovac-Oštrovi	Mačkovac-Crišnjevi
	Reference	Kroll 2009; 2015	Reed 2013	Reed 2013
	Date	ca. 1800-1200 cal BCE		ca. 1400-1100 cal BCE
	No. of samples	64	3	25
Cereals				
Hordeum vulgare	Grain	18		
Triticum aestivum/durum	Grain			
Triticum dicoccum	Grain	15		1
Triticum dicoccum	Chaff	28		
Triticum monococcum	Grain	2		
Triticum monococcum	Chaff	4		
Triticum spelta	Grain			
Triticum spelta	Chaff			
Triticum spelta/aestivum	Grain			
Triticum spelta/dicoccum	Grain			
Triticum spelta/dicoccum	Chaff			
Triticum sp.	Chaff			1
Avena sp.	Grain	1		343
Avena sp.	Chaff	1		13
Secale cereale	Grain			
Panicum miliaceum	Grain	2	16	10
Setaria italica	Grain			4
Pulses				
Lathyrus sativum	Seed	1		
Lens culinaris	Seed			1
Pisum sativum	Seed	2		
Vicia ervilia	Seed	1		
Vicia faba	Seed	1		

Table 1. Cereals and pulses identified from Bronze and Iron Age sites in Croatia that contained millet.

(Šoštarić *et al.* 2008; 2017). The most significant site for this period is Sisak-Pogorelac, where a pot filled with over a million foxtail millet grains was recovered from the floor of a wooden building (Reed and Drnić 2016). Along with foxtail millet, around a hundred thousand broomcorn millet grains were also present, likely as a weed of the crop due to similarities in size. Work is continuing at the site and more samples are yielding both foxtail and broomcorn millet along with large numbers of broad beans and acorns (*Quercus* sp.), as well as a small number of other cereals, pulses, fruits and wild/weed species (Reed 2020).

Recent stable isotope analyses of humans and animal remains add to this evidence. In coastal Croatia, stable carbon and nitrogen isotope analyses were carried out on human and animal bones from three Bronze Age sites: Gusića Gomila, Jukića Gomila, and Brnjica (Miller 2018). Only two individuals from Brnjica showed signs of small consumption of C4 plants and/or marine foodstuffs. While in the neighbouring region of Lika, Zavodny *et al.* (2017) examined the stable isotopes of 36 human and

Orubica-Veliki Šeš	Kalnik-Igrišče	Nadin-Gradina	Sisak -Pogorelac	Kaptol-Gradići
Reed 2013	Mareković 2013; Mareković *et al.* 2015; Reed *et al.* 2021	Nye 1996	Reed, Drnić 2016; Reed 2020	Šaić 2014
ca. 1300-1100 cal BCE	ca. 1000-800 cal BCE	ca. 5th-1st century BCE	ca. 6th-4th century BCE	820-410 cal BCE
2	158		3	1
	17,475	+		5
	9576			124
	5847		24	91
	91			9
	410		8	4
				5
	2189	+		1620
	70	+		40
	6			69
	822			138
				9
		+	24	4
	71			2
	7			
1	36,931	+	104,000	6
	1037		1,342,667	1
	4973			
	12			
	9990		580	

30 faunal remains from 12 Bronze and Iron Age sites. They found no C4 signatures within the animal remains suggesting that millet (a C4 plant) was not regularly used for fodder (also Zavodny *et al.* 2019). Of the human remains, they found that most individuals appear to have eaten comparable proportions of millet, approximately 20% of the overall diet regardless of age or sex, from the Middle Bronze Age onwards (at Bezdanjača, 1430-1290 cal BCE and Veliki Vital, 1420-1295 cal BCE). As the Iron Age progresses, millet consumption increases to almost 40% of the diet at the sites of Mala Metaljka, Sultanov Grob and Trošmarija (Zavodny *et al.* 2017).

Lightfoot *et al.* (2015) demonstrated varying quantities of C4 carbon isotope signatures from the bone collagen of individuals dated to the Iron Age in Croatia, also suggesting the consumption of millet or the consumption of livestock foddered with millet. In particular, they concluded that

> '*although millet was available to individuals throughout the study area and periods, it was consumed on a significant scale only in inland Croatia during the Iron Age*' (Lightfoot *et al.* 2015).

Additionally, they identified possible differentiations in the social status at the Iron Age coastal site of Nadin-Gradina between individuals buried in pits, who produced a more pronounced C4 signature, and those buried in stone-lined graves. Research by Nicholls (2017, 311) has also shown that individuals inhabiting central/eastern Slovenia and northeastern Croatia were ingesting a high quantity of C4 plants from the Middle Bronze Age to the Early Iron Age. In addition, the study found high $\delta^{13}C$ values in cattle, sheep/goat and pig remains at certain sites, suggesting the consumption of C4 plants, probably millet.

New millet radiocarbon dates

Since the paper by Motuzaite-Matuzeviciute *et al.* (2013), pre-Bronze Age finds of millet have generally been treated with caution. Thus, the discovery of a relatively large number of foxtail millet grains within an occupation layer thought to date to an Eneolithic settlement at the site of Lasinja raised questions regarding its provenance in the deposits, *i.e.* can they be securely dated to the Eneolithic? No millet grains have been dated in Croatia before this study and four sites, with relatively secure deposits, were selected for this project. These sites were Eneolithic contexts at Lasinja, Bronze Age Mačkovac-Crišnjevi and Mačkovac-Oštrovi and Iron Age Sisak-Pogorelac. Finds of both broomcorn and foxtail millet grains were selected. Within the present study, radiocarbon dating was conducted on single millet grains at the laboratory in Poznan. The standard protocols for sample processing followed Brock *et al.* 2010 (see Filipović *et al.* 2020 for further details).

The sites

Lasinja

Since 2010, the Archaeological Museum in Zagreb has been conducting systematic excavations at the site of Lasinja-Talijanovo Brdo. The site is situated on a natural hill to the south of the Kupa River and has, so far, yielded material dated to the Copper, Bronze and Iron Ages. Due to a nearby stone quarry, the south-western part of the site has been destroyed (Balen 2013, 399). No permanent structures have been discovered at the site, except working areas in the form of pits, so it seems likely that the position was used seasonally or when local raw materials were exploited. The excavated remains of material culture fall into the known repertoire of the Lasinja culture production of pottery. The recovered vessel fragments are of poor quality, but the most numerous pottery forms include bowls and pots, as well as ceramic spoons with holes for hafting. The site also yielded many chipped stone artefacts. Only two samples (*c.* 22 litres) taken from features thought to belong to the Eneolithic phase yielded archaeobotanical remains (Reed 2017). A grain of both broomcorn and foxtail millet was taken from one occupation layer context for radiocarbon dating.

Mačkovac-Crišnjevi

Systematic excavations began at the site in 1997 by the Nova Gradiška Municipal Museum. The settlement is located 1 km north of Mačkovac, which is situated on the left bank of the Sava River, approximately 15 km south of Nova Gradiška. The settlement is elevated up to 2 m above the floodplain and covers an area of approximately 2 hectares (Karavanić *et al.* 2002). Three trenches were opened in

1997 and 1998, covering around 323m². Numerous features have been identified within the excavated area including house floors, hearths, pits and evidence of a metallurgical work area. Previously, a Bronze Age hoard was recovered at the site in 1985 and, since then, further bronze items as well as pottery and animal remains have been found (Karavanić *et al.* 2002). The identification of several bronze needles and pottery types have dated the site from the Middle to beginning of the Late Bronze Age, concurrent with the Virovitica group and culturally belonging to the Barice-Gređani group (13th-12th century BCE). Between 2000 and 2003, 28 samples (308 litres) were collected from 18 features, with 25 of those containing carbonised plant remains (Reed 2013). A grain of broomcorn millet was taken from one of the pit samples for radiocarbon dating.

Mačkovac-Oštrovi

Mačkovac-Oštrovi is a Late Bronze Age necropolis and is believed to have belonged to the nearby settlement of Mačkovac-Crišnjevi. Between 2003 and 2009, excavations were led by the Nova Gradiška Municipal Museum. The excavations revealed 73 graves, belonging to the Barice-Gređani group of the Urnfield culture (Mihaljević and Kalafatić 2006, 2009, 2010). All the graves show a similar burial ritual, where the burnt bones of the deceased were collected into a vessel which was laid into the ground upside down (Mihaljević and Kalafatić 2009). Three samples (33 litres) were collected from three different grave areas, although two (from area M10) were from two closely associated graves. Here, one grain of broomcorn millet from within one of the cremation graves was radiocarbon-dated (Reed 2013).

Sisak-Pogorelac

The prehistoric settlement located in today's town of Sisak was founded near the confluence of the Kupa and the Sava Rivers in the later phase of the Late Bronze Age, around 1000 BCE. In the Late Hallstatt period, it became a key regional centre, and its importance continued in the Late Iron Age, when the settlement was spreading along both banks of the Kupa River (Drnić and Miletić Čakširan 2014; Drnić and Groh 2018; Drnić 2020). In 35 BCE, the indigenous settlements known from the ancient sources as Segestica and Siscia were conquered by the Romans, who established a military stronghold that was gradually transformed into an important provincial city – Colonia Flavia Siscia.

Ongoing excavations at the Pogorelac site in Sisak commenced in 2012, led by the Archaeological Museum in Zagreb. In trench 1, under a thick layer of house daub, the remains of an above-ground structure that was oriented northeast-southwest was found (Structure 2). It consisted of a yellow clay floor, several irregularly shaped rock fragments and the remains of wooden beams made of oak (*Quercus* sp.). A thick layer of daub and a large amount of charcoal, together with burnt wooden architectural parts and a clay floor suggest that the structure was destroyed by fire. Some typical Late Hallstatt pottery dates Structure 2 to between the end of the 6th and 4th centuries BCE. On the surface of the floor in Structure 2, a pot full of approximately 1343,000 charred grains of foxtail millet and 104,000 broomcorn millet grains were recovered. A grain of both broomcorn and foxtail millet from the pot sample was radiocarbon dated (Reed and Drnić 2016).

Results

The results of the radiocarbon dating of the broomcorn and foxtail millet grains can be seen in Table 2. Interestingly the foxtail and broomcorn millet from Lasinja have an Iron Age date of the 4th century cal BCE. The grain taken from the secure pot sample at Sisak-Pogorelac has a 4th-3rd century cal BCE date, which corresponds

Site name	Material	Sample number	Context	Calibrated age (95.4% / 2σ hpd range)	BP age	Laboratory code
Mačkovac-Crišnjevi	*Panicum miliaceum* grain	[SJ71]	Pit	1596-1135 BCE	3120 ± 70	Poz-104900
Mačkovac-Oštrovi	*Panicum miliaceum* grain	30 [SJ55]	Fill of pot in a cremation burial	1411-1223 BCE	3055 ± 35	Poz-104921
Sisak-Pogorelac	*Setaria italica* grain	60 [SJ105]	Fill of pot in building floor	399-207 BCE	2260 ± 35	Poz-100059
Lasinja	*Setaria italica* grain	11 [SJ2]	Occupation layer	360-53 BCE	2150 ± 50	Poz-100058
Lasinja	*Panicum miliaceum* grain	11 [SJ2]	Occupation layer	341-49 BCE	2115 ± 30	Poz-104923

Table 2. New radiocarbon dates for broomcorn and foxtail millet grains at Mačkovac-Crišnjevi, Mačkovac-Oštrovi, Sisak-Pogorelac and Lasinja.

with the archaeological evidence. Mačkovac-Crišnjevi had the oldest date of 16th to 12th century cal BCE and Mačkovac-Oštrovi had a date of 14th to 13th century cal BCE. These dates place the broomcorn millet age to the Late Bronze Age.

Discussion and conclusion

The new radiocarbon dates taken from the broomcorn and foxtail millet grains from Lasinja, Mačkovac-Crišnjevi, Mačkovac-Oštrovi and Sisak-Pogorelac provide important insights into the arrival and adoption of millet in Croatia. The concentration of foxtail and broomcorn millet from a possible Eneolithic occupation layer at Lasinja dates to the Iron Age rather than the Eneolithic. This suggests that the pit may date to the Iron Age, rather than being intrusive as little material culture was found in the pit and the site had evidence of Bronze Age and Iron Age occupations. Both Mačkovac-Crišnjevi and Mačkovac-Oštrovi have two broomcorn millet grains that date to the Late Bronze Age, while the foxtail millet from Sisak-Pogorelac is consistent with the Iron Age date of the site. These dates correspond with the stable isotope evidence that suggest millet began to be consumed during the Middle/Late Bronze Age, but possibly in a minor capacity. By the Late Bronze Age, millet became a more significant part of the diet in inland Croatia, while on the coast this may not have occurred until the early Iron Age.

Millet was not the only crop to have been introduced at this time, since archaeobotanical evidence showing an increase in cultivation of spelt (*Triticum spelta*) (Akeret 2005), free-threshing wheat (such as *Triticum aestivum/durum*) and broad bean (*Vicia faba*). Within Serbia, Hungary and Croatia we also see for the first time the oil plant gold-of-pleasure (*Camelina sativa*) and safflower (*Carthamus tinctorius*) during the Late Bronze Age (Kroll 1990; Medović 2002; Gyulai 2010, 105; Reed *et al.* 2021). The mechanisms behind the adoption of these new crops is still unclear as there are many factors involved in the decision to adopt or reject a new crop variety. Current evidence restricts determination of what these driving mechanisms may have been, but they could have been associated with environmental constraints, cultivation and processing technologies, nutritional and agronomic qualities, social relationships between source and receiving regions, and cultural associations of status, ritual and culinary appeal.

One factor considered recently by Zavodny *et al.* (2017) for the cultivation of millet in the Lika region of Croatia during this period was that locals began to diversify crops to manage food security. Diversification is a strategy that can be used to minimise the risk of crop failure through the cultivation of a wide range of crops with different growing conditions. They propose that the marginal environment, with poor soil and long winters, prompted the adoption of millet by farmers in order to stagger growing seasons with a greater range of crops and thus minimise risk (Zavodny *et al.* 2017). Even during the Roman period, Strabo (5.i.12) remarks that, in the Po River valley, millet was a secure protector against famine when other crops failed. This phenomenon of increased crop varieties was also seen across western and central Europe (Bakels 1991, 2009) and the Mediterranean (Valamoti and Jones 2003). This suggests that agricultural strategies were intertwined with wider socio-economic or environmental changes that occurred during the Bronze Age.

Overall, the data from Croatia is still relatively sparse and more information is needed to understand when millet first arrived to the region and how millet cultivation and agricultural developments were integrated within other socio-economic developments.

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The earliest finds of millet and possible associated changes in material culture in Slovenia

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Abstract

We present an overview and review of archaeobotanical results on the earliest occurrence of crop plant remains from the area of what is today Slovenia, focusing primarily on the phenomenon of the appearance of millet and associated material culture in the Bronze Age and the Iron Age. In addition, we present an overview of the development of prehistoric harvesting tools and settlement patterns in Slovenia from the Neolithic to the Iron Age. Based on the available results from archaeological sites in Slovenia, the appearance of broomcorn millet and foxtail millet, together with oat, rye, lentil and faba bean, can be placed in the Late Bronze Age. In the Early Iron Age, the importance of millets increases, while the introduction of free-threshing wheat represents another agricultural innovation at this time. Just as emmer and einkorn are typical cereals of the Copper Age in the region, so millets are of the Late Bronze Age and, especially, of the Early Iron Age. Pulses were less common in the Copper Age and became more important in the Late Bronze and Early Iron Age. Barley seems to have been equally important through all of these periods. Collected wild fruits and nuts were more important for the diet during the Copper Age than during the Late Bronze Age and Early Iron Age. However, we emphasise that, the way in which archaeobotanical sampling/collecting, storing and sieving was done (if it was done at all) may have played an important role in the amount and type of results obtained. Even so, some major conclusions on the spectrum of crops used in different periods remain valid.

Introduction

Slovenia is located in southeastern Europe, along northernmost part of the Adriatic Sea, at the intersection of the Alpine, Mediterranean, Pannonian and Dinaric worlds (Fig. 1). It borders Italy to the west, Austria to the north, Hungary to the north-east and Croatia to the east and south. The topography of Slovenia is relatively diverse (including mountains, mountain plateaus, plains, valleys, karst fields, and the Adriatic coast), and the different landforms alternate over short distances. The transition between landscapes or parts of them is gradual. Due to its geographical position, Slovenia is a distinct transition country. Important transport links between Italy and central and eastern Europe have always passed through its territory. The climate is temperate, being a mixture of influences of the Alpine, Mediterranean and continental climates.

Little is known about the prehistoric plant economy (cultivation and gathering) in Slovenia, with the exception of that of pile-dwellings from the 4th millennium BCE (Copper Age). Therefore, the answers to the questions of when the first signs of cultivation appeared, where this cultivation came from and how it developed after its introduction are still incomplete. This study reviews and extends the earliest archaeobotanical data on cultivation and plant gathering in Slovenia. The aim is to provide a long-term perspective on plant-human interactions, together with archaeological information from specific sites in the area where archaeobotanical analyses were carried out, focusing on the earliest known evidence of broomcorn millet (*Panicum miliaceum*) cultivation.

The cultivation of plants (as well as the material culture) in what is today Slovenia most probably originated from the southeastern regions of the Balkans. It is also very likely that some influences arrived via the Mediterranean route, across the Adriatic Sea and from the Apennine Peninsula (*e.g.* Ihde 1995). Despite scarce archaeobotanical evidence, it is generally accepted that plant cultivation was practised in the territory of Slovenia by the Late Neolithic. The oldest flint stones with 'gloss' (referring to a characteristic shine that proves that they were used as harvesting tools) come from Late Neolithic layers (5th millennium BCE) at Moverna vas, in Bela krajina, and at Dragomelj, near Ljubljana (see Results).

Our contribution summarises archaeobotanical and archaeological evidence from Slovenia that could provide hints on when, how and why millet became one of the most common crops. The three main areas covered are the oldest ^{14}C-dated millet grains and their frequency through time; possible climatic changes in the period when millet appeared; and the oldest finds of harvest implements and their increasing efficacy through time, as a possible indicator for improving agricultural techniques.

Summary of economic activity and settlement patterns from the Neolithic to the Iron Age in Slovenia

The Neolithic in Europe was characterised by some major changes in the way people lived. They settled in permanent settlements, and agriculture and the keeping of livestock became the main economic activities. They cultivated cereals and pulses and raised animals, such as sheep, goats, cattle and pigs. The production and use of ceramic vessels was extremely important because the ability to cook foods radically changed eating habits. Easier access to food led to population growth and an incipient division of labour, while surplus production boosted trade, all of which led to social stratification (*e.g.* Bogaard and Styring 2017).

The territory of present-day Slovenia was influenced by the developing Neolithic cultures that surrounded it. The interior and the eastern part of Slovenia were connected with the Pannonian Basin, whereas the Karst and the Slovenian coastal area were connected with the eastern Adriatic coast and thus indirectly with the Mediterranean Sea. In western Slovenia, traces of Neolithic settlement have been found mainly during excavations of karst caves, while in central and eastern Slovenia settlement traces have been found either on the plain, on river terraces, at river bends or on naturally protected elevations (Guštin 2005). The settlement of Gradec, near Mirna, occupied in the middle of the 5th millennium BCE, was protected by a stone wall (Dular *et al.* 1991, 84-90, 119-128, 140-142). The first pile-dwelling settlement appeared on the shore of the lake in what is now known as the Ljubljansko barje [the Ljubljana wetlands] (Velušček 2006).

The first metal age was the Copper Age, also known as the Eneolithic. In addition to stone, horn and bone tools and weapons, copper objects appeared in small quantities. The first finds related to copper metallurgy in Slovenia date back to the middle of the 4th millennium BCE. The objects in question are a piece of copper slag and fragments of crucibles from the wetland pile-dwellings of Hočevarica (Šmit 2004), Maharski prekop (Velušček and Greif 1998, 31-33) and Stare gmajne (Velušček 2009, 18-25). Copper metallurgy experienced a real heyday in the first half of the 3rd millennium BCE. The so-called Dežman pile-dwellings, near Ig, produced numerous copper objects (awls, daggers, axes) and, even more importantly, typical metallurgical accessories, such as moulds, crucibles and clay blowpipes, which indicate the local production of copper objects there (Korošec and Korošec 1969). Compared with the Neolithic, Slovenia showed a much denser settlement pattern in the Copper Age. Settlements developed in a similar environment as in the Neolithic period, and pile-dwelling settlements flourished in the Ljubljansko barje.

Little is known about the settlement pattern of Slovenia in the Early Bronze Age. At that time, the pile-dwelling culture in the Ljubljansko barje declined, while the Prekmurje plains were relatively densely populated, as recent research has shown (Šavel 2009; Kerman 2011a-c; Guštin, Tomaž 2016; Pavlin 2015; Guštin *et al.* 2017). Both regions belonged to the same cultural area, which was characterised by the so-called Litzen pottery.

In the Middle Bronze Age, the Karst and Istria experienced the rise of the Kaštelir culture, which continued uninterrupted into the Iron Age. The culture is named after the *kaštelir*, a settlement fortified with stone walls. The Štajerska (Styria) region was part of the central European Tumulus culture, which was characterised by tumulus burials. The territory of Slovenia was at that time a transit zone on the trade route between Italy and the Danube Basin, as indicated by the characteristic sword and sickles found by a chance in the riverbed of the Ljubljanica (Pavlin 2006; Turk *et al.* 2009, 228) and by the short sword from Lavrica (Šinkovec 1996, 143, Fig 21.1).

Towards the end of the 14th century BCE, Europe experienced great changes related to the mass migrations of peoples. These caused the collapse of the Mycenaean culture in Greece, the Hittite kingdom, and numerous cities in the Middle East. The so-called Sea Peoples pushed as far as Egypt, where they were defeated by Rameses III.

Because of the nature of the burials at this time, the Late Bronze Age is also known as the Urnfield period. Central and eastern Slovenia were inhabited by people who cremated the deceased and buried their remains in urns in flat necropolises. They belonged to the cultural sphere that stretched from western Hungary, through Croatia to northern Bosnia.

In the Late Bronze Age in central and eastern Slovenia, settlements were located on naturally protected, elevated terrain, which was additionally fortified with wooden palisades. Recent excavations during the construction of motorways in northeastern Slovenia have revealed numerous lowland Bronze Age settlements along the rivers Drava and Mura (Dular 2013, 101-110, Figs. 44-48). The shape of these settlements, their spatial context, and the construction of their houses are illustrated by the following examples.

Near Orehova vas, there was a settlement on the plain, by a stream. Here, 27 floor plans of buildings were discovered, which had been built using earth-fast construction (Grahek 2015, 29-41, 349). The scattered settlement of Oloris was surrounded by a moat, over which a wooden fence stood. The walls of the houses consisted of upright beams carrying interwoven wattle and daub. The houses had a fireplace and a storage pit under the floor (Dular *et al.* 2002, 23-46). The settlement of Ormož had a slightly different kind of protection. In the south, it was protected by the river Drava, while the other three sides were surrounded by a dike and an earthwork. Inside the settlement, a network of roads up to 4 m wide and paved with gravel were documented. These streets were lined with houses of different sizes. They were built in the same way as at Oloris (Dular and Tomanič Jevremov 2010, 83-97). Excavations at the Tribuna site, in Ljubljana, have also brought to light a settlement from the Late Bronze Age (10th-8th century BCE) with an urban design. It consisted of houses of different sizes, also variously spaced, built in earth-fast construction. The houses were arranged in a grid, and the streets between them were paved (Vojaković *et al.* 2011, 26-31).

Contacts with the Mediterranean region also brought knowledge related to iron metallurgy. This and the abundance of easily accessible limonite iron ore formed the basis for the establishment of iron production towards the end of the 9th century BCE, which is thus taken as the start of the Iron Age locally. For a brief insight into Iron Age settlement, we can use data from the most researched region, Dolenjska. Here, new settlements were established either in the vicinity of older Urnfield settlements, which slowly died out, or in previously uninhabited areas. As a rule, they stood on elevated ground and were fortified by 2-3 m thick stone walls that followed the shape of the terrain. The walls were built using the dry-stone wall technique, from unworked stone blocks, and reinforced with vertical wooden beams driven into the ground. They were built in one go, and some were later repaired or supplemented. The surface areas of the settlements differ in size, from just a few to more than 10 ha. With an area of about 20 ha and 2.3 km long walls, Cvinger, near Vir, which is near Stična, was a real metropolis for that time. The houses were built in two ways. In the first method, which was adopted from the Bronze Age, upright posts were driven into the ground (earth-fast construction). In the second method, the upright posts were not driven into the ground, but stood on a horizontal beam (post-pad construction). This was laid on the bare earth or, sometimes, on a stone drainage bed. The floors of the houses were made of beaten clay. Near one of the walls was the fireplace, around which the kitchen equipment was arranged: ceramic vessels, hand mills for grinding grain, firedogs, clay rings and coils. The weights hanging on strings testify that looms were also among the household items (Gabrovec 1994).

The settlement with an urban character at Most na Soči, right on the border with Italy, was different. It stood on a naturally protected plateau above the confluence of two rivers. On the third side, access was protected by a stone wall. The houses were located on a sunny slope. They stood in rows along cobbled streets lined with ditches and canals. They had a stone foundation on which a wooden structure of horizontal and vertical beams and planks stood (Svoljšak and Dular 2016).

Short history of archaeobotanical investigations in Slovenia

The investigation of fossil plant macro-remains from archaeological sites is considered to have started relatively early in Slovenia, *i.e.* when the first pile-dwelling site in the Ljubljansko barje region was discovered, in 1875. The first results on its rich archaeobotanical remains, with a focus on wooden piles, were published soon after (Deschmann 1875, 1878). Since then, archaeobotanical reports from pile-dwellings have been common, but only isolated (occasional) plant macro-remains were collected during the excavations prior to 1998 (Schmid 1910, 1915; Korošec 1953; Šercelj 1981-1982; Culiberg 1984). The wet-sieving technique was first tested in Slovenia in 1989, at the Palaeolithic cave site of Divje Babe I (Turk 2007), where mainly charcoal fragments were extracted (Culiberg 2007). Thereafter, the flotation method was used at some other archaeological sites, *e.g.* at the Early Iron Age sites of southeastern Slovenia (Culiberg and Šercelj 1995; Dular and Tecco Hvala 2007).

Finally, in 1998, the wet-sieving method was employed at a waterlogged site as well – the Hočevarica pile-dwelling site (Velušček 2004). Thanks to the excellent preservation through waterlogging, the results for this site were outstanding (Jeraj 2004; Jeraj *et al.* 2009). In 2007, the method was supplemented with the semi-flotation technique, based on the Swiss model (Tolar *et al.* 2010). The first application of this method was at the Stare gmajne pile-dwelling settlement with rich assemblage of waterlogged plant material (Tolar *et al.* 2011). Since then, 6 cultivated and more than 20 gathered plant taxa have been regularly identified at the lake dwellings of the Ljubljansko barje (4th-3rd millennium BCE; Copper Age), which is comparable to the plant spectrum at other circum-Alpine lake dwellings (Tolar *et al.* 2011, 2016; Tolar 2018a).

Nowadays, most excavations in Slovenia use wet-sieving techniques and various methods of sampling (*i.e.* profile, systematic and judgement; Andrič *et al.* 2016, 62-65). On dry-land sites, plant remains are poorly preserved and mostly charred; charcoal predominates. Unfortunately, careful extraction of archaeobotanical remains is still not a standard, as some archaeologists do not pay enough attention to field sampling and subsequent proper processing of archaeobotanical sediment samples (*i.e.* fine wet sieving with semi-flotation using smaller than 2 mm mesh size). The loss of fragile and small seeds, such as millet grains, is certainly a consequence of negligence. Therefore, there is a great potential to find earlier archaeobotanical evidence of agriculture in Slovenia, especially given the geographical location of its territory.

Materials and methods

The main method used in this study is a review of archaeobotanical and archaeological investigations of selected prehistoric sites in Slovenia. We focused on the earliest evidence of cultivated plants and related agricultural tools, such as harvesting knives. We consider 14 sites in the archaeobotanical part of this study (Table 1; Fig. 1) and we include some additional ones in the archaeological review. They were selected according to the earliest absolutely dated evidence of crop macro-remains and the accessibility of archaeological and archaeobotanical data.

Data sources and study sites

The dataset on archaeological features and archaeobotany comes from existing publications and from manuscripts that are in preparation for publication. We have summarised our own results, including those unpublished (Archive of the Institute of Archaeology ZRC SAZU). Unfortunately, the quantification of the archaeobotanical results is not comparable, because some datasets are presented as absolute numbers of plant remains in an unknown amount of sediment, some as concentrations per litre of sediment, some as grams, and some as frequencies (see Table 2). The main objective is to make an inventory of the earliest finds of cultivated and gathered plant remains, focusing on the appearance of millet.

To track the earliest (Copper Age) absolutely dated traces of plant cultivation (remains of *e.g.* barley and wheat) in Slovenia, this study considers two different site types – dry-land and waterlogged. At the dry-land cave site of Ajdovska jama, excavated several times and over many years (from 1884 to 1990), less reliable archaeobotanical results from older excavations are available. Five cultural horizons were defined here, from the Late Neolithic to the Middle Ages, by different excavators (Horvat 1989; Culiberg *et al.* 1992 and references therein). The second horizon, radiocarbon dated to 5625±130 BP (after Culiberg *et al.* 1992) was determined to be the most intensively visited – the cave was used as a cemetery and ritual site in this period. At the time of the early excavations, flotation and wet sieving were not yet established and the recovered archaeobotanical material is scarce. In this study, we refer to a ^{14}C-dated

Table 1. The 14 sites with archaeobotanical data considered in this study (excavation years noted in parentheses).

Copper Age	Late Bronze Age	Early Iron Age
Ajdovska jama (1884, 1938, 1967, 1982-1990)	Dragomelj (1997, 2000-2001)	Six sites in southeastern Slovenia (1990-2000)
Strojanova voda (2012)	Orehova vas (2006-2007)	Ljubljana-Tribuna (2008)
Stare gmajne (2007)	Grosuplje (2011)	Most na Soči (1971-1984)

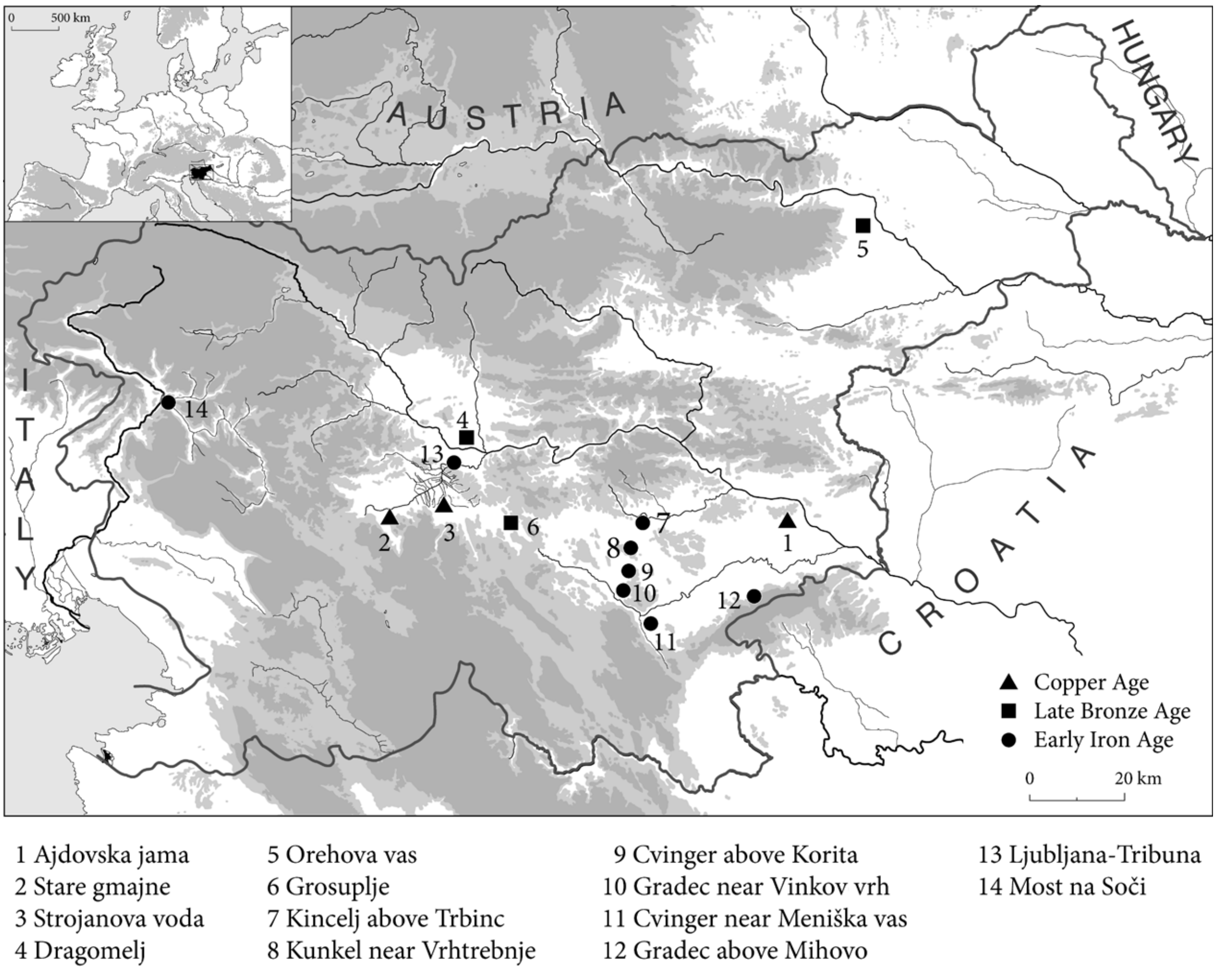

Figure 1. The location of archaeobotanically-studied sites mentioned in the text. The six Early Iron Age sites in southeastern Slovenia are those marked with numbers 7-12.

stratigraphic unit (labelled SE43), where most of the cultivated plant remains were found and identified (see Table 2). It yielded from 1 to 1050 carbonised grains of crop plants in an unknown amount of sediment. The frequencies of the seeds are listed in Table 2; for the original absolute numbers of seeds/fruits, see Culiberg *et al.* (1992).

The second-earliest crop cultivation sites so far recorded are the two waterlogged Copper Age pile-dwelling sites of Strojanova voda and Stare gmajne. Both were recently investigated and examined with fine flotation methods, using up to 0.355 mm mesh size (see Tolar *et al.* 2010). The results are representative and reliable, expressed in seed/fruit concentrations per litre of sediment sample (Table 2; Tolar *et al.* 2011; Tolar 2018a).

The earliest archaeobotanical evidence of millet cultivation in Slovenia comes from three locations, all from the 12th century cal BCE (Late Bronze Age): Dragomelj, Orehova vas and Grosuplje (Turk and Svetličič 2005; Tolar (in Grahek 2015); Archive of the Institute of Archaeology ZRC SAZU).

For the 'post-millet appearance' period, this study considers the Early Iron Age sites from southeastern Slovenia: Cvinger near Meniška vas; Kunkel near Vrhtrebnje; Kincelj above Trbinc; Gradec above Mihovo; Cvinger above Korita; Gradec near Vinkov vrh (Culiberg, Šercelj 1995; Dular and Tecco Hvala 2007); Ljubljana-Tribuna (available from the Archive of the Institute of Archaeology ZRC SAZU; Vojaković *et al.* 2011); and Most na Soči (Tolar 2018b) (see Table 2; Fig. 1). Numerous other sites either have been archaeobotanically analysed but not yet published due to the limited results and/or absence of absolute-dated archaeobotanical remains (Archive of the Institute of Archaeology ZRC SAZU).

Results and discussion

Overview of the archaeobotanical finds of cultivars in Slovenia from the Late Neolithic to the Early Iron Age

Before the appearance of millet

Wild plants were used throughout Slovenia during and after the Stone Age (Culiberg 1999, 2011). The earliest absolutely dated macro-remains of cultivated plants in Slovenia are naked and hulled barley (*Hordeum vulgare*), einkorn (*Triticum monococcum*) and emmer (*Triticum dicoccum*). They were found at pile-dwelling settlements of the Ljubljansko barje (4th millennium cal BCE) and in the Ajdovska jama cave (5th-4th millennium cal BCE) (Table 2; Culiberg *et al.* 1992; Jeraj *et al.* 2009; Tolar *et al.* 2011; Tolar 2018a).

The earliest plant cultivation in dry locations in Slovenia is poorly understood. An example is the cave cemetery of Ajdovska jama, which was in use from the Late Neolithic onwards and where large assemblages of macro-remains of cultivated plants (such as wheat and barley) were discovered, but which were unfortunately insufficiently documented in terms of stratigraphy and chronology (Culiberg *et al.* 1992). This could be the site with the earliest evidence of plant cultivation in Slovenia. Barley and wheat predominate, but there are also remains of oat (*Avena sativa*) and faba bean (*Vicia faba*) that were not radiocarbon dated.

Dating to the well-researched Late Neolithic, Copper Age and Early Bronze Age (*i.e.* 4600-1700 cal BCE), the waterlogged pile-dwelling sites of the Ljubljansko barje provided a lot of representative data on plant, animal and cultural material. Most of the results come from the 4th millennium BCE (Copper Age) sites, where the cultivation of emmer, einkorn, barley (both naked and hulled), flax (*Linum usitatissimum*), pea (*Pisum sativum*) and opium poppy (*Papaver somniferum*), as well as the domestication of dog, sheep, goat, cattle and pig, has been established (*e.g.* Toškan and Dirjec 2004; Tolar *et al.* 2011). Archaeobotanical results from younger (3rd and 2nd millennium BCE) pile-dwellings are sparse due to the unsuitable recovery methods used prior to 2007 (Tolar *et al.* 2010) and because, subsequently, no excavations have been carried out of the youngest pile-dwelling sites.

Well-dated plant remains from pile-dwellings in Slovenia indicate a continuous cultivation of six crops from at least about 4000-3100 cal BCE (Tolar 2018a; Tolar *et al.* 2011). Even older pile-dwellings in the area of the Ljubljansko barje are known, such as the site of Resnikov prekop, from 4600 cal BCE (Velušček 2006), but with so far no crop macro-remains from this period, likely due to the taphonomic effect of the fluctuating nearby river (Culiberg 2006). It is assumed that plant cultivation in the Ljubljansko barje must have already started in the 5th millennium BCE.

There is a gap in knowledge on the use of plants in Slovenia for the period 1700-1200 cal BCE. Plant macro-remains from this period are poorly preserved (they come from dry sites), and archaeobotanical studies are rare and lacking in information.

	Copper Age		
Date or time-span	4356-3995 cal BCE	4000 cal BCE	3300 cal BCE and 3100 cal BCE
Site	**Ajdovska jama, cave cemetery; SE43**	**Strojanova voda, pile dwelling**	**Stare gmajne, pile dwelling**
Taxon / *measure of quantity*	*frequency*	*avg. concentration per 1 L of sediment in CL*	*avg. concentration per 1 L of sediment in CL*
Hordeum vulgare	1326	155	102
Triticum monococcum	3049	116	24
Triticum dicoccum	792	142	150
T. durum/turgidum/aestivum	2		
Cerealia	82		
Avena sativa	2		
Avena/Secale			
Avena/Bromus			
Secale cereale			
Papaver somniferum		820	635
Linum usitatissimum		32	75
Pisum sativum			1
Panicum miliaceum			
Sinapis arvensis			
Setaria italica			
Panicum/Setaria			
Lens culinaris			
Vicia faba (fragments)	1		
Lathyrus sativus			
Solanum sp.			1
Physalis alkekengi		115	14
Fragaria vesca		226	92
Rubus idaeus			1
Rubus fruticosus agg.		375	60
Cornus mas		13	1
Cornus sanguinea		4	1
Corylus avellana (fragments)		3	6
Juglans regia (fragments)			
Quercus sp.		33	92
Trapa natans		6	3
Sambucus sp.		550	1
Prunus sp.			1
Maloideae		56	141
Crateaegus sp.		6	2
Vitis vinifera sylvestris		2	1
REFERENCES	Culiberg ***et al***. 1992	Tolar 2018a	Tolar ***et al***. 2011
Notes about the dates	date cited after the reference	radiocarbon and dendro-date	radiocarbon and dendro-date

Table 2. Overview of the archaeobotanical evidence through time from Slovenia.

Late Bronze Age			Early Iron Age		
1190-900 cal BCE	1190-900 cal BCE	1130-970 cal BCE		1000-400 cal BCE	
Dragomelj	**Orehova vas**	**Grosuplje**	**sites in south-eastern Slovenia (7-12 in Fig. 1)**	**Ljubljana-Tribuna**	**Most na Soči**
absolute number of grains/seeds	*absolute number of grains/seeds*	*absolute number of grains/seeds*	*absolute number of grains/seeds or, where presented as words, an estimate*	*absolute number of grains/seeds*	*weight or absolute number of grains/seeds*
160	1	2	a lot	76	
			some		
1				1	
			63	7	
81	17	2		60	56.63 g of porridge + 5 g of food remains
			9		
					55.37 g of porridge
86					
32			1		
			2		
1			1	3	
80	34	258	many	120	37.12 g
			many		
8			some	28	52.74 g of porridge
3					70 g of food remains
10	5	5	38	78	
1			6	3	5
				1	
				2	
				3	
				1	
				279	
			13	4	
			10	5	
10		2		8	4
					2
				6	
1			4	17	
				1	
1					
Tolar unpublished data	Tolar data published in Grahek 2015	Tolar unpublished data	Culiberg and Šercelj 1995	Tolar and Vojakovič unpublished data	Tolar 2018b
radiocarbon date	radiocarbon date	radiocarbon date		radiocarbon date	

Site	^{14}C AMS-date on single (individual) millet grains	Overall quantity of millet grains in the dated deposits
Dragomelj	1192-919 cal BCE (95.4%) [Poz-104925, Poz-104926, Poz-104927]	Altogether 14 grains in two buildings
Orehova vas	1193-923 cal BCE (95.4%) [Poz-104924, Poz-104985]	A total of 25 grains from a fireplace
Grosuplje*	1134-971 cal BCE (83.1%) [Poz-45566: 2880 ± 35 BP]	More than 200 grains in a pit ('pithos')

*Table 3. Calibrated radiocarbon dates of carbonised millet grains from three Late Bronze Age sites in Slovenia (for the original data see Filipović et al. 2020; *details on the date for Grosuplje are kept in the Archive of the Institute of Archaeology ZRC SAZU).*

Appearance of *Panicum miliaceum* in Slovenia

The earliest finds of millet grains from Slovenia are known from three sites; they were all radiocarbon dated (Table 3).

In addition to millet, the Late Bronze Age inhabitants of Dragomelj cultivated nine more cultivars: barley, emmer, other wheats (*Triticum* ssp.), oat, rye (*Secale cereale*), pea, foxtail millet (*Setaria italica*), lentil (*Lens culinaris*) and faba bean. Wild plant gathering seems to have played a less important role, since only three wild plant taxa were recovered: hazel (*Corylus avellana*), elder (*Sambucus* sp.) and grape vine (*Vitis vinifera* ssp.) (Table 2). The sites of Orehova vas and Grosuplje show an absolute predominance of broomcorn millet (Table 2), signalling that it was already a very important, if not the main crop at that period.

After the appearance of millet

The Late Bronze Age and Early Iron Age can be considered as periods of agricultural expansion in Slovenia. The plant macro-remains from the Early Iron Age settlement at Most na Soči show that broomcorn millet and foxtail millet were already two of the main crops in that period. The charred remains of prepared food, *i.e.* porridge, from those two cultivars as well as from cereals (*Triticum* sp., wheat and *Avena/Secale*, oat/rye), were also found in two Early Iron Age houses at Most na Soči (Tolar 2018b). The find of charred crust resembling porridge has parallels in the find at the Late Bronze Age site of Stillfried, in Lower Austria (Kohler-Schneider 2001). There, the analysis showed a mixture of millet, barley and rye brome (*Bromus secalinus*) – a weed species that was probably tolerated, and therefore not removed, because of its nutritional value. The composition of the find from Most na Soči (Fig. 2) corresponds well to the one described from Stillfried. In addition to the remains of millets and wheats, legumes (*i.e.* faba bean) and two gathered plant taxa (hazelnut and walnut (*Juglans regia*)) were also recognised at Most na Soči (Table 2).

At all of the six Early Iron Age sites from southeastern Slovenia considered in this study (Fig. 1), systematic sampling and wet sieving of sediments was carried out, representing the second time this had been done in Slovenia (the first time was at the Palaeolithic cave site of Divje Babe I; see Introduction). Systematic excavations were carried out at these sites for more than ten years, starting in the early 1990s, under the supervision of J. Dular from the Institute of Archaeology ZRC SAZU, in Ljubljana (Dular and Tecco Hvala 2007). Colleagues from the Institute of Biology ZRC SAZU carried out the identification of plant macro-remains recovered with the 'initial flotation method' (Culiberg and Šercelj 1995), with which only larger and more resistant charred grains of cultivated plants were obtained (Dular and Tecco Hvala 2007, 30-31). They found that there are no significant differences between the crop spectra at the investigated Late Bronze Age and Early Iron Age sites in southeastern Slovenia. The species they identified were hulled and free-threshing wheats (*Triticum monococcum/dicoccum*, *T. aestivum/durum/turgidum*), barley, broomcorn millet, foxtail millet, flax, oat, rye, pea, faba bean, lentil and other Fabales (*e.g.* vetch (*Vicia* sp.)); they are all represented in both periods. The frequencies of plant remains differ between the periods, but the small sample and non-systematic recovery preclude any definite conclusions (Dular

Figure 2. Food remains ('porridge') from House 6 at Most na Soči made of foxtail millet (Setaria italica) *and other cereals (after Tolar 2018b, 448, Fig. 2).*

and Tecco Hvala 2007, 209). In any case, it could be stated that among the cereals at these sites, free-threshing wheats prevail, oat and rye are also present, but hulled wheats are almost absent (Table 2). Free-threshing wheat is more productive and highly nutritious, and its flour can be used for making leavened bread. Therefore, its increased presence may be related to a change in culinary practices (Megaloudi 2004, 155). Further, in comparison with hulled wheat, cultivation of free-threshing wheat requires a higher labour input and may reflect more intensive agricultural practices and perhaps also increased population density. Once harvested, however, its processing is easier and faster than that of other prehistoric cereal crops (Nesbitt 1995, 74). Among the gathered plants, only three taxa were recognised at Early Iron Age southeastern Slovenian sites (Table 2): blackberry (*Rubus fruticosus*), raspberry (*Rubus idaeus*) and elderberry (*Sambucus nigra*).

Tribuna is a multi-phase archaeological site in Ljubljana and, among the Early Iron Age sites discussed here, one of the most recently excavated (in 2008). It has layers from the Late Bronze Age (ca. 1100 cal BCE), from the Iron Age to the Roman period, and from modern times. Lots of sediment samples from all four phases were wet sieved, but they were subsequently dried, which caused some loss of fine and fragile plant macro-remains, a factor that should be taken into account when interpreting the archaeobotanical results. The Early Iron Age settlers at Tribuna consumed different kinds of cereals (barley and wheats), legumes (lentil, faba bean, grass pea (*Lathyrus sativus*) and pea) as well as foxtail and broomcorn millet. The last seems to have been very important (see Table 2). Additionally, ten possibly gathered plant taxa were recognised, but except for raspberry, in smaller quantities (Table 2).

Possible climatic changes in Slovenia and adjacent areas in the Bronze Age

Very few palaeoclimatological studies are available for Slovenia and environs. It can be assumed that there were significant differences in past climatic conditions between the regions south and north of the Alps as well as between different altitudes within the Alps, where vegetation is sensitive to climatic fluctuations. Badino *et al.* (2018) have recognised a cold phase in the period ca. 2000-1500 cal BCE in the western Italian Alps. They have reconstructed temperatures suggesting a temperature decrease of

1.8 °C compared with the previous period. On the other hand, glaciers in the Alps experienced a reduction in size (making them smaller than today), during most of the Holocene and until ca. 2000-1000 cal BCE (Ivy-Ochs *et al.* 2009; Solomina *et al.* 2015), indicating melting due to warmer conditions. Badino *et al.* (2018) also detected a warm peak around 1280-1150 cal BCE. In Italy, there are additional indicators of a warm and dry environment during the Bronze Age (*e.g.* Mercuri *et al.* 2012), but this may not apply to neighbouring Slovenia (Andrič *et al.* 2017) or, if it does, can only be proposed for lowland regions in eastern and southern Slovenia.

Few studies so far have focused on environmental changes in the southeastern Alps. A 12 m-long core from the central part of Lake Bohinj, in northwestern Slovenia, reflects environmental conditions and human-environment interactions over the past 6600 years (Andrič *et al.* 2020). It has been suggested that at ca. 6000 cal BP, Lake Bohinj was surrounded by mixed forest (of conifers and deciduous oak (*Quercus*)). Beech (*Fagus*) became dominant after ca. 1300 cal BCE. In the Bronze Age and especially in the Iron Age (1500-500 cal BCE), when the region was densely populated, anthropogenic clearing of forest is detected. It is evident that, around 1000 cal BCE, river floods were not as common as before, but the proportion of beech did not fall, which means there was no increase in aridity, unlike what was documented in the marine core from the central Adriatic (Mercuri *et al.* 2012). The pollen record from that core shows a gradual, irreversible trend towards increasing aridity from ca. 3700 cal BCE and less cool conditions from around 3100 cal BCE. The reduction in precipitation has also been evidenced before and during the Early Bronze Age (ca. 1900-1600 cal BCE; Mercuri *et al.* 2012).

Archaeological evidence: Harvesting tools from the Mesolithic to the Late Bronze Age

Harvesting tools appeared at the same time that agriculture emerged. The predecessor of the sickle is the harvesting knife. Such knives are comprised of flat or slightly curved bone or wooden handles with a groove into which quartz wedges are glued with resin (Fig. 3.1-5). A characteristic shine (knowns as sickle gloss; German: *Sichelglanz*) is visible on the working edges of the wedges, which proves that they were used as harvesting tools. That this shine is the result of friction that occurs when cutting grass or harvesting cereals has been confirmed through experiments (Steensberg 1943, 10 f.; Unger-Hamilton 1988; Juel Jensen 1996; Petru 1997, 97; Anderson 1999). The oldest preserved harvesting knives belong to the Mesolithic Natufian culture in Palestine (Fig. 3.1). Variously shaped Neolithic harvesting knives are known from Egypt (Fig. 3.2), Asia Minor, Cyprus, the Balkans (Fig. 3.4), and pile-dwellings in Italy (Fig. 3.3) and Switzerland (Fig. 3.5) (Steensberg 1943, 126; Mellaart 1961, 45, Pl. 4a; Müller-Karpe 1968, 509; Rageth 1974, 193, Fig. 12, Pl. 103.1-3, Pl. 118.5; Egloff 1984, 64, Fig. 19; Perini 1987, 395, Fig. 186; Speck 1990, 262, Fig. 13; Ramseyer 2000, 218, Fig. 178; Gurova 2005).

The first Neolithic sickles, which have a concavely curved blade, originate from Mesopotamia. They were made of very hard, fired clay. The sharp edge is finely serrated (Fig. 3.6) (Steensberg 1943, 133). No completely preserved Neolithic sickles are known from central Europe. However, a reconstruction of the appearance of a Late Neolithic sickle is made possible by finds from two sites in northwestern Switzerland (Fig. 3.7). The stone wedge was found on the island of Werd, near Eschenz (Hasenfratz 1985, 110), and the wooden handle on the site of Niederwil-Egelsee, which belongs to the Pfyn culture (Pfahlbauquartett 2004, 49, cat. No. 45).

Sickles have been used in Egypt since at least the 1st Dynasty. A set of quartz wedges (Flinders Petrie 1891, 12, 54; Müller-Karpe 1968, 409) was inserted into a curved wooden handle, which may have consisted of one or more parts (Fig. 3.8-9).

Figure 3. Harvesting tools from the Mesolithic to the Late Bronze Age. 1. Kebara; 2. Fajum; 3. Lago di Ledro; 4. Karanovo; 5. Egozwill 3; 6. unknown site in Mesopotamia; 7. Eschenz-Island Werd and Niederwil-Egelsee; 8. Sakkara; 9. Kahun; 10. Barche di Solferino; 11. Fiavé; 12. Dunaújváros-Kosziderpadlás II; 13. Senomaty; 14. Balaton area (after: 1 – Mellaart 1961; 2, 5, 8 – Müller-Karpe 1968; 3 – Rageth 1974; 4 – Gurova 2005; 6 – Steensberg 1943; 7 – Pfahlbauquartett 2004; 9 – Flinders Petrie 1891; 10-11 – Perini 1987; 12 – Mozsolics 1967; 13 – Chvojka et al. 2017; 14 – Angeli and Neuninger 1964). For the scale of individual objects, see the cited literature.

Such sickles are also depicted in frescoes with harvest scenes on the walls of tombs (Müller-Karpe 1974, Pl. 40.8, Pl. 47, Pl. 49.9, Pl. 60.3, Pl. 75.3, Pl. 78.3, Pl. 81.3, Pl. 96.5). In northern Italy, sickles similar to the Egyptian ones are known; these are referred to as sickles *a mandibola* (Fig. 3.10) and sickles of the Fiavé type (Fig. 3.11). They were in use until the Middle Bronze Age (Perini 1987, 395, Figs. 185-186, 1988, 59).

At the beginning of the Middle Bronze Age, the first bronze sickles joined the sickles with stone blades. Bronze tanged sickles are typical for southeastern Europe at this time. As the Dunaújváros-Kosziderpadlás II and Senomaty hoards show, the first sickles had a flat tang (Fig. 3: 12-13). The sickle from the former hoard is one of the few made for use with the left hand, and the sickle from the latter was made for use with the right hand (Mozsolics 1967, 135, Pl. 49: 10; Chvojka *et al.* 2017, Pl. 78: 17). At the beginning of the Late Bronze Age, bronze sickles with two to six vertical ribs on the tang (Fig. 3: 14) began to appear in the hoards *en masse*. We encounter them until the beginning of the Iron Age, and then they disappear. They are replaced by similarly shaped iron sickles with a flat tang. Whereas the number of tanged sickles from the Bronze Age reaches into the thousands, the number from the Early Iron Age is only a fraction of that. Whether this is due to the state of research or something else is a question that cannot be answered at the moment.

In Slovenia, the oldest flint pieces with gloss come from the Late Neolithic layers (5th millennium BCE) of the site of Moverna vas, in Bela krajina, located on a riverbank (Petru 1997, 89), and from the settlement of Dragomelj, near Ljubljana, located on a plain. At Dragomelj, up to 15% of the flint pieces show signs of having been used in harvesting (Petru 2005, 82, Fig. 4; Turk and Svetličič 2005; Turk and Turk 2019, Fig. 139). Of similar age are the three flint pieces with gloss from the settlement of Kamna gorica, near Ljubljana, also located on a plain (Petru pers. comm.).

From the Copper Age, we know of the flint pieces with gloss from the Trhlovca cave, near Divača (Petru 2004, 202), and from the pile-dwelling settlement of Hočevarica, in the Ljubljansko barje (Velušček 2004, 5, Fig. 34.1.34). Two flint pieces from the multi-period settlement of Col 1, situated on a plain near Podgračeno, in the Dolenjska region, are dated to the transition from the Neolithic to the Copper Age (Petru 2020, 104 no. 214, 105 no. 235). Due to the unclear stratigraphic situation, it is not known whether the flint piece with gloss from the Mala Triglavca cave, near Divača, dates to the Neolithic or to the Bronze Age (Petru 2004, 201).

Three completely preserved, left-handed metal sickles found in the Ljubljanica River belong to the Middle Bronze Age (Pavlin 2006, 79-76, Fig. 2.1a-3b). They can also be interpreted as gifts to the gods. No hoards are known from the Middle Bronze Age. In contrast, more than 60 hoards are known from the Late Bronze Age. Sickles, either entire or fragmented, are present in about three quarters of the hoards, and their combined number exceeds 300. Traces of hammering and sharpening prove that they were used primarily as harvesting tools. In addition to being found in hoards, they are found as individual finds both in and outside settlements (Teržan 1995). Particularly noteworthy is the Tribuna site, in Ljubljana. Among other things, at least three fragments of sickles were found there (Vojaković pers. comm.).

Summary and conclusions

Based on the available results from archaeological sites in Slovenia, the appearance of broomcorn millet and foxtail millet, together with oat, rye, lentil and faba bean, can be placed in the Late Bronze Age. In the Early Iron Age, the importance of millet increases, while the introduction of free-threshing wheat represents another agricultural innovation at this time. Just as emmer and einkorn are typical cereals of the Copper Age in the region, so millets are of the Late Bronze Age and, especially, of the Early Iron Age. Pulses were less common in the Copper Age and became more important also in the Late Bronze Age and Early Iron Age. Barley seems to have been equally important through all of these periods. Collected wild fruits and nuts were more important for the diet during the Copper Age than during the Late Bronze Age and Early Iron Age. However, the way in which archaeobotanical sampling/collecting, storing and sieving was done (if it was done at all) may have played an important role in the amount and type of results obtained, especially from excavations prior to 2007. Therefore, the identified remains only give a general impression of the staple crops used at the studied sites.

According to some recent reviews of the Bronze Age archaeobotanical finds from Europe (Stika and Heiss 2013; Filipović *et al.* 2020), broomcorn millet became a major (or even main) crop during the transition from the Middle to the Late Bronze Age. In Slovenia, the same phenomenon may be present, but the scarce archaeobotanical research, especially for the period between 2300-1200 BCE, cannot yet confirm the occurrence of millet before the 12th century BCE. The earliest finds of millet from neighbouring countries date from the Middle Bronze Age, namely to the 16th or 15th centuries BCE in Italy, Hungary, Croatia and to the 15th century BCE in Austria (Filipović *et al.* 2020). Both possible millet transition routes (via the Balkans or the Apennines or both; see Introduction) would thus allow for the possibility of an even earlier arrival of millet in Slovenia.

The crops introduced in the Late Bronze Age and later, in the Iron Age, were probably all used mainly for the preparation of porridge (see Fig. 2) and flat bread, and they are all quite resistant to unfavourable climatic conditions. For Slovenia, there is limited palaeoclimatic evidence for this period (Andrič *et al.* 2017, 2020). The pollen record from the marine core from the central Adriatic (Italy) shows a gradual, irreversible trend towards increasing aridity, less cool conditions and a reduction in precipitation before and during the Bronze Age (Mercuri *et al.* 2012), which could have been one of the reasons for the introduction of more drought-resistant crops in lowland (drier and warmer) regions in Slovenia.

Towards the end of the 14th century BCE, Europe experienced great changes in connection with the mass migrations of people. Central and eastern Slovenia were inhabited by people who belonged to the cultural sphere that stretched from western Hungary through Croatia to northern Bosnia. Large, Late Bronze Age settlements on the plains point to increased population density, which led to more intensive and efficient agricultural practices. At Late Bronze and Iron Age sites in Slovenia, cultivation of millets and free-threshing wheats increased, while that of hulled wheats decreased. Millets and free-threshing wheats are both more productive in comparison with hulled wheats. Although the cultivation of free-threshing wheat requires higher labour input (*i.e.* larger population), its processing is easier and faster. The greater presence of millets and free-threshing wheat may also be related to changes in culinary practices. Interesting research is going on at the moment involving analysis of ceramic forms in relation to food preparation, from various Slovenian archaeological sites dated to the Bronze Age and the Early Iron Age. Results to date reveal that some new forms of vessels (as well as changes in ceramic recipes) developed in the 12th-11th century BCE, which may be connected to changes or innovations in cooking techniques, perhaps linked with the appearance of millet. Later, in the Early Iron Age, these ceramic forms were used widely and regularly (Vinazza 2021).

Concerning the harvesting equipment in the studied region, bronze sickles with two to six vertical ribs on the tang began to appear at the beginning of the Late Bronze Age. We encounter them until the beginning of the Iron Age, and then they disappear. They are replaced by similarly shaped iron sickles with a flat tang.

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On the 'ancient' evidence for *Panicum miliaceum* and *Vicia faba* in central Germany (primarily Saxony-Anhalt)

Monika Hellmund

Abstract

Broomcorn millet was domesticated in Asia, and not in the region known as the Fertile Crescent, in the Middle East. Archaeobotanical finds of *Panicum miliaceum* (broomcorn millet) in central Europe have been reported to date as early as the Neolithic; dozens of archaeological sites with finds of *P. miliaceum* dated archaeologically to the Neolithic are mentioned in the literature. AMS radiocarbon dating enables investigation of trace amounts of organic material, such as grains of *P. miliaceum*, to accurately date them and either confirm or refute the archaeological dating. This chapter discusses current research concerning broomcorn millet in central Germany, primarily the state of Saxony-Anhalt. It discusses sites with supposed Neolithic finds of *P. miliaceum* and sites with Late Bronze Age, Pre-Roman Iron Age or Roman period finds. It also discusses the difficulty of separating features of different ages on multi-period archaeological sites. Sites with single finds of broomcorn millet are much more common than those that yielded mass finds. In many cases, *P. miliaceum* and *Vicia faba* were found together in archaeological deposits. The radiocarbon dates prove that *P. miliaceum* became a staple crop during the Late Bronze Age, and they do not support a Neolithic date for the introduction of either *P. miliaceum* or *V. faba* in Saxony-Anhalt.

Introduction

Germany is often mentioned in the context of the earliest finds of broomcorn millet in Europe. In 2006-2007, a new permanent exhibition was prepared and installed at the Landesmuseum für Vorgeschichte (State Museum for Prehistory) in Halle (Saale), in central Germany (Meller 2012). It included the crop species of the earliest (Early Neolithic) farmers in the region, both as herbarium specimens and as carbonised grains from archaeological sites. This exhibition was the impetus to re-investigate finds of ancient crops like *P. miliaceum* from the sites of the Neolithic and younger periods in Saxony-Anhalt in the last 15 years.

In sites of the Lusatian culture (Late Bronze Age to Pre-Roman Iron Age), lumps of charred grains of broomcorn millet have been preserved. Additionally, some mass finds of broomcorn millet are known from pits in settlement sites from the Late Bronze Age and the Iron Age in Saxony-Anhalt. Stray finds of grains exist as well. Both charred lumps and mass finds of broomcorn millet from eight features as well as individual finds of *P. miliaceum* from 15 settlement pits were the focus of the radiocarbon dating.

Until recently, *P. miliaceum* was said to have first appeared in Europe in the Neolithic (Bertsch and Bertsch 1949; Schultze-Motel 1994; Kroll 2001). It was said to be of minor importance as a crop because only single finds were present in assemblages (Willerding 1980; Kreuz 1990; Van Zeist *et al.* 1991; Körber-Grohne 1994; Zohary and Hopf 1994; Lüning 2000). Hunt *et al.* (2008) compiled data on 41 published sites with ancient finds of *P. miliaceum* and *Setaria italica* (foxtail millet) dated to before 5000 cal BCE in the Old World. The authors emphasised the necessity of providing detailed descriptions of morphological criteria and of the archaeological features that yielded the finds. Motuzaite-Matuzeviciute *et al.* (2013) note that only radiocarbon dating of the archaeobotanical material in question can elucidate when broomcorn millet became a staple crop in central Europe. *P. miliaceum* was the dominant cultivated millet species in the region investigated here. In contrast, *S. italica* has only rarely be proven.[1]

The wild progenitor of *P. miliaceum* has never been identified, and it may no longer exist (Miller *et al.* 2016). Some potential domestication regions in Asia have been discussed (Hegi 1979; Geisler 1991). The wild progenitor of *S. italica* is considered to be *Setaria viridis*; this latter species is widespread in central Asia. The region of domestication of *S. italica* is not known either.

Early agriculture of *P. miliaceum* in Asia

Early finds of both crops are documented from the early 6th millennium BCE in northern China, near the Yellow River, and in other regions of northeastern China (Hunt *et al.* 2008). Some authors suggest that this area was a centre for dry-land agriculture and initial millet domestication (Ventresca Miller and Makarewicz 2019). Liu *et al.* (2009) argued that early farming in northern China featured the cultivation of both broomcorn millet and foxtail millet, but there are only a few finds of millet grains and even fewer that are radiocarbon dated. At the Early Neolithic sites in Xinglonggou, the upper Liao River region in northeastern China, along the eastern edge of Inner Mongolia, 1400 grains of *Panicum miliaceum* and 60 grains of *Setaria italica* have been excavated, and remains of *P. miliaceum* were directly dated by AMS to ca. 5720 to 5660 cal BCE (7670-7610 cal BP; Zhao 2011). Zhao states that these caryopses were of domesticated plant species; in contrast, Stevens and Fuller (2017) note that the '*Xinglonggou* Panicum *grains are small and consistent with an early pre-domestication cultivation stage, not domestication*'. Li *et al.* (2020) compiled data on directly dated broomcorn millet grains to reconstruct millet agriculture dispersal from northeastern China to the Russian Far East around the middle of the 4th millennium BCE.

Genetic investigations of recent *P. miliaceum* and *P. ruderale* suggest there may be two independent domestication centres in China, one on the Loess Plateau (cluster A) and one in northeastern China (cluster B). The routes of westward spread

1 The archive of State Office of Heritage Management and Archaeology Saxony-Anhalt in Halle (Saale) mentions a mass find of perhaps *Setaria italica* from the site of Gräfenhainichen, county of Wittenberg. The material has not yet been re-located and the find thus remains unconfirmed.

could have been the prehistoric 'Oasis Route' for cluster A and the 'Steppe Route' for cluster B (Xu *et al.* 2019). Along the migration trail from northeastern China to Europe, the 'Inner Asian Mountain Corridor' has to be overcome (Miller *et al.* 2016). Leipe *et al.* (2019, 2) suggest that the '*most probable route connecting the Upper Yellow River and the western central Asian steppes runs along the southwestern slopes of the Mongolian Altai and the southern Mongolian Plateau*'. Broomcorn millet was present on the western edges of the Eurasian Steppe in southeastern Kazakhstan by 2200 cal BCE (Frachetti *et al.* 2010). Filipović *et al.* (2020) documented the current state of the art on the introduction of broomcorn millet in central Europe, based on new and previously produced radiocarbon dates. Recent dating of charred grains of broomcorn millet indicates that the earliest presence in central and southeastern Europe was in the 16th century BCE.

Cultivation of broomcorn millet: Ecological and climatic demands

At present, broomcorn millet is seldom cultivated in central Europe. The crop has a moderate demand on soil nutrients and low water requirements; it tolerates drought but does not like cold or wet soils. Uniquely, this crop can be cultivated in very different climatic conditions. Varieties of broomcorn millet require a very short growing period and mature quickly, even at higher altitudes (Geisler 1991). In central Europe, the growing period is stated to be about 100 days, from May to August or at the latest from mid-June to September. In some other regions of the world, the vegetation period amounts to 60-90 days (Zohary *et al.* 2012) or even just 30-45 days (Frachetti *et al.* 2010). In contrast to those of other cereals, grains within the panicle of *P. miliaceum* do not all ripen at the same time; the grains at the top ripen first. The panicle is harvested by hand or with a sickle (Steinbrück 1908). A minimum temperature of 10 °C is necessary for germination, and the seedlings have a high frost sensitivity (Mehnert *et al.* 1964).

Broomcorn millet was the first C4 plant to be introduced in central Europe. In contrast to most of the other important world crops, which are characterised by C3-photosynthesis, *P. miliaceum* is characterised by C4-photosynthesis, which gives it an advantage in more arid climates, where water is scarce. *P. miliaceum* leaves a distinct isotopic signal in human and animal bones when used for either human nutrition or as fodder for domestic animals (*e.g.* Tafuri *et al.* 2009). Millet grains have a well-balanced nutritional composition (Bray 1981). The grains can be cooked like rice or consumed as a porridge or in soups, and they can be baked into a flatbread. They are used for human diet as well as for animal feed. It can be assumed that in the past the non-edible residues of the plant were fed to domestic animals.

Material and methods

Archaeological finds of broomcorn millet from already published and unpublished sites in Saxony-Anhalt were radiocarbon dated, with a focus on extant grains of *P. miliaceum* or accompanying cereal grains, preferably originating from large deposits (Table 2). Sometimes the carbonised grains of broomcorn millet themselves were dated, and wherever possible, five or more grains were dated. Because of the very low content of carbon in grains of broomcorn millet, sometimes the co-occurring grains of larger cereals from the same deposit were included in the sample for dating, based on the assumption that other grains in the same sample of stored grains, such as *Hordeum vulgare* or *Triticum dicoccum,* or pulses, such as *Vicia faba*, must be of the same age as the grains of broomcorn millet.

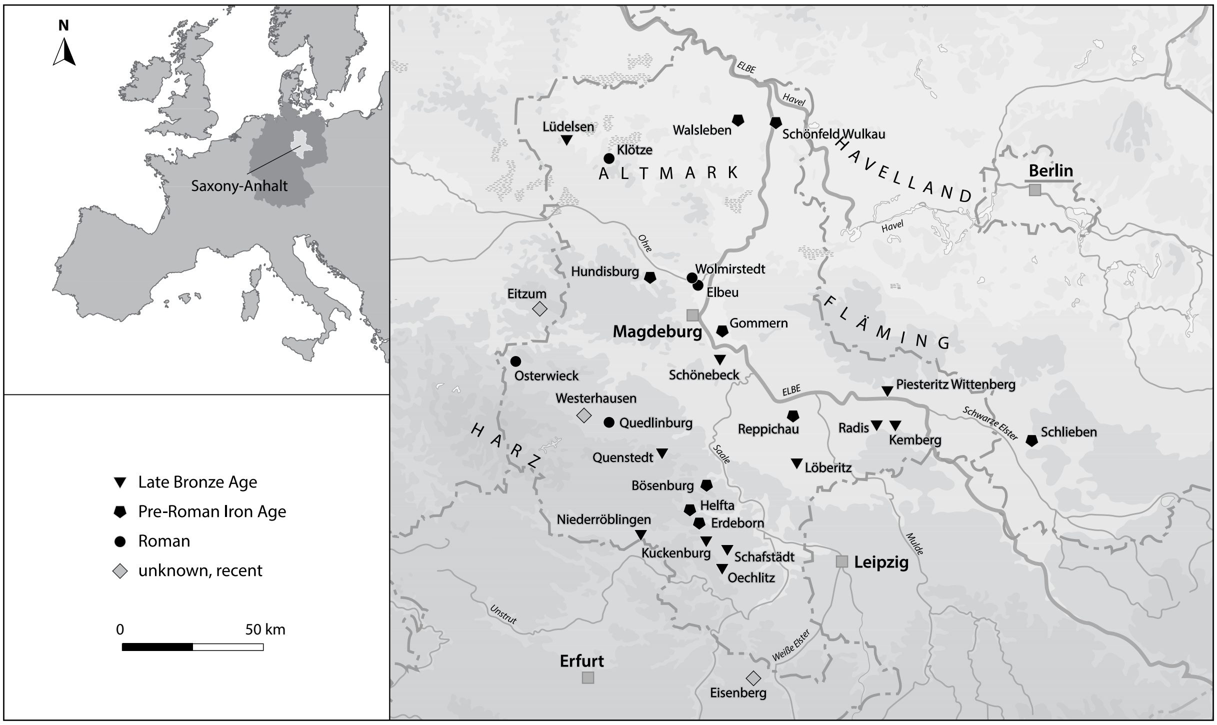

Figure 1. Locations of the sites in Saxony-Anhalt and surrounding regions in central Germany mentioned in the text. Dating (assumed or confirmed): Late Bronze Age, Iron Age, Roman period and unknown/recent (map by B. Parsche, LDA Halle (Saale), based on a design by the author. Map base: D 1000, Bundesamt für Kartographie und Geodäsie, Nr. 01/2002, 1:2,000,000).

Results

The radiocarbon dates of contexts with broomcorn millet in Saxony-Anhalt and the immediate surroundings are described here. The location of the sites mentioned in the text is shown on the map in Figure 1. Unless otherwise mentioned, the sites are located in the German federal state of Saxony-Anhalt. An overview of archaeological phases, cultures and periods used in central Germany from the Bronze Age until the Early Middle Age, together with the placement of the sites in Saxony-Anhalt mentioned in the text, is presented in Table 1. The radiocarbon dates and the calibrated ages are compiled in Table 2. The calibrations were carried out with OxCal v4.4.2[2] based on the IntCal20 atmospheric curve (Bronk Ramsey 2009; Reimer *et al.* 2020). The calibrated timespans are displayed in multi-plots (Figs. 2-5). Photos of the examined grains and lumps of broomcorn millet are presented in Figure 6.

2 https://c14.arch.ox.ac.uk/oxcal.html

Temporal indicator		General period	Phase according to regional chronology*	Cultural attribution	Sites in Saxony-Anhalt
410	CE	Early Middle Ages	FMA	Thuringians	
165	CE	Period of Germanic Migration Roman Period	RKZ C-VWZ	Germanic tribes	Wolmirstedt Elbeu Klötze Osterwieck Quedlinburg
60	BCE		Lt D2-RKZ B		
150	BCE	Late Iron Age (La Tène)	Lt D1	Jastorf culture Wahlitz group Naumburg group Oder-Warthe group	Quedlinburg Hundisburg
200	BCE		Lt C2	Jastorf culture Naumburg group Oder-Warthe group	Walsleben Gommern Wulkau-Schönfeld Helfta
275	BCE		Lt C1	Jastorf culture Naumburg group	
300	BCE		Lt B2b		
400	BCE		Lt B1-2a	Jastorf culture Thuringian culture	
450	BCE		Lt A		
525	BCE	Early Iron Age (Hallstatt)	Ha D3	Jastorf culture House urn culture Billendorf culture Thuringian culture	
575	BCE		Ha D2		Erdeborn Bösenburg Reppichau Niederröblingen Schlieben (BB)
625	BCE		Ha D1	Elb-Havel group House urn culture Billendorf culture Thuringian culture	
750	BCE		Ha C		
1075	BCE	Late Bronze Age (Urnfield period)	Ha B1-3 = P IVb-V	Elb-Havel group Saalemündungs group Lusatian culture Unstrut group	Quenstedt Lüdelsen Kemberg Niederröblingen Löberitz Kuckenburg Oechlitz Schönebeck
1250	BCE		Ha A1-2 = P IIIb-IVa		Niederröblingen Piesteritz-Wittenberg Schafstädt Radis
1325	BCE		Bz D = P IIIa	Lusatian culture Unstrut group	
1475	BCE	Middle Bronze Age	Bz C = P II	Lüneburg group Fulda-Werra group	
1550	BCE		Bz B = P II		
2200	BCE	Early Bronze Age	Bz A = P I	Únětice culture	

* Bz = Bronzezeit (Bronze Age)
* Ha = Hallstatt
* Lt = La Tène
* RKZ = Römische Keiserzeit (Roman period)
* VWZ = Völkerwanderungszeit (Migration period)
* FMA = Frühmittelalter (Early Middle Ages)
* P = Period

Table 1. Chronology of archaeological phases, cultures and periods in central Germany and the sites in Saxony-Anhalt mentioned in the text. The time span is Bronze Age to Early Middle Ages (by R. Schwarz, Halle (Saale), modified by the author).

Supposed Neolithic finds of broomcorn millet in central Germany

Until 2008, there was a scientific consensus that broomcorn millet was already present in central Germany in the Early Neolithic, either as a crop or as a weed in cereal fields (Kreuz 1990; Wasylikowa *et al.* 1991; Körber-Grohne 1994; Stika and Heiss 2013; Behre 2008). Lüning (2000) emphasised that *P. miliaceum* was a component of the Linear Pottery culture package of crop species in the region. The same locations with ancient finds of broomcorn millet have been described in different archaeobotanical reports. Willerding (1980) and Rösch (1999) mentioned 10 Linear Pottery sites with *P. miliaceum* in eastern and central Europe, with the locations Hundisburg (Haldensleben) and Eisenberg as the westernmost ones. Körber-Grohne (1994) suggested that the oldest evidence for *P. miliaceum* comes from central Germany and named these two sites: Eisenberg, in Thuringia, and Hadmersleben (correct name: Haldensleben; see Hummel 1968; Hellmund 2012a), in Saxony-Anhalt (Fig. 1). Other authors also described these two sites as yielding ancient finds of broomcorn millet (*e.g.* Willerding 1980; Kreuz 1990; Körber-Grohne 1994; Schultze-Motel and Gall 1994; Zohary and Hopf 1994). Lüning (2000) listed three further Neolithic sites in central Germany as containing broomcorn millet, as well as five sites in eastern Europe. Wasylikowa *et al.* (1991) mentioned some more localities in eastern Europe. Most of these finds are not radiocarbon dated.

The site of **Eisenberg** (county of Saale-Holzland, federal state of Thuringia) was excavated in 1925 and was archaeobotanically analysed in the 1950s by Rothmaler and Natho (1957). Schultze-Motel re-examined the material. The assemblage consisted of *Triticum dicoccon*, *Triticum monococcum*, *Hordeum distichum/vulgare* (hulled), *P. miliaceum* and *Cannabis sativa*. Both Rothmaler and Natho (1957) and Schultze-Motel and Gall (1994) expressed doubts about the assignment of the hemp finds in the Linear Pottery culture contexts to *C. sativa*. A further re-examination indicates that the attribution of broomcorn millet to the Neolithic is in doubt as well.[3]

For Saxony-Anhalt, Körber-Grohne (1994) mentioned the site of Hadmersleben. This must be the village of **Hundisburg**, near the town of Haldensleben (county of Börde) (Hummel 1968; Willerding 1980; Hellmund 2012a). The archaeobotanical material was stored in the local Museum Haldensleben and marked with the old labels created by Rothmaler, who did the first analysis. This material was accidentally rediscovered during a student excursion to the Museum in the 1950s. Grains of broomcorn millet (Fig. 6.1) from Hundisburg were radiocarbon dated, and the date indicates a time span of 150-46 cal BCE (1σ, Table 2, Fig. 2) (Hellmund 2012a). Evidently, Hundisburg is not the site with the oldest find of broomcorn millet in Saxony-Anhalt.

At the site of **Eitzum** (town of Schöppenstedt, county of Wolfenbüttel, federal state of Lower Saxony), two grains of *P. miliaceum* were found in structures of the Linear Pottery culture (Kreuz 1990). In more recent publications, Kreuz doubted the archaeological dating of the small grains of *P. miliaceum* to the Neolithic and wrote: '*Solitary finds of* P. miliaceum *(broomcorn millet) are certainly later intrusions in the Linear Pottery Culture pits, transported there by earthworms, mice or other animals, as proven by various 14^C^ dates*' (Kreuz and Marinova 2017, 646).

In Westerhausen, at the site of **Jätchenberg**, near the town of Thale (county of Harz), a stone grave of the Globular Amphorae culture with a human skeleton, as well as two adjacent pits with burials of two and five cattle, respectively, were detected in 2003 (Meller 2012; Döhle and Pape 2021). The contents of some pots

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3 B. Zach, Blaubeuren, Jena, and the author examined the material in question in January 2020 at the Institute for Archaeology in Jena, and the grains of *Panicum miliaceum* should be dated soon.

Laboratory * number	Site and feature (f.)	Material	Radiocarbon date	Calibrated age 1σ cal BCE	Calibrated age 2σ cal BCE
KIA-33854	Bösenburg	1 barley grain	2452 ± 33 BP	749-434	756-413
MAMS-47955	Gommern-Gerstenberg	1 barley grain	2244 ± 23 BP	381-229	387-206
KIA-33853	Hundisburg	7 broomcorn millet grains	2080 ± 30 BP	150-46	175 cal BCE-8 cal CE
MAMS-22384	Kemberg	fragment of wood	2701 ± 21 BP	896-811	900-809
MAMS-22383	Kemberg	fragment of wood	2752 ± 20 BP	917-837	969-828
Erl-6712	Löberitz	1 barley grain	2818 ± 50 BP	1046-906	1118-835
KIA-37253	Niederröblingen, f. 3635	14 grains of broomcorn millet	2951 ± 31 BP	1221-1115	1261-1051
KIA-34310	Niederröblingen, f. 3636	5 grains of broomcorn millet	2968 ± 33 BP	1256-1125	1364-1053
KIA-35825	Niederröblingen, f. 3637	1 hulled barley grain	3012 ± 26 BP	1369-1215	1384-1129
KIA-34311	Niederröblingen, f. 3646	1 hulled barley grain	2476 ± 28 BP	754-543	770-426
MAMS-47954	Niederröblingen, f. 3709	2 fragments of hulled barley grains	2975 ± 24 BP	1258-1128	1283-1113
KIA-36818	Niederröblingen, f. 4377	1 spelt grain	2548 ± 21 BP	791-596	796-567
KIA-34309	Niederröblingen, f. 4718	1 emmer grain	2951 ± 34 BP	1224-1111	1266-1021
KIA-36817	Niederröblingen, f. 4883	5 grains of broomcorn millet	2790 ± 59 BP	1010-840	1109-815
MAMS-47959	Niederröblingen, f. 5359	1 spelt grain	2594 ± 25 BP	800-780	809-770
KIA-34308	Niederröblingen, f. 5377	1 einkorn grain	2813 ± 64 BP	1051-848	1190-819
MAMS-47961	Niederröblingen, f. 5397	2 fragments of hulled barley grains	2901 ± 25 BP	1123-1019	1201-1008
KIA-37255	Niederröblingen, f. 9100	4 emmer grains	2973 ± 31 BP	1259-1126	1369-1055
MAMS-47952	Piesteritz-Wittenberg	fused grains of broomcorn millet (8 mg)	2962 ± 23 BP	1219-1126	1264-1058
MAMS-47958	Quenstedt, f. 10	1 barley grain	2735 ± 25 BP	902-833	926-816
KIA-33851	Quenstedt, f. 116	1 fragment of faba bean seed	2743 ± 31 BP	911-833	977-813
Poz-31957	Quenstedt, f. 12	5 broomcorn millet grains	2805 ± 35 BP	1005-916	1051-836
Poz-31960	Quenstedt, f. 290	2 fragments of faba bean seeds	2740 ± 35 BP	910-831	978-810
MAMS-47960	Quenstedt, f. 9	1 emmer grain	2749 ± 25 BP	916-835	974-822
KIA-38121	Radis	fused grains of broomcorn millet (15 mg)	2994 ± 36 BP	1285-1128	1386-1113
MAMS-47953	Reppichau	5 grains of broomcorn millet	2499 ± 23 BP	761-553	773-543
KIA-33852	Schafstädt	1 hulled barley grain	2977 ± 34 BP	1261-1127	1375-1055
MAMS-39145	Schönfeld-Wulkau	1 hulled barley grain	2251 ± 25 BP	384-231	391-206
KIA-33855	Walsleben	5 grains of broomcorn millet	2182 ± 33 BP	353-174	369-116

* KIA = Leibniz-Laboratory for Radiometric Dating and Stable Isotopic Research of Kiel University (Germany)

* Erl = AMS ^{14}C-Laboratory of the Friedrich-Alexander-University Erlangen-Nürnberg (Germany)

* Poz = AMS Laboratory of the Adam Mickiewicz-University in Poznań (Poland)

* MAMS = ^{14}C-Laboratory Curt-Engelhorn-Centre Archaeometry gGmbH in Mannheim (Germany)

Table 2. Radiocarbon dates of the sites and features mentioned in the text. Calibration using OxCal v4.4.2 and IntCal20 (Bronk Ramsey 2009; Reimer et al. 2020).

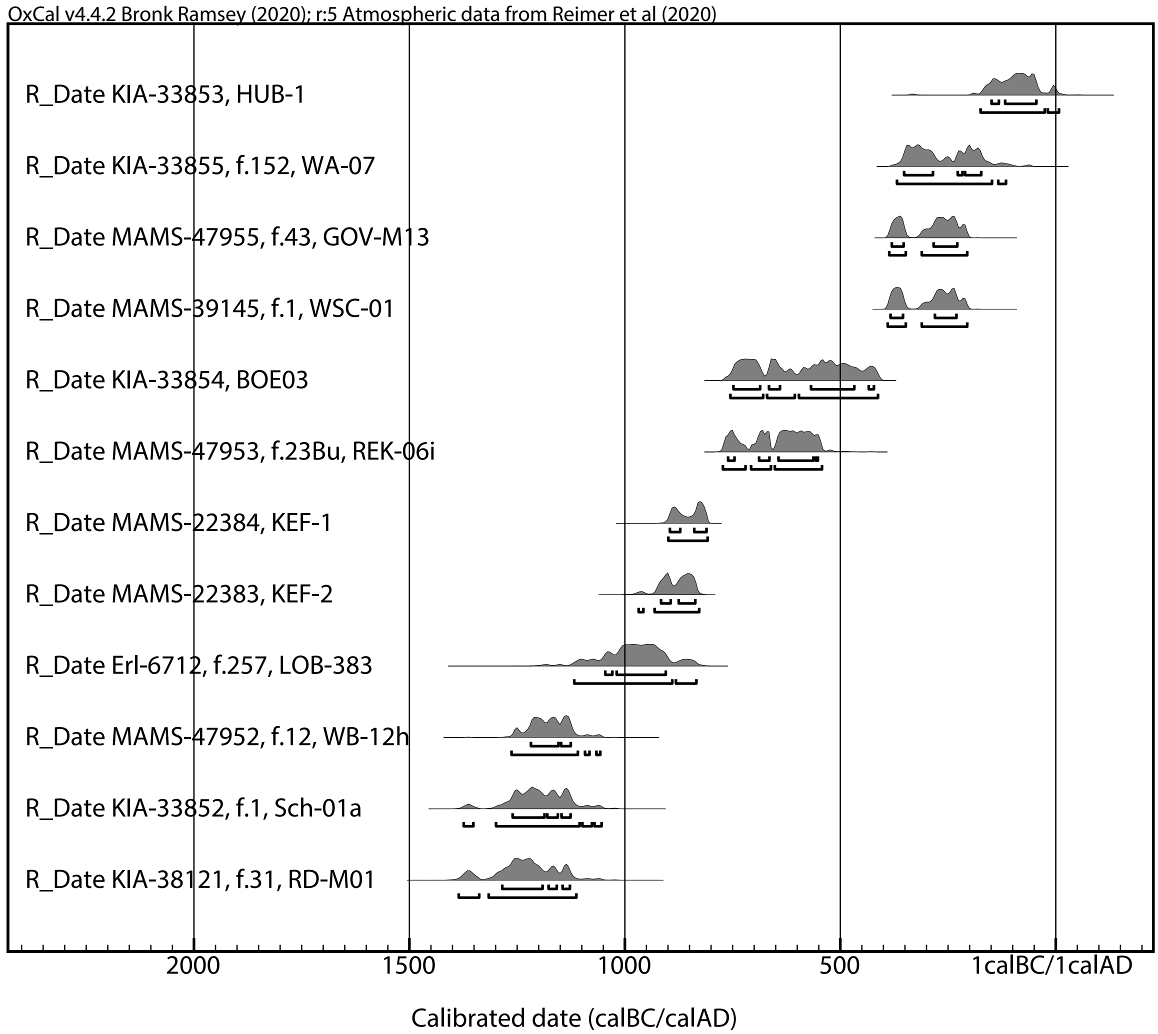

Figure 2. Radiocarbon dates from the following sites and materials: charred millet 'porridge' from Radis (RD) and Wittenberg-Piesteritz (WB); mass finds of millet from Reppichau (REK), Hundisburg (HUB) and Walsleben (WA); single finds of millet from Löberitz (LOB), Kemberg (KEF; date on wood), Bösenburg (BOE), Wulkau-Schönfeld (WSC), Gommern-Gerstenberg (GOV) and Schafstädt (SCH). Calibration using OxCal v4.4.2 and IntCal20 (Bronk Ramsey 2009; Reimer et al. 2020). Prepared by the author.

found in the grave were analysed. Sample WEH-04 contained uncarbonized grains of *P. miliaceum* and other plants. It was assumed that this is a recent contamination; indeed, the radiocarbon date (KIA-31868) of the subfossil grains of broomcorn millet proved that they post-date 1954 CE.

As part of a scientific project of Kiel University, megalithic tombs in Altmark in the northern part of Saxony-Anhalt were investigated, including the 'king's burial' in **Lüdelsen** (community of Jübar, county of Salzwedel), belonging to the Funnel Beaker culture (Diers 2018). H. Kroll analysed a large number of archaeobotanical samples from this site, detecting grains of *P. miliaceum* in two samples from Sector 7. Their radiocarbon dates fall in the Late Bronze Age, not the Neolithic (KIA-42500: 2783±37 BP, 1σ 997-854 cal BCE, 2σ 1015-830 cal BCE; KIA-42499: 2684±40 BP, 1σ 897-804 cal BCE, 2σ 910-794 cal BCE) (Diers 2018; Filipović *et al.* 2020).

Although located in the federal state of Brandenburg, the site of **Rathsdorf** (town of Wriezen, county of Märkisch-Oderland) is mentioned because of its published Neolithic age, as emphasised by Jahns *et al.* (2018) and Effenberger (2017). As described in Diers (2018) and Jahns *et al.* (2018), the radiometric dating of two grains of *P. miliaceum* from features no. 384 and no. 385 indicate the Neolithic age (KIA-42498: 3826±49 BP, 1σ 2399-2152 cal BCE, 2σ 2459-2142 cal BCE). Therefore, Rathsdorf was thought to have yielded the oldest finds of broomcorn

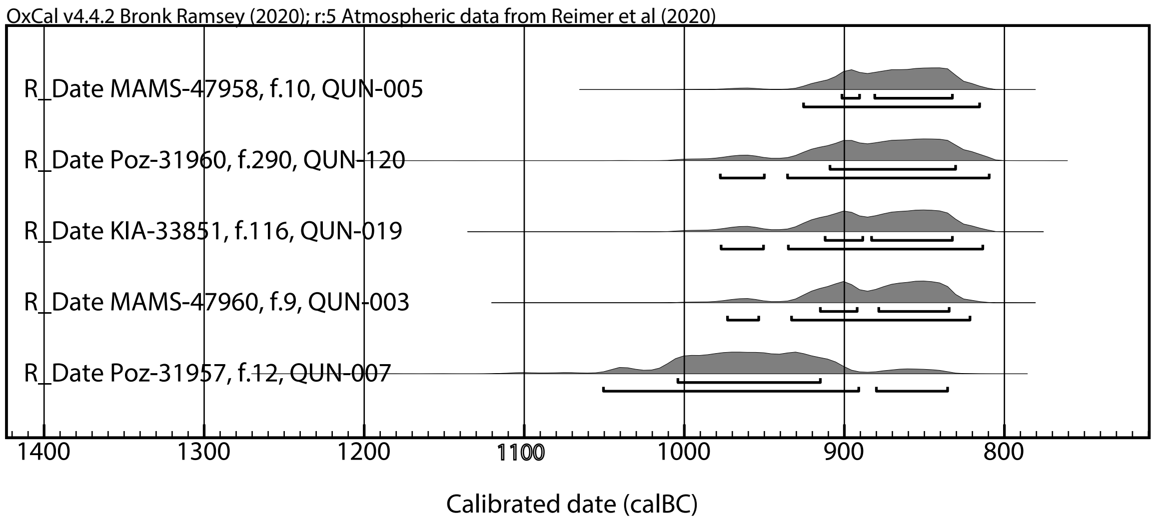

Figure 3. Quenstedt-Schalkenburg. Radiocarbon dates for the pits suggested to belong to the Bernburg culture. Dated grains: pit no. 10 – barley; pit no. 290 – faba bean; pit no. 116 – faba bean; pit no. 9 – emmer; pit no. 12 – P. miliaceum. *Calibration using OxCal v4.4.2 and IntCal20 (Bronk Ramsey 2009; Reimer et al. 2020). Prepared by the author.*

millet in Brandenburg. However, Filipović *et al.* (2020) did not include this date in their Millet Dating Programme because it was obtained on a pooled sample of grains originating from multiple features and they considered it unreliable. There are other issues with this date too: the $\delta^{13}C$ value for the dated sample hints at the potential inclusion of C3 plant material (Filipović pers. comm.) and the dates produced by the Leibniz-Laboratorium in Kiel during this period (the dating was done in late 2010) turned out to be too old due to errors in the laboratory procedures.[4]

The town of **Quenstedt** (municipality of Arnstein, county of Mansfeld-Südharz) is situated in the northeastern forelands of the Harz Mountains; ca. 1 km southwest from it, in the Hengstbach valley, the so-called Schalkenburg hillock rises to a height of 20-25 m above the valley. On top of it is a multi-period archaeological site, excavated between 1967 and 1986. An area of 1.2 hectare was uncovered, including a circular palisade enclosure of the late Stroke-Ornamented Ware (*Stichbandkeramik*) culture; burials of different Neolithic cultures and of the Early Bronze Age Únětice culture; settlement pits of the Middle Neolithic Bernburg culture; and pits and postholes of a Late Bronze Age and Early Iron Age settlement, fortified by a rampart and a ditch cutting off the spur from the surrounding flat terrain (Behrens and Schröter 1980; Sosnowski 2006, 2014, 2015). Schultze-Motel analysed the archaeobotanical material and the present author conducted quantitative analysis (Schultze-Motel and Hellmund in press). Most finds of broomcorn millet at the site derive from the Late Bronze Age and Early Iron Age settlement, but in some cases they were also found in pits together with ceramics belonging to the Neolithic Bernburg culture. Grains of *P. miliaceum* were present in the assemblages from pits no. 9, 10, 12 and 116. Fragments of faba bean were found in features no. 116 and 290. Occasionally, *P. miliaceum* and *V. faba* were found in the same pit. One barley grain from pit no. 10, two fragments of *V. faba* from pit no. 290, one emmer grain from pit no. 9, a fragment of *V. faba* from pit no. 116 and several grains of *P. miliaceum* (Fig. 6.2) from pit no. 12 were radiocarbon dated. Four dates point to the 9th century cal BCE, and the radiocarbon date for pit no. 12 (millet) points to the 10th century cal BCE (1σ, Table 2, Fig. 3).

4 Meadows *et al.* (2015) discuss the problematic measurements produced by the radiocarbon laboratory in Kiel and state that '*the late-2010 and 2011 results are too old*' (Meadows *et al.* 2015, 1046).

Broomcorn millet in the Bronze Age in Saxony-Anhalt

Finds of broomcorn millet attributed to the Late Bronze Age are more common in Saxony-Anhalt than those attributed to the Neolithic. Due to the lack of sites from the Middle Bronze Age, little is known about the plant spectra from this period. Botanical finds from the Early Bronze Age (Únětice culture) are rare as well. No remains of *P. miliaceum* from the Únětice culture period are known (see section on the site of Oechlitz, below).

Mass finds and single finds of broomcorn millet in the Lusatian (Lausitz) culture

At the end of the 14th century BCE, communities of the Lusatian culture advanced from eastern Europe westwards. Their presence expanded from Poland into Bohemia, Moravia and Germany, specifically Brandenburg, Saxony and the eastern part of Saxony-Anhalt. In Saxony-Anhalt, they reached the Elbe River and settled in the area of the present-day town of Wittenberg (Schunke 2018). The first traces of the Lusatian culture date to Period III (1325-1150 BCE) of the chronology devised by Oscar Montelius. Settlement activity increased during Periods IV (1150-1000 BCE) and V (1000-750 BCE) and decreased during the Early Iron Age, when the Lusatian culture transformed (from an archaeological point of view) into the Billendorf culture (750-450 BCE) (Schmidt and Göricke 1985; Meller 2015) (Table 1). The Lusatian culture groups cremated their dead and buried them beneath earthen barrows surrounded by broad ditches (Schwarz 2003). The communal cemeteries often comprise dozens of burial mounds (Jockenhövel 2013).

The site of **Radis** (near the town of Kemberg, in the region of Wüste Mark Gemeln), lies in a forested area 12 km south of the Elbe. During rescue excavations in this forest in 1952-1953, a lump of charred millet 'porridge' was discovered in barrow no. 31, near a broken, ovoid pot lying next to some metal finds (Schmidt and Göricke 1985). The lump of fused grains of broomcorn millet measured 27.5 ml and weighed approximately 7.67 g. The radiocarbon date on a fragment of the porridge (Fig. 6.5) spans the 13th and 12th centuries cal BCE (1σ, Table 2, Fig. 2).

Schmidt and Göricke (1985) also mentioned the site of **Piesteritz** (in the town of Lutherstadt Wittenberg, in the county of Wittenberg) as another site of the Lusatian culture. In 1994, salvage excavation took place at a burial location here (Wurda 1994), during which soil samples from pots as well as lumps of fused broomcorn millet grains were recovered. Sample WB-12i (Fig. 6.9) contained 4.525 g and sample WB-12h contained 7.1 g of the grains. Another sample had seeds of *V. faba* in it as well as millet. The grains of *P. miliaceum* (Fig. 6.3) were dated to the period between the mid-13th and 12th century cal BCE (1σ, Table 2, Fig. 2).

From 1000 BCE onwards, settlements of the Lusatian and Billendorf cultures were often fortified. One of these is the fortification of **Kemberg** (Wittenberg county) (Meller 2015; Nebelsick and Swieder 2018), a waterlogged site from the end of the Late Bronze Age, considered the oldest fortified settlement of the Lusatian culture (Ha B and Ha C-D1). Timber from this site was dated to ca. 968 and 955 den BCE; two radiocarbon dates on wood fragments exist as well, and they point to the 9th century cal BCE (1σ, Table 2, Fig. 2). Archaeobotanical investigations of Kemberg revealed residues of *P. miliaceum*, including an uncarbonized glume (Fig. 6.10) (Hellmund 2018).

The archive of the State Museum of Prehistory in Halle (Saale) houses plant remains from the site of Malitschkendorf, near **Schlieben,** located east of the Elbe (county of Elbe-Elster, federal state of Brandenburg). They were collected in 1828, by F.A. Wagner, and also in 1931. Other material was kept in different archives and analysed by several researchers. Buschan (1895, 73, 213) mentioned charred lumps of broomcorn millet and seeds of faba bean. In the archive in Halle (Saale), there are four samples from Schlieben. The most diverse plant spectrum was documented in sample SCB-8286, consisting mostly of *Triticum dicoccon* (emmer grains and chaff), *V. faba, Pisum sativum, P. miliaceum*, naked wheat and several grains of barley. In addition, fragments of carbonised porridge of broomcorn millet were found. The site has been dated archaeologically to the Late Bronze to the Early Iron Age (Ha B-D1) (Nebelsick and Swieder 2018); no radiocarbon dates have yet been obtained.

Broomcorn millet at the sites of Late Bronze Age archaeological groups in Saxony-Anhalt

During the Late Bronze Age, different regional cultures developed in Saxony-Anhalt, named for a dominant river flowing through their respective areas of settlement: the Unstrut group (ca. 1325-750 BCE), the Saalemündungs group (1300-750 BCE) and the Elb-Havel group (Meller 2015) (Table 1). The Saalemündungs group was partially influenced by the neighbouring Lusatian culture and partially also by the Nordic Bronze Age culture. Cremation was quite common. From about 1000 BCE, the Saalemündungs group expanded farther south, into the areas of settlement of the Unstrut group. The Unstrut group continued the tradition of the Middle Bronze Age barrow culture. Inhumation in wooden coffins persisted for a long time, but around 1000 BCE, cremation became the dominant burial rite (Meller 2015). Further regional subdivision of the Unstrut group is represented by the Helmsdorf group in the northeastern and the Wandersleben group in the southwestern part of its distribution. These two subgroups were separated roughly by the low mountain ranges of the Schmücke and the Finne, which delimit the Thuringian Basin to the north-east (Schwarz pers. comm.). The richness of the bronze hoards found along the middle course of the Saale River (Schunke 2004) mirrors the wealth of the population of the Helmsdorf group, which was accumulated through salt production in the salt mines that existed in and near the city of Halle (Saale).

Mass finds of broomcorn millet in settlement pits

There are some mass finds with carbonised grains of broomcorn millet in the territory of Saxony-Anhalt. Prior to the construction of the A71 motorway from Sangerhausen to Erfurt in Thuringia, rescue excavations were carried out. The site of **Niederröblingen** (municipality of Allstedt, county of Mansfeld-Südharz) is located near the floodplain of the Helme in the southern Harz foreland. A tell-like settlement was detected here, the first known from central Germany, with a height in the centre of about 1.80 m. This site was occupied starting with the Linear Pottery culture. The accumulation of cultural layers accelerated during the Late Bronze Age (Meller 2011).

The archaeological situation at Niederröblingen is highly complex. On a visit to the site during the preparation of a new excavation area, the present author discovered two small pits filled with mass finds of carbonised grains of *P. miliaceum*. A third feature with a mass find of broomcorn millet was detected later. Initially, five grains of *P. miliaceum* from feature no. 3636 (Fig. 6.6) were sent for dating; the response from the Leibniz-Laboratory for Radiometric Dating in Kiel was that the amount of organic material had been too small. The second attempt at dating led to a result, showing that the material dated to the period encompassing the 2nd half of the 13th and the early 12th century cal BCE (1σ, Table 2, Fig. 4). Within the mass finds, grains of *P. miliaceum* were mostly found in the 1 mm fraction of the sieved sample (Fig. 6.4). Grains from feature no. 3635, located near the pit (no. 3636), date to the same period (Fig. 4). Five grains of broomcorn millet from the third mass find (pit no. 4883) were also dated (Fig. 6.7), and these returned a date in the 10th to 9th centuries cal BCE (1σ, Table 2, Fig. 4). A further 14 pit silos with charred

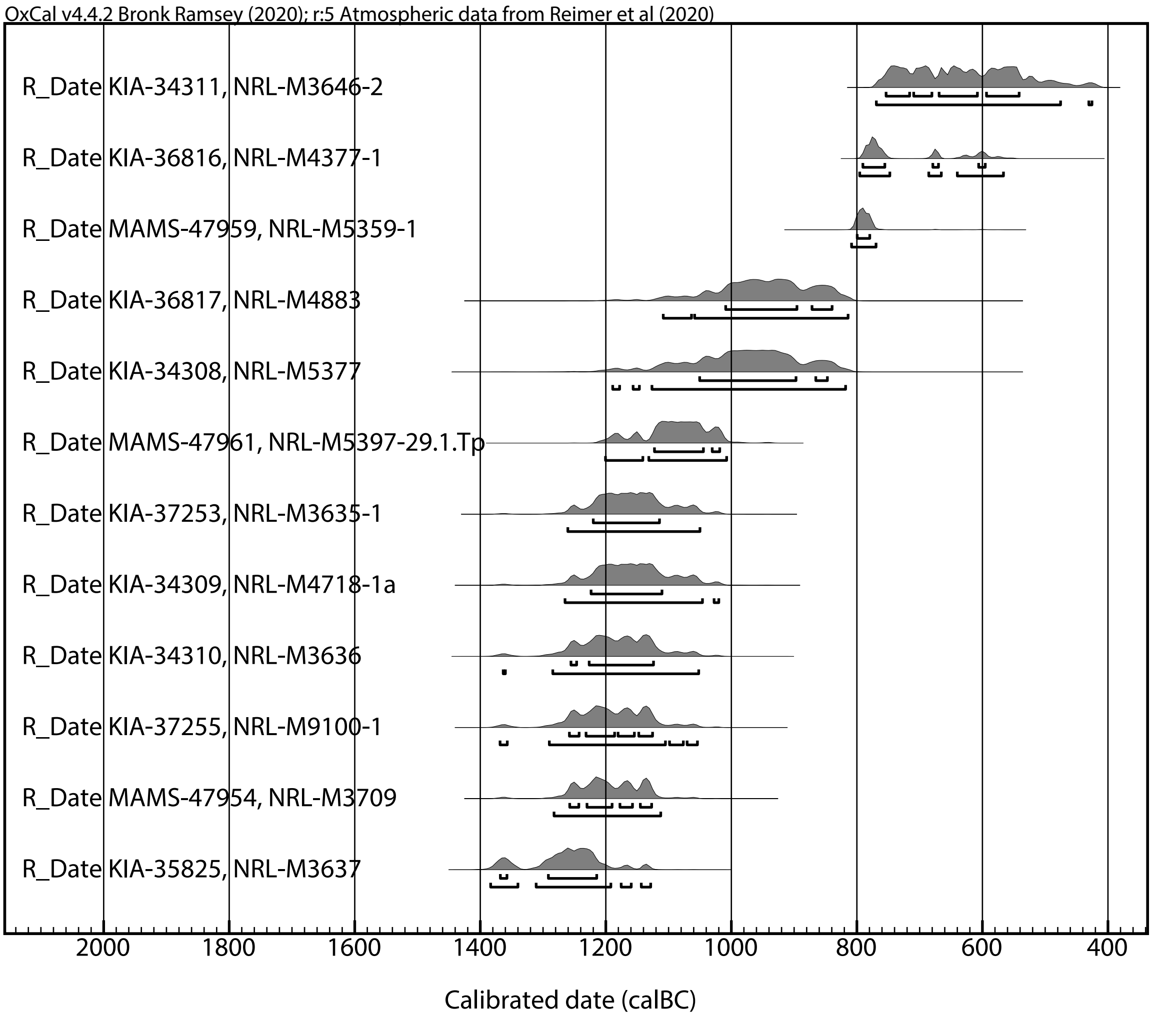

Figure 4. Niederröblingen. Mass finds dominated by Panicum miliaceum: Feature nos. 3636, 3635 and 4883 from which broomcorn millet grains were dated; other features with single grains of Panicum miliaceum *and grains of emmer, barley, einkorn and spelt, which were also dated. Calibration using OxCal v4.4.2 and IntCal20 (Bronk Ramsey 2009; Reimer et al. 2020). Prepared by the author.*

cereals were excavated at Niederröblingen. Finds of *P. miliaceum* are known from 12 dated granary pits (Table 2, Fig. 4). Most of these features date to the period before 780 cal BCE, whereas three of them date to the Early Iron Age (1σ, Table 2, Fig. 4). Other granary pits mostly contained grains of other cereals, such as barley, spelt, emmer, einkorn and bread wheat. Remains of *Papaver somniferum* and *Camelina sativa* were also found but are relatively rare (Hellmund and Petzschmann 2011).

The exceptionally large find of charred cereals and pulses, about 400 L in volume (sample REK-06i), from the site of **Reppichau** (community of Osternienburger Land, county of Anhalt-Bitterfeld) in central Saxony-Anhalt consists of thousands of grains of broomcorn millet, peas, hulled barley and emmer. Grains of *P. miliaceum* (Fig. 6.8) have been dated to 760-550 cal BCE (1σ, Table 2, Fig. 2).

Another mass find of charred grains of *P. miliaceum* was recorded in **Walsleben**, a village belonging to the Hanseatic town of Osterburg (Altmark), in the county of Stendal. The site contained primarily remains of a Roman period occupation, located on an elevation near the Uchte River; archaeological traces of the Pre-Roman Iron Age and the Neolithic were less common (Kolb and Müller 1996). The analysed sample consisted of several thousand grains of broomcorn millet and hundreds of faba bean seeds. Barley was the second-most dominant crop species and emmer was present as well. Grains of broomcorn millet have been dated (Fig. 6.12). Contrary to the assumption by the excavator that they come from the Roman period, their absolute age falls between the 4th and 2nd centuries cal BCE (1σ, Table 2, Fig. 2).

Late Bronze Age sites with single finds of broomcorn millet

The construction of new tracks on the railway between Nürnberg (English: Nuremberg) and Halle (Saale) and Leipzig was preceded by excavations in the south of Halle (Saale). Preliminary results have been published (Hellmund 2017; Meller and Becker 2017). Charred grains of *P. miliaceum* (Fig. 6.11) were detected in settlement pit no. 20394 near **Oechlitz** (town of Mücheln, county of Saalekreis). The preliminary archaeological dating of this find was to the Early Bronze Age, specifically the Únětice culture, and so the material had been considered by the present author (Hellmund 2017) as deriving from this period. However, subsequent inspection of the updated database and discussion with an archaeologist led to the correction of the temporal attribution, since it was established that the pit belongs to the Late Bronze Age (Knoll and Fröhlich 2017) and not to the Únětice culture. For now, there are no radiocarbon dates available for this site.

At the site of **Schönebeck** (county of Schönebeck), several Neolithic and Bronze Age wells were excavated in advance of the construction of a bypass road. A bronze hoard was discovered outside a Late Bronze Age wooden box well (Bogen 2012). At the base of the shaft created for this well, three layers of the wooden box were preserved. According to the dates, the lowest wooden box was constructed in the Early Bronze Age, in 1995±10 den BCE. The middle and upper wooden boxes were dated to 1248±10 den BCE and 1223±10 den BCE, respectively. It can be assumed that the backfill in the well dates to the later phase of use, not to the earlier phase. The carbonised grains of *P. miliaceum*, found in the uppermost wooden box, were therefore assigned to the Late Bronze Age (Hellmund 2012b). Radiocarbon dates on the botanical macro-remains from the fill of the well are pending.

In 1992, a large deposit of cereals was recovered from a pit during the rescue excavation that preceded the building of a commercial area in **Schafstädt**, a village near the town of Bad Lauchstädt (county of Saalekreis). Barley was dominant in the deposit; grains of *P. miliaceum* and remains of a number of segetal and ruderal weeds, such as *S. viridis*, were also present (Hellmund 2012c). One grain of hulled barley returned a radiocarbon date of 13th to 12th century cal BCE (1σ, Table 2, Fig. 2).

In advance of a gas pipeline construction, a prehistoric settlement near **Löberitz**, near the town of Zörbig (county of Anhalt-Bitterfeld), was investigated. A well that had dried out (Leinthaler 2004) yielded several grains of *P. miliaceum* (Hellmund 2004). Radiocarbon dating of a barley grain pinpointed the 11th to 10th century cal BCE (1σ, Table 2, Fig. 2) as the time when the well was in use (Hellmund 2012a).

The University of Jena recently excavated the multi-period site of **Kuckenburg** (municipality of Obhausen, county of Saalekreis) (Ettel *et al.* 2016). Plant remains from the Late Bronze Age (Ha A2-B) have been uncovered, including isolated finds of *P. miliaceum*.[5]

Pre-Roman Iron Age sites in Saxony-Anhalt with single finds of broomcorn millet

In the 1960s, a settlement pit with a large amount of charred cereal grains was excavated near **Bösenburg** (village near town of Gerbstedt, county of Mansfeld-Südharz). Hulled barley dominated the deposit; emmer, einkorn, spelt wheat were also represented, along with grains of broomcorn millet, *V. faba* and *Linum usitatissimum* (Schmidt *et al.* 1965; Schultze-Motel and Kruse 1965). The radiocarbon date on a barley grain falls in the period between the 8th and 5th centuries BCE (1σ, Table 2, Fig. 2) – that is, in the Early Iron Age (Hellmund 2012a).

5 The plant material is being processed by B. Zach, Blaubeuren.

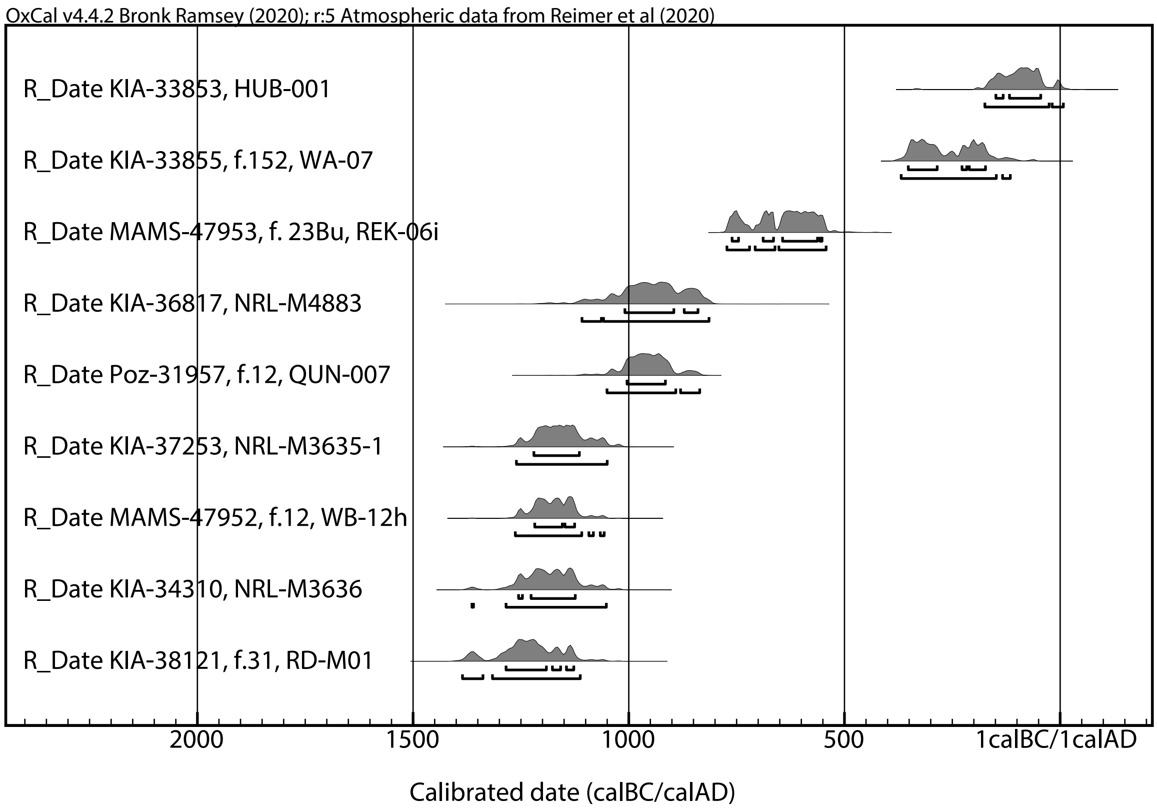

Figure 5. Radiocarbon dates on grains of Panicum miliaceum *from the following sites in Saxony-Anhalt: Hundisburg (HUB), Walsleben (WA), Reppichau (REK), Niederröblingen (NRL), Quenstedt-Schalkenburg (QUN), Wittenberg-Piesteritz (WB), Radis (RD). Calibration using OxCal v4.4.2 and IntCal20 (Bronk Ramsey 2009; Reimer et al. 2020). Prepared by the author.*

At the site of **Erdeborn** (municipality of Seegebiet Mansfelder Land, county of Mansfeld-Südharz), a large pit contained numerous fragments of *briquetage* as well as wood charcoal pieces and charred fruits and seeds (Ipach 2016). The ceramics date the site to Hallstatt Ha C to D2, that is, the Early Iron Age. Grains of broomcorn millet were detected here (Hellmund 2016).

In proximity to the construction serving as flood protection east of the River Elbe, an oven containing human bones, charcoal, clay plaster and charred grains was uncovered at the site of **Schönfeld-Wulkau** (municipality of Kamern, county of Stendal) (Petzold in press). The archaeological finds date to La Tène phase C1. The archaeobotanical material was mostly composed of barley, but broomcorn millet was also present (Hellmund in press). A radiocarbon date on a barley grain confirms the timespan, of the 4th to 3th century cal BCE (1σ, Table 2, Fig. 2).

In 1982, a rescue excavation took place on a sand dune rising above the floodplain of the Elbe, where the multi-period site of **Gommern-Gerstenberg** is located, near the town of Gommern (county of Jerichower Land) (Weber and Albert 1984). In a pit with a large concentration of barley, some grains of emmer, einkorn and broomcorn millet were also found. Despite the assumption of the excavator that the material derives from the Early Iron Age, the radiocarbon date on a barley grain gave a span of the 4th to 3th century cal BCE, that is, the Late Iron Age (1σ, Table 2, Fig. 2). In further excavations at this site, the famous 'princely grave of Gommern', dating to the Roman period, was uncovered.

In the area of the so-called '**Königshof**' (royal court) in Helfta, in the town of Lutherstadt Eisleben (county of Mansfeld-Südharz), in addition to remains from the Middle Ages, a structure of the La Tène culture was excavated and investigated by Schoknecht (1986). Here, within a large deposit of barley, grains of broomcorn millet and associated weeds were attested.

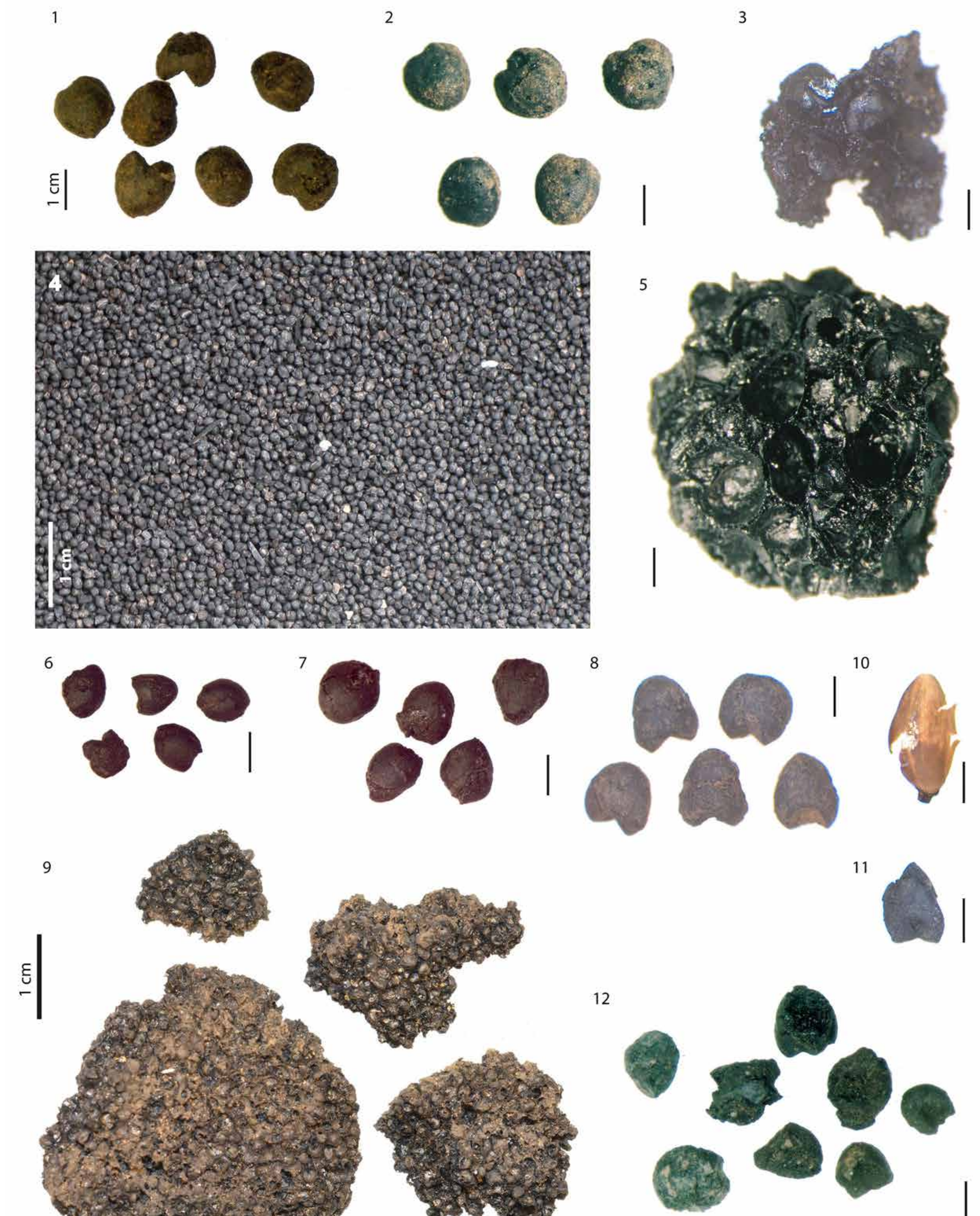

Figure 6. Selected finds of broomcorn millet grains from sites in Saxony-Anhalt, some radiocarbon dated: 1. Hundisburg HUB-001, 2. Quenstedt-Schalkenburg QUN-007, 3. Piesteritz-Wittenberg WB-12h, 4. Niederröblingen NRL-M3635 (1 mm sieve fraction), 5. Radis RD-M01, 6. Niederröblingen NRL-M3636, 7. Niederröblingen NRL-M4883, 8. Reppichau REK-06i, 9. Piesteritz-Wittenberg WB-12i (fused carbonised grains), 10. Kemberg KEF-1110-2 (uncarbonised glume), 11. Oechlitz OEC-20394-6, 12. Walsleben WA-07. Scale 1 mm except for 4 and 10, where the scale is 1 cm. Radiocarbon dated: grains 1-3, 5-8, 12 and fragments of 3 and 5. (Photo: Monika Hellmund).

Sites from the Roman period in Saxony-Anhalt with single finds of broomcorn millet

There are several Roman sites in Saxony-Anhalt with small numbers of finds of *P. miliaceum*: Osterwieck, county of Harz; Elbeu[6], county of Börde (Paysen and Nelle 2020); Wolmirstedt, county of Börde; Quedlinburg, county of Harz; and Klötze, county of Altmarkkreis Salzwedel (Leineweber and Willerding 2000). These finds were not radiocarbon dated, but dendrochronological dates were produced for wood fragments from the wells at Elbeu and Klötze.

Radiocarbon dates on the grains of *P. miliaceum* in Saxony-Anhalt: An overview

The radiocarbon dates obtained on the grains of broomcorn millet from Saxony-Anhalt are compiled in Figure 5. Apart from sample QUN-007 from Quenstedt-Schalkenburg, the samples were mass finds (concentrations). The dating shows that *P. miliaceum* was an important staple crop during the Late Bronze and the Pre-Roman Iron Age, and that it was also cultivated in the Roman period.

Discussion

The results show that, actually, there are no confirmed finds of broomcorn millet from either the Neolithic or the Early Bronze Age in Saxony-Anhalt. None of the recorded grains of broomcorn millet pre-date 1400 BCE. This is in line with the finding by Filipović *et al.* (2020) that *P. miliaceum* arrived in Europe in the 16th century BCE and in north-central Europe specifically in the 13th/12th century BCE. As noted above, the dating of the previously published finds of *P. miliaceum* from Oechlitz (Hellmund 2017) as Early Bronze Age must be revised because the finds have recently been archaeologically re-assigned to the Late Bronze Age.

The cultivation of broomcorn millet began in Saxony-Anhalt at about 1300/1200 BCE, early in the Late Bronze Age (Bz D-Ha A). The oldest records of broomcorn millet relate to burial sites of the Lusatian culture and a settlement site of the Unstrut group (Niederröblingen). The features at Quenstedt-Schalkenburg containing *P. miliaceum* are younger than those at Niederröblingen (Table 1). With regard to the seeds of faba bean from Quenstedt, Schultze-Motel already doubted the Neolithic age of their find context, pit no. 116:

'*Charred remains* [of faba bean] *are completely absent from the Neolithic in our area … The occurrence of charred faba beans in pit 116 can only be accepted from a botanical point of view with great reservations*' (pers. comm. cited by Behrens and Schröter 1980, 99 translated by the author).

The radiocarbon-dated faba bean from pit no. 116 at Quenstedt-Schalkenburg dates to the 11th to 10th century cal BCE (Figs. 3, 5). Some of the pits at the site contained pottery of the Neolithic Bernburg culture together with finds of broomcorn millet. In five cases, the grains were directly radiocarbon dated, allowing for the exact age of the broomcorn millet to be established and the find to be assigned to the Late Bronze Age. Two of the pits with Bernburg culture pottery contained broomcorn millet and faba bean, another pit had broomcorn millet, and further three pits contained seeds of faba bean. These plant materials cannot automatically be attributed to the Neolithic based solely on the presence of the characteristic Bernburg culture pottery. On the contrary, it can be assumed that other finds of

6 However, dendro-dates on the wood from the well place this site in the Roman period, not in the Pre-Roman Iron Age.

broomcorn millet and faba bean from the pits at Quenstedt-Schalkenburg are also likely from the Late Bronze Age/Early Iron Age.

'Ancient' finds of *P. miliaceum* and *V. faba* in adjacent areas

Another 'early' find of *P. miliaceum* was reported from the ritual site located on the burial grounds of **Drehna**, part of the town of Luckau (county of Dahme-Spreewald, federal state of Brandenburg) (Rösler 1983). K. Kloss identified small pieces of carbonised crusts found in a pit as being composed mainly of the grains of '*Hirse*', presumed by the author to refer to *P. miliaceum*, but this material should be reinvestigated. Other features at this site were archaeologically dated to the end of Period III (Tiedtke 2015), that is, the beginning of the Late Bronze Age according to the cultural periodisation applied in central Germany (Table 1).

In the federal state of Hesse, first indications of *P. miliaceum*, proposed to have been associated with the Únětice culture, were discovered at the sites of **Mardorf** (Kreuz 2000) and **Linsenberg**, in the Glauberg area. As far as is known, no ^{14}C-dates were produced for these grains, but the radiocarbon dating of other plant material found confirmed an Early Bronze Age date for the sites (Kreuz 2016). However, as long as there is no corresponding radiocarbon dating of the grains of broomcorn millet, it remains only a hypothesis that broomcorn millet was already being cultivated in the Early Bronze Age. Given that a broomcorn millet grain from other sites in Hesse – for example **Bruchenbrücken**, county of Friedberg (Kreuz 1990) – was radiocarbon dated to the period between the end of 16th and early 14th century cal BCE (2σ; Motuzaite-Matuzeviciute *et al.* 2013), it seems likely that the cultivation of *P. miliaceum* began earlier in the adjacent regions to the south of Saxony-Anhalt.

Changes in the spectrum of crop plants due to climatic variations?

During the Bronze Age, two climatic deteriorations were recorded, one in the middle of the 2nd millennium, the so-called Löbben fluctuation, with an assumed shift towards cooler and wetter climatic conditions, and a second one around 800 BCE (Göschenen phase 1). Lake-level transgressions led to the final abandonment of wetland settlements on the lake shores in Switzerland and the surrounding regions (Della Casa 2013). The varied climate during the Subboreal period, with alternating wet and dry phases, may have initiated or accelerated the introduction of new crop species. In this context, cultivation of the warm-season plant *P. miliaceum* would have been beneficial during the suggested dry episodes in the Bronze Age. In the so-called 'Mitteldeutsches Trockengebiet' in parts of Thuringia and Saxony-Anhalt, where the present-day rainfall is less than 500 mm per year, cultivation of *P. miliaceum* may have been particularly favoured. It has been suggested that a climate suitable for growing wine grapes is good for broomcorn millet too (Steinbrück 1908). But cultivation in the past was not restricted to such areas, and the large deposits of *P. miliaceum* in settlement pits described above, as well as the charred millet porridge in graves, prove its cultivation in a range of local climates.

Broomcorn millet and faba bean: A meal for the dead?

Some of the described finds of broomcorn millet come from burial sites (*e.g.* Piesteritz-Wittenberg and Radis in Saxony-Anhalt, Drehna in Brandenburg). The question arises as to whether the plants detected in burial contexts were in some way special, *i.e.* exotic, and/or whether they were part of everyday diet. Frachetti *et al.* (2010), for example, interpreted the millet grain found in a 3rd millennium BCE burial cist in Kazakhstan as an element of the ritual. This is especially relevant where large deposits or fused grains of millet ('prepared food') have been found. There is a mention in the literature of another location with such a find – **Ostro-Jiedlitz** (county of Kamenz, federal state of Saxony), dated to the Early Iron Age (Ha C2-D1) (Nebelsick and Swieder 2018), where Pax and Hofmann (1915) found carbonized lumps of probable *P. miliaceum* grains. Effenberger (2017) and Jahns *et al.* (2018) did not record any remains of charred millet 'porridge' from graves in Brandenburg, but charred grains of broomcorn millet and seeds of faba bean have been found, for example, at the site of **Großbahren** (in the town of Sonnewalde, county of Elbe-Elster, federal state of Brandenburg) (Effenberger 2017). In his old compilation, Netolitzky (1914) mentions other sites where charred broomcorn millet crusts were found. But it is uncertain whether these finds have been saved and stored in archives.

Broomcorn millet in ritual contexts

The grains of broomcorn millet found in burial contexts can be interpreted as grave goods – food for the dead. According to *Handwörterbuch des deutschen Aberglaubens* [*Concise Dictionary of German Superstitions]*, millets represented food for the soul that appeared in entertainment at funeral feasts. Therefore, broomcorn millet could be understood as a food for the dead. Moreover, millets were perceived as a symbol of fertility because of the many small grains, and they were also considered as symbolising wealth (Bächtold-Stäubli *et al.* 1987a).

Faba bean in ritual contexts

V. faba is often found in graves of the Lusatian culture and in settlement pits of the Late Bronze Age. Schultze-Motel (1972) and Jäger (1965, 1987) reported that the earliest finds of this species come from central Germany. More finds have since been added, including those from the sites of Quenstedt-Schalkenburg, Wittenberg-Piesteritz, Walsleben, Coswig (Anhalt) and Buroer Feld in Saxony-Anhalt. In the former village of Tornow (town of Lübbenau/Spreewald, county of Oberspreewald-Lausitz, federal state of Brandenburg), *V. faba* has been documented at a site dated to the Bronze Age Period V (Ha B) (Jäger 1965). Finds of *V. faba* were also registered at the ritual site on the burial ground of Drehna, in the state of Brandenburg (Rösler 1983).

Faba bean was also important in the ancient cult of the dead, according to the folk knowledge described in the *Concise Dictionary of German Superstitions*. In the Roman period, it was used in the cult of the soul (Bächtold-Stäubli 1987b). Faba bean may have been as important in prehistoric times in ritual contexts as its presence in the graves suggest. Pliny described how faba bean was used in the celebrations of the dead because of the belief that the beans preserved the soul of the deceased (Lenz 1859).

Broomcorn millet and faba bean in settlement structures

The settlement pits at Niederröblingen yielded three mass finds of cereals dominated by broomcorn millet and dating from the Late Bronze Age; no legumes were detected there. At Quenstedt-Schalkenburg, small amounts of *P. miliaceum* were discovered in more than a dozen features. Here, broomcorn millet was one of the most important crop species, after emmer and barley. It can be assumed that, in the pits, *P. miliaceum* became mixed with the older, Neolithic Bernburg culture pottery as a result of soil movement or bioturbation. Indeed, during the Late Bronze Age, and again at the end of the Hallstatt period and beginning of the La Tène culture, the site underwent large-scale digging and levelling as part of the construction of the fortification (Sosnowski 2014, 2015). Unlike at Niederröblingen, at the Late Bronze Age site of Quenstedt-Schalkenburg, legumes such as *V. faba* played an important role alongside cereals.

Based on the frequent finds of *P. miliaceum* and *V. faba* in the settlements at Quenstedt-Schalkenburg and Walsleben, and the substantial evidence for broomcorn millet at Niederröblingen, it can be concluded that both species played an important role in human diet. Apparently, no distinction was made between the food of the living and the food for the dead.

Conclusion

The direct ^{14}C-dating of grains of *P. miliaceum* and seeds of *V. faba* confirms that there are no Neolithic remains of these species in Saxony-Anhalt. Thus far, there is no evidence for the presence of broomcorn millet in the Early and Middle Bronze Age either. Actually, there are now doubts about the age of all 'ancient', non-radiocarbon-dated (single) finds of broomcorn millet from Saxony-Anhalt, especially those stated to be older than the middle of the 2nd millennium BCE based on their archaeological context. In Hesse, a somewhat earlier cultivation of *P. miliaceum* can be assumed, as indicated for example by the radiocarbon date on millet grains from Bruchenbrücken. Climatic changes, namely deterioration caused by cool and humid conditions and/or the intervening drier periods, may have promoted the growing of *V. faba* and *P. miliaceum*. The introduction of new crops could have been a response to the changing climatic conditions or a result of increased cultural connections, exchange and trade with regions in eastern or southeastern Europe, where the evidence for these two species is older, as shown by the radiocarbon dates on broomcorn millet grains. A definite and obvious advantage of the cultivation of new crop species would have been diversification of the subsistence base as a way of reducing the risk of crop failure.

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Millets in Bronze Age agriculture and food consumption in northeastern France

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Abstract

Populations of the Early Bronze Age and the Middle Bronze Age left a small footprint in northeastern France, settlement evidence being very scarce and funerary contexts barely more numerous. Starting from the 14th *c.* BCE onwards, important changes occurred in settlement and land use. An ongoing development of settlements, expanding into previously unexploited environments, is observed. This major demographic increase was sustained by a new and dynamic agropastoral economy, in which broomcorn millet seems to have played a central role. To better understand this role, as well as the chronology of changes in farming practices, archaeobotanical research on Bronze Age data from northeastern France has been coupled with radiocarbon dating of the earliest records of broomcorn millet. Results suggest that the introduction of broomcorn millet in France did not take place before the 14th *c.* BCE, a date in line with the recently published chronological model of the spread of millet in Europe (Filipović *et al.* 2020).

The introduction of millet was not the only change occurring in Bronze Age farming systems. Archaeobotanical evidence indicates that the diversification of crops, integrating new species of cereals, pulses and oil plants, together with a less cereal-focused farming production, had generated a resilient agriculture, securing crop production and thus promoting soaring demographics. Consequently, the gathering of wild carbohydrate resources, such as acorns, declined.

If not the only new crop, broomcorn millet was one of the most widespread new crops during the Late Bronze Age in northeastern France (Bouby *et al.* 2017). Its diffusion seems to have been quick and thorough. Millet was part of the daily diet on every small farm; it was also on the menu for festive meals during large

collective gatherings and accompanied the dead as a funerary offering. This small-seeded cereal was indeed the emblematic plant of food identity during the Late Bronze Age.

Introduction

As the star cereal of the European Bronze Age, broomcorn millet (*Panicum miliaceum*) has been the subject of intense interdisciplinary research for the past 15 years, the issues and methods of which have strongly evolved over time (Liu *et al.* 2018). Questions have shifted from the origin of the plant and the hypothesis of multiple domestications, eastward and westward of central Asia (Jones 2004; Hunt *et al.* 2008; Zohary *et al.* 2012), to the tracking and chronology of the paths of the spread of millet from China to Europe. The development of Chinese archaeobotanical investigations (Ren *et al.* 2016), complemented by stable isotopes studies (Lightfoot *et al.* 2013), advances in archaeogenetic research (Hunt *et al.* 2014; Hunt *et al.* 2018) and radiocarbon dating programmes on European prehistoric millets (*e.g.* Motuzaite Matuzeviciute *et al.* 2013) have indeed succeeded in demonstrating both the seniority of Chinese records and the Chinese origin of broomcorn and foxtail millets (Miller *et al.* 2016; Liu *et al.* 2018). The earliest European records have been brought forward by several millennia, to the time of the first material evidence of contact between East and West, during the Bronze Age (Sherratt 2006). Research has subsequently focused on the modelling of the westward dispersal of millet from China and the identification of the hubs and tempo of diffusion in Europe (Miller *et al.* 2016; Liu *et al.* 2018; Filipović *et al.* 2020). In the framework of recent millet research, many direct dating programmes have already been conducted all over Eurasia (*e.g.* Filipović *et al.* 2018; Herrscher *et al.* 2018), while others are still in progress.

Now that the question of the chronology of the arrival of millet in Europe is being resolved, other issues are emerging about the changes possibly brought about by this new cereal crop ('the millet effect'). Innovations may have concerned many different aspects, such as farming systems, human and animal diet, population increase, expansion, and the organisation of societies. These topics were discussed during the Millet International Workshop held in Kiel, November 2019, and this article formed a contribution to it. It provides unpublished information on French data related to the research questions just mentioned.

Starting with the 'when' of the arrival of millet, we present chronological data from northeastern France, incorporating both chrono-cultural and direct dating. An extensive archaeobotanical synthesis was initially carried out based on all available data from Bronze Age settlements in this area. A series of radiocarbon dates was then obtained from the earliest records, to check their antiquity. This set of dates documents a new milestone in the history of millet diffusion in Europe, extending westward the recent works on more eastern regions. Northeastern France had strong connections with central Europe during the Middle Bronze Age and Late Bronze Age (MBA, LBA, from approximately 1650/1600 to 800/750 BCE) (Mordant 2013) and was probably the gateway into France for millet (Bouby *et al.* 2017).

Continuing with the 'how' and 'why', we present factual data on changes in farming systems and subsistence economy that took place in LBA societies after the introduction of millet. We discuss the role of millet in crop husbandry organisation as well as in the daily diet and festive celebrations and underline the fact that this small-seeded cereal of Chinese origin, today a minor crop in Europe, was a major element of the food identity, not only in northeastern France, but in a large part of Europe during the LBA.

Before presenting the archaeobotanical data, we present the archaeological background. Settlement and land use underwent major changes during the Bronze Age, concomitant with those observed in farming systems. It is therefore essential to explore these changes to better understand the overall scheme.

Bronze Age in northeastern France: The archaeological background

Several archaeological overviews concerning the Bronze Age in France have been published in the past decade (Mordant 2013; Carozza *et al.* 2017a; Lachenal *et al.* 2017; Guilaine and Garcia 2018). However, despite the exponential increase in discoveries over the past 25 years, which ensures we have a reliable archaeological dataset, there has been no re-evaluation of knowledge about land use during the Early Bronze Age (EBA) and MBA (2300/2200-1350 BCE) in northeastern France. Overall, finds relating to domestic occupation remain very sparse for these early phases, in striking contrast to the spectacular number of discoveries for the subsequent period, starting at the transition between the MBA and the LBA (14th *c.* BCE; Carozza *et al.* 2017b, Figs. 5-8). This observation is particularly true for the westernmost part of the study area, in the Île-de-France and Champagne regions (Fig. 1). Even in extensively excavated areas, such as the Upper Seine Valley and the Marne Valley (Peake *et al.* 2017a, 2017b; Peake 2020, 13-15) or the plain of Troyes (Riquier *et al.* 2017a, 2017b), funerary contexts and settlement sites from the EBA and MBA are not visible. Traces of occupation mainly consist of some isolated pits or waste accumulations in oxbow lakes, with an extremely small footprint and no evidence of buildings or organised settlement. Starting from the middle of the 14th *c.* BCE and the transition to LBA1 (1350-1100 BCE), settlements multiply exponentially, are more visible in the landscape, and more permanent. At first, they come as modest and isolated open-air farms, comprising pits with rich archaeological deposits, sometimes associated with small post-framed buildings. Then, during the five centuries of the LBA (1350-750 BCE), land occupation intensifies, extending out of the valleys and onto the plateaus of Île-de-France and the chalk plain of Champagne, while settlements diversify. During LBA3 (900-750 BCE), although most settlements are still small farmsteads, others develop into hamlets, such as the sites of Buchères, in Champagne (Riquier *et al.* 2012); Rosières-aux-Salines, in Lorraine (Koenig and Klag 2017); and Marolles-sur-Seine, in Île-de-France (Peake *et al.* 2017a). At the very end of the LBA, fortified sites, with a more ostentatious rather than truly defensive character, appear in the Upper Seine Valley, punctuating it spatially at regular intervals, and illustrating the hierarchy of Bronze Age society. These high-status sites interact with smaller settlements and sometimes host seasonal collective gatherings and feasts, such as at Villiers-sur-Seine (Auxiette *et al.* 2015; Peake 2020). Palisaded storage areas start to develop at the beginning of the Early Iron Age (EIA), with dozens of granaries in the Champagne chalklands (Desbrosse and Riquier 2012) and storage pits and granaries on the loess plateaus of Île-de-France (Peake *et al.* 2017a) and in the Moselle Valley (Deffressigne *et al.* 2002).

In Picardy, a similar evolution took place. A low human footprint for the EBA and MBA is followed by a significant rise in the number of settlements starting at LBA2 (1100-900 BCE). During LBA3, some houses are grouped into hamlets, such as in Choisy-au-Bac, and the development of large storage areas is observed (Buchez *et al.* 2017). In other northeastern regions, such as Alsace (Michler *et al.* 2017), Lorraine (Koenig and Klag 2017), and northern Burgundy (Ducreux 2017), EBA settlements are more visible, but not very numerous. Different types of building plans have been documented, such as large, three-aisled post-framed buildings in the Moselle Valley or two-aisled buildings in Alsace. The MBA seems to be a period of extremely low population size and land use everywhere in northeastern France. This changes at the

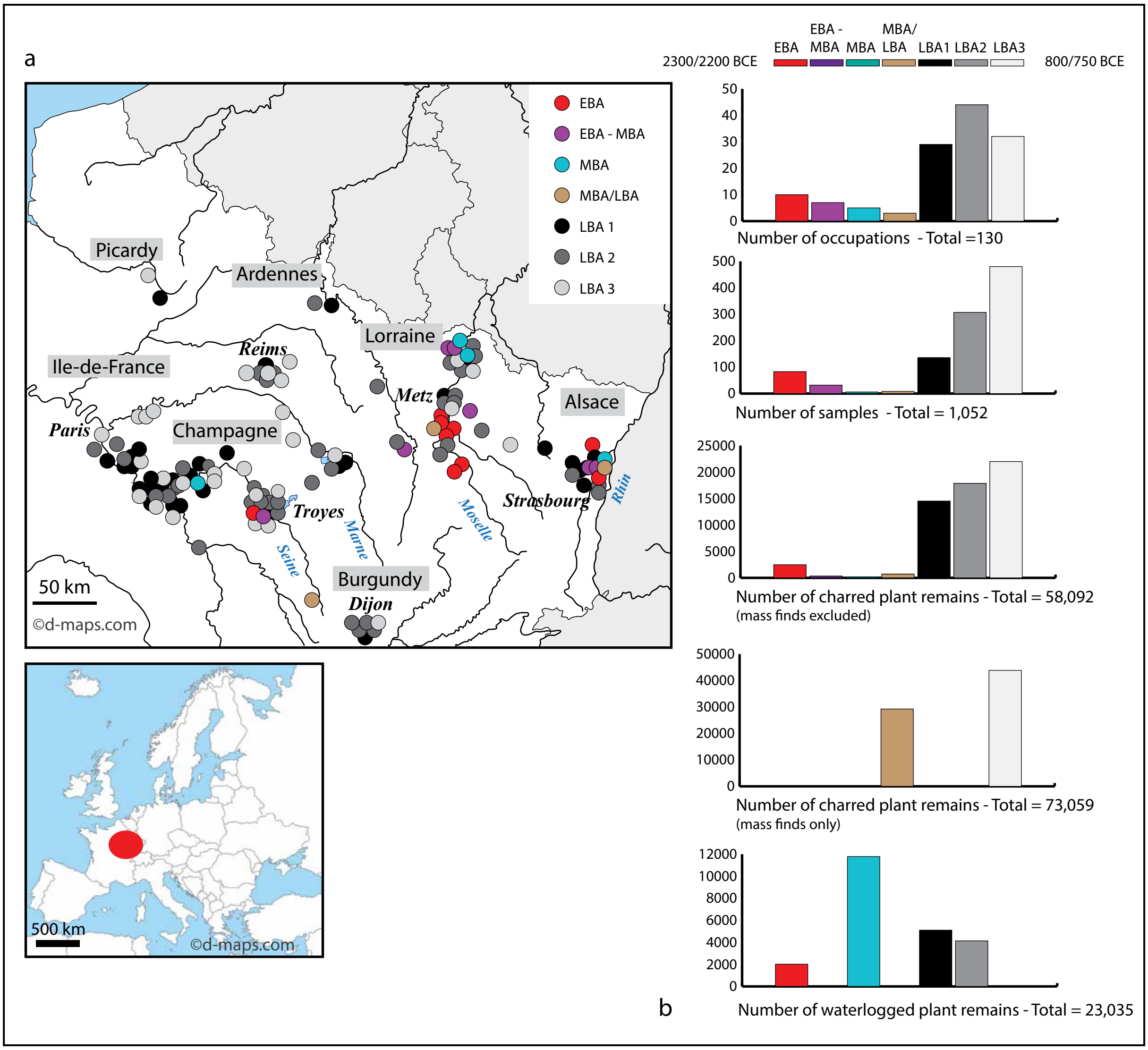

Figure 1. (a) Location of 130 Bronze Age settlements with archaeobotanical data in northeastern France (b) Results of the archaeobotanical synthesis per Bronze Age phase. EBA=Early Bronze Age; MBA=Middle Bronze Age; LBA=Late Bronze Age. Mass finds=concentrations of ≥100 remains per litre.

beginning of the LBA, when a sudden and impressive increase in human occupation is observed throughout the area. This would continue for several centuries.

The reasons for such a low human footprint during the EBA and MBA are unknown. Hypotheses include erosion of sites, or an economy based on a semi-nomadic way of life, with settlements leaving few traces (Riquier *et al.* 2017b). The sudden increase in settlements in such areas as the Upper Seine Valley, which had been almost deserted during the MBA, has been linked to potential migrations from eastern regions, as the source of cultural influences in funerary material shifted from west to east at the end of the MBA (Peake *et al.* 2017b). The whole phenomenon – sluggishness and then a marked surge in population – seems to have been a Europe-wide occurrence (Stika and Heiss 2013; Kneisel *et al.* 2015a), and thereby may also have been linked to large-scale events affecting agriculture, such as climate change, although showing complex and regionally different developments (Magny *et al.* 2007; Kneisel *et al.* 2015a; Capuzzo *et al.* 2018). In reality, it is likely that a complex combination of many different parameters was the cause.

For whatever reason, a sparse population with a low environmental impact seems to have been the rule in most places in northeastern France until the end of the MBA. From the 14th *c.* BCE onwards, a new rural society emerges and develops.

It is characterised by a densification of population networks, supported by a very dynamic agropastoral economy. Millets seem to have played a central role in this new economy. An overview of data tracing the time of the arrival and the rhythm of spread of millet cultivation may help us identify its role.

Arrival and adoption of millet cultivation in northeastern France: Synthesis of the archaeobotanical evidence

The overview of archaeobotanical data with a focus on millets that we aim to present in this paper was carried out for the millet workshop held in Kiel, November 2019. As several recent works had demonstrated that millet did not arrive in Europe during the Neolithic (see Introduction and Conclusions to this volume), we chose to consider only finds dated to the Bronze Age. This work constitutes an important update of previous work. Following the very first research on millets in France, published at a time when the finds of this plant were scarce and studies concerned mainly southern France (Marinval 1992, 1995), a national survey gathering all available French data for the Bronze Age and Early Iron Age was conducted in 2011 and published in 2017 (Bouby *et al.* 2017). Information was collected from 272 French sites, 47 of which fall within the geographical and chronological target of our present work. Since this broad synthesis, the activity of rescue archaeology, coupled with the continued expansion of archaeobotany in northeastern France, has more than doubled the available data for Bronze Age in the research area. The quantity of additional data, and the need for a higher chronological resolution than the one used in the 2011 survey, made it necessary to carry out a new study, this time at a regional level.

Material

The geographical framework of this overview, northeastern France (Fig. 1a), includes the Grand Est region (bringing together the former regions of Champagne-Ardenne, Lorraine, and Alsace); the eastern part of the Île-de-France (département of Seine-et-Marne) and Hauts-de-France (département of Aisne in Picardy) regions; and the northern part of the Bourgogne-Franche-Comté region (départements of Yonne, Côte-d'Or, and Haute-Saône). The Bronze Age in this area lasts from approximately 2300/2200 to 850/750 BCE. It is culturally divided into the Early Bronze Age (2300/2200-1600 BCE), the Middle Bronze Age (1600-1350 BCE) and the Late Bronze Age (1350-800/750 BCE), which is itself split into LBA1 (1350-1100 BCE), LBA2 (1100-900 BCE) and LBA3 (900-800/750 BCE). The data presented here derive from 130 distinct occupation phases from a total of 96 settlement sites, some sites having been occupied in several phases (Fig. 1b). The dataset was assembled by 12 archaeobotanists, belonging to different institutions, and represents all available information for the study as of November 2019 (see Table 3 below).

Most settlements are small, isolated and open-air family farms, but there are some exceptions for LBA3, when the range of site types diversifies (see above). For this period, it also includes a hamlet-like site (Buchères; Riquier *et al.* 2012, 2015), fortified aristocratic settlements (such as Villiers-sur-Seine; Auxiette *et al.* 2015; Peake 2020) and palisaded enclosures with numerous granaries (as at Bazancourt; Desbrosse and Riquier 2012).

Sampled features mainly consist of waste pits, storage pits and postholes; they also include several ditches, ovens, hearths and wells. Systematic bulk sampling was carried out, with a minimum volume of 10 litres per sample whenever possible. Samples were processed by water-flotation or wet sieving, using a minimum mesh size of 0.25 to 0.5 mm.

Site	Location	Archaeological context	Number of charred grains dated	Dating by relative chronology (BCE)	Laboratory sample number	Direct dating ^{14}C (years BP)	Direct dating (cal BCE) with 2σ probability (95.4%)	AMS $\delta^{13}C$ (‰)	Carbon mass [mg]
Réau *Parc d'activités de l'A5*	Seine-et-Marne, Île-de-France	Pit	6	1350-1100	Poz-129554	3045 ± 30	1401-1220	−8.5	1.56
Balloy *La Haute Borne*	Seine-et-Marne, Île-de-France	Pit	8	1350-1200	Poz-129551	3040 ± 30	1401-1216	−10.9	0.64
Gingsheim *Steinbrünnen, Aschenbuckel*	Bas-Rhin, Alsace	Pit	5	1350-1200	Poz-129549	2980 ± 30	1375-1059	−14.3	1.48
Hérange *Gross Eichholz*	Moselle, Lorraine	Pit	6	1350-1200	Poz-129550	2960 ± 30	1265-1054	−11.3	2.06
Sézannes *Maison de Santé*	Marne, Champagne	Pit	10	1350-1200	Poz-129552	2945 ± 35	1262-1020	−15.1	0.19
Courceroy *Les Dizaines*	Aube, Champagne	Well	1	1350-1100	Poz-129553	2865 ± 30	1125-926	−16	0.68
Réau *Centre Pénitencier*	Seine-et-Marne, Île-de-France	Pit	3	1350-1100	Poz-133340	2835 ± 30	1109-908	−6.7	1.391
Ville-Saint-Jacques *Le Bois d'Echalas*	Seine-et-Marne, Île-de-France	Storage pit	10	1350-1100	Poz-129182	2475 ± 30	770-423	−8.4	1.73
Pont-sur-Seine *La Gravière*	Aube, Champagne	Building postholes	10	1450-1300	Poz-129548	2335 ± 30	514-236	−14	2.25

Table 1. Results of AMS ^{14}C-dating of early finds of broomcorn millet in northeastern France.

Results

Results of direct AMS-radiocarbon dating

At the time of the presentation in Kiel, nearly all reported dates for the archaeobotanical material came from relative dating, based on the association of fossilised plant remains with cultural artefacts, mainly pottery, in archaeological layers. A few dates derived from radiocarbon dating on charcoal, cereal caryopses or animal bones, but there was no direct dating of millet remains. Being fully aware that this has resulted in misleading ages for intrusive grains of millet, as demonstrated by the results of the radiocarbon dating programmes recently carried out in Europe (Motuzaite Matuzeviciute *et al.* 2013; Filipović *et al.* 2020), we have since undertaken direct dating on broomcorn millet, starting with the earliest (and most questionable) finds. The goal was to remove doubts about the age of these remains and to specify the date of millet arrival in the study area. These first direct dates launch a database that will help, once it is more extensive, to trace the routes of the introduction and spread of millets in France. The database will also allow comparisons with neighbouring countries where large radiocarbon dating programmes have already been conducted.

During the process of selecting the grains to be dated, some of the earliest finds presented in Kiel were discarded for various reasons: dubious taxonomic identification for Pagny-lès-Going-Aéroport de Moselle, Lorraine (2200-1500 BCE); re-attribution of the feature of the find to a later date for Warcq-Bois de Charnois, Ardennes (from 1450-1300 to 1200-1100 BCE); and material not accessible in the case of Ay-sur-Moselle-Les Vélers Jacques (1350-1200 BCE). A total of 10 samples of the remaining earliest discoveries of broomcorn millet, 9 of which concern charred grains and 1 of which concerns waterlogged glumes, were submitted to Poznań Radiocarbon Laboratory (Poland) for AMS-dating. The finds come from different

Figure 2. Some of the plant remains sent for radiocarbon dating: (a) Waterlogged lemma/palea of Echinochloa crus-galli/Panicum miliaceum *from Erstein-Parc d'Activités du Pays d'Erstein, Bas-Rhin; Charred grains of* Panicum miliaceum *from (b) Hérange-Gross Eichholz, Moselle, (c) Sézannes-Maison de Santé, Marne, (d) Réau-Parc d'activités de l'A5, Seine-et-Marne, (e) Pont-sur-Seine-La Gravière, Aube, (f) Balloy-La Haute Borne, Seine-et-Marne, (g) Gingsheim-Steinbrünnen, Aschenbuckel, Bas-Rhin, (h) Ville-Saint-Jacques-Le Bois d'Echalas, Seine-et-Marne.*

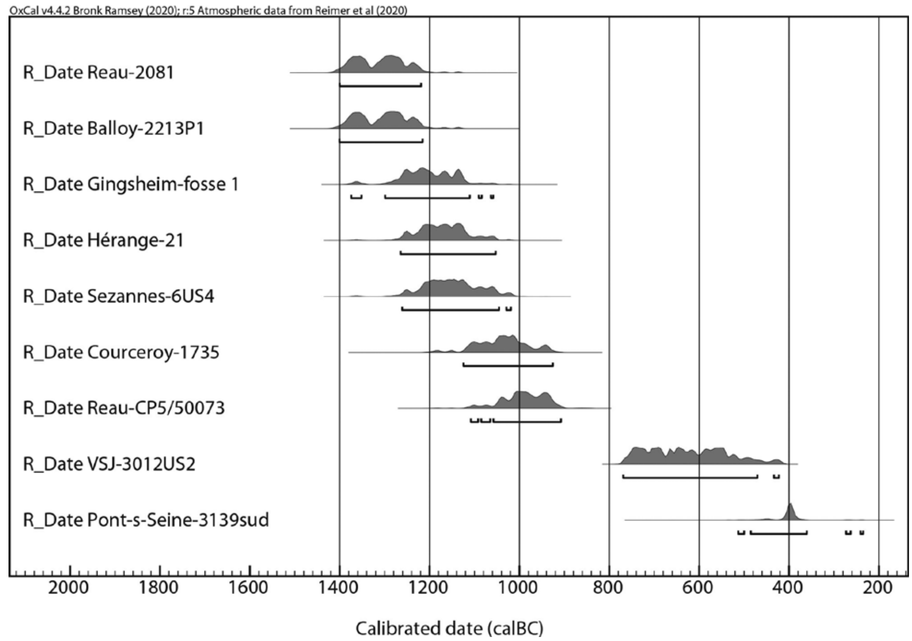

Figure 3. Calibrated AMS ^{14}*C dates of broomcorn millet from northeastern France (calibration with OxCal v.4.4.2 and IntCal 2020 software; Bronk Ramsey 2009, 2017; Reimer* et al. *2020).*

areas, covering the entire northeastern quarter of France, from Alsace to Île-de-France (Fig. 1a). The results of the AMS-dating are presented in Table 1 and Figure 3.

The supposed earliest find consists of six waterlogged lemma/palea (Fig. 2a) recently recovered from a well at the site of Erstein-Parc d'Activités du Pays d'Erstein, Bas-Rhin, in Alsace (Croutsch *et al.* 2016b). They appeared to be an interesting discovery, as the different types of dating performed on the well layer (dendrochronology on the oak fixtures, typo-chronology of the pottery and radiocarbon dating on a human bone) all converge to the 16th *c.* BCE (Croutsch *et al.* 2016a). But, identification of the glumes as coming from *P. miliaceum* was doubtful and could not be ascertained because of the poor preservation of the glumes; *Echinochloa crus-galli* was a more likely candidate (Kroll pers. comm.). Moreover, the remains could not be radiocarbon dated because of their low carbon content. For both reasons, this find was not taken into consideration.

The charred grains from Pont-sur-Seine-La Gravière and Ville-Saint-Jacques-Le Bois d'Echalas (Fig. 2e, h) turned out to date to a much later period than expected (Table 1, Fig. 3), namely 514-236 cal BCE (Late Iron Age) and 770-423 cal BCE (Iron Age), respectively. These two sites are multi-phase settlements, with occupations whose relative chronology encompasses the radiocarbon dates (Issenmann *et al.* 2009; Dupéré *et al.* 2013; Toulemonde 2013).

The other six radiocarbon dates fall within the expected timeframe according to the cultural chronology (Table 1). The earliest finds are recorded from Île-de-France (Balloy, in the Upper Seine Valley, and Réau, on the Sénart plateau). Given the current state of our direct dating results, we can conclude, at least provisionally, that broomcorn millet did not arrive in northeastern France before the 14th *c.* BCE.

Results of the archaeobotanical synthesis

Archaeobotanical studies carried out on the 96 Bronze Age sites identified a total of 131,151 charred plant remains from 1052 samples. Of these remains, 58,092 came from waste assemblages and 73,059 from four cereal mass finds. A total of 23,035 waterlogged plant remains have also been recovered, from wells at five different sites. As expected, the distribution of data is uneven, with the Late Bronze Age accounting for more than 95% of the charred material (Fig. 1b).

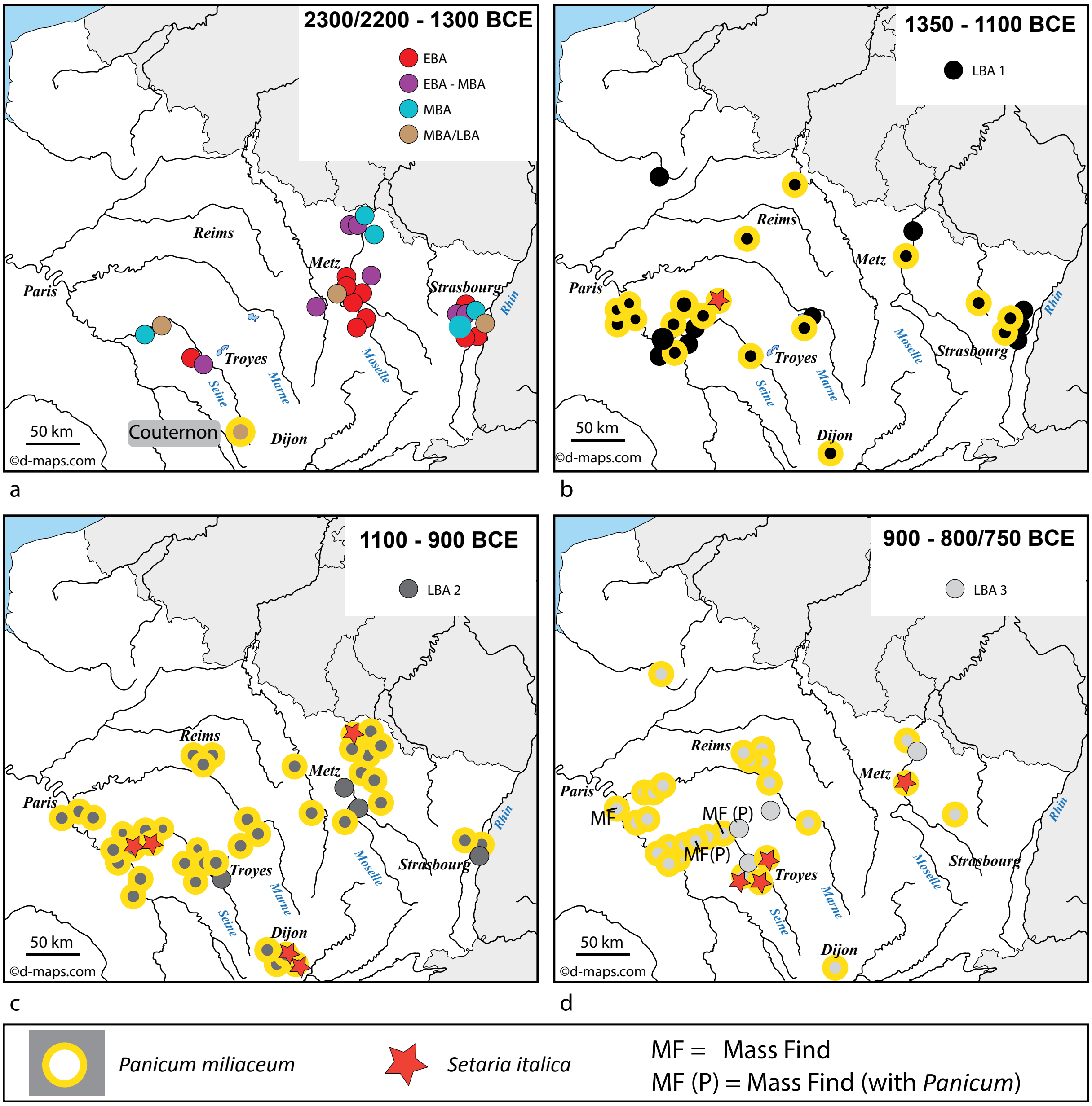

Figure 4. Records of broomcorn millet (Panicum miliaceum) *and foxtail millet* (Setaria italica) *from northeastern France: (a) from the Early Bronze Age (EBA) to the Middle Bronze Age-Late Bronze Age transition (MBA/LBA), (b) during LBA1, (c) during LBA2, (d) during LBA3.*

Early Bronze Age and Middle Bronze Age (2300/2200-1350 BCE)

Nine sites have been dated to the EBA. They are mainly located in the eastern part of the study area, in Alsace and Lorraine, where more settlements are known for this period than farther west (Fig. 4a). The archaeological material dates four of these sites to 2200-1650 BCE, and five others to 2000-1650 BCE. Altogether, they yielded 2,483 charred and 2,017 waterlogged plant remains. No millet is reported from these assemblages. Seven more sites are less accurately dated to the EBA/MBA (Fig. 4a). Plant remains are scarce (347 charred remains) and millet is absent.

For the MBA, the five sites analysed are again mainly located in Alsace and Lorraine (Fig. 4a). Charred remains are even scarcer (179) and comprise no millet, if we exclude the doubtful millet from Erstein-Parc d'activités du Pays d'Erstein (see above).

At the end of the MBA/beginning of LBA (15th-14th *c.* BCE), human occupation gradually increased. Four settlements were studied for this period and two of them supposedly yielded broomcorn millet. However, as explained earlier, the radiocarbon dating of some of the grains of the large, charred deposits (2453 caryopses of broomcorn millet) found in Pont-sur-Seine-La Gravière (Champagne) resulted in a much later date for the millet (Fig. 3). It corresponds to the beginning of the EIA, the time of the second settlement phase at this site. At Couternon-Larrey (Burgundy), two grains of broomcorn millet were found in a silo pit dated to the MBA-beginning of LBA (Wiethold 2007).

Late Bronze Age (1350-800/750 BCE)

From the very beginning of the LBA, human settlements multiplied, and almost all of them, from east to west, cultivated broomcorn millet (Fig. 4b, Table 2, Table 3). The few sites that did not yield millet caryopses are also those that revealed very scarce remains of domestic plants in general. It is as if this cereal started to be cultivated everywhere simultaneously or at least within a very short timeframe, and was intricately linked to the expansion of human settlement, which had become visible and more permanent. There is no evidence of a slow beginning followed by a progressive increase. This could be due to the absence of data for the MBA. Maybe the first attempts at millet cultivation are invisible, much like the MBA settlements.

Cultivation of the new cereal maintains momentum throughout the LBA (Fig. 4c, d, Table 2). Both the ubiquity of broomcorn millet (Table 2) and the proportions of its caryopses in relation to those of other cereals (barley, wheat and Cerealia) during the three phases of the LBA (Fig. 5) confirm its importance in agricultural production since the very beginning of this period. Previous research has already shown that the ubiquity of millet could regularly reach 60% to 70% of the samples per site in some parts of the Upper Seine Valley or Champagne (Toulemonde 2013; Goude *et al.* 2016). Charred mass finds are not recovered before LBA3 (10th-8th *c.* BCE); when they appear, they include millets as well as other cereals (Figs. 4d, 5).

But what about foxtail millet (*Setaria italica*)? The first discovery comes from Sézannes, Champagne. It is comprised of a single charred caryopsis, dated to the 14th-13th *c.* BCE (Fig. 4b). Charred grains of broomcorn millet from a different layer within the same feature have been radiocarbon dated to 1262-1020 cal BCE (Table 1). Other records are available for the following period (12th-10th *c.* BCE) from all over northeastern France (Fig. 4c, d). *Setaria italica* may have been introduced as a weed of *Panicum miliaceum*, since only a few grains, associated with larger amounts of broomcorn millet, are initially present. Then, at the end of LBA3 (10th-8th *c.* BCE), the site of Buchères-Parc Logistique de l'Aube (Champagne) provided a cache of 200 grains of *Setaria*, mixed with 60 grains of *Panicum* and other cereals, suggesting that *Setaria* could have been a crop in its own right at that time. More *Setaria* is recorded for the Early Iron Age, confirming that its cultivation was well established, even if it seems to have never been as widespread as *Panicum miliaceum*.

Period (BCE)	Number of settlements with more than 20 charred grains of domestic plants (=X)	Number of settlements with broomcorn millet (% of X)
14th-13th *c.*	6	5 (83%)
14th-12th *c.*	6	5 (83%)
13th-11th *c.*	6	5 (83%)
12th-11th *c.*	6	6 (100%)
12th-10th *c.*	23	23 (100%)
11th-10th *c.*	6	5 (83%)
10th-9th *c.*	13	12 (92%)
10th-8th *c.*	18	15 (83%)

Table 2. Ubiquity of broomcorn millet in Late Bronze Age settlements over time.

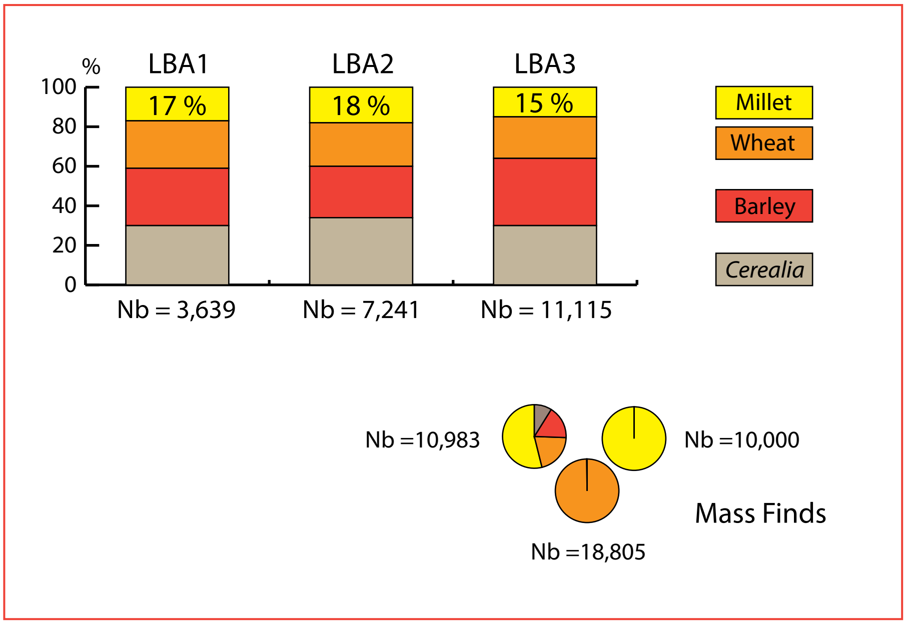

Figure 5. Proportions (in %) of the main categories of cereals for each phase of the Late Bronze Age (LBA), calculated from the total number (nb) of charred grains in all sites of one phase. Waste assemblages (bar-charts) and mass finds (pie-charts) are analysed separately.

Conclusion on the dating of millets from northeastern France

Archaeobotanical results (Table 3) coupled with radiocarbon dates of the earliest discoveries of broomcorn millet show that *Panicum miliaceum* was not introduced in northeastern France before the 14th *c.* BCE. It is likely that the cultivation of broomcorn millet started between the 14th and the 13th *c.* BCE and spread very rapidly, becoming part of every small farm production throughout the area.

Further radiocarbon evidence concerning the cultivation of broomcorn millet in northeastern France comes from miliacin, a chemical marker strictly associated with *Panicum miliaceum*. It was isolated from a Bronze Age silo and a Late Iron Age silo at the site of Obernai, in Alsace (Courrel *et al.* 2017). The miliacin was archived in the soil filling the silos. It presumably resulted from past cultivation of millet during the Bronze Age, because the miliacin recovered from the silo of the Iron Age proved to be older than the structure itself. Four radiocarbon dates have been obtained on the miliacin extracted at different depths of the fills of the two silos. The resulting ^{14}C ages (1560-1259, 1438-996 and 2044-826 cal BCE for the Bronze Age silo; 1461-894 cal BCE for the Iron Age silo) encompass those provided by our dates on millet grains.

These observations are also consistent with the recently published chronological model of millet arrival in Europe (Filipović *et al.* 2020) based on radiocarbon dates. This model shows that by the mid-14th *c.* BCE, cultivation of broomcorn millet spread into central Europe, the area nearest to northeastern France, while earlier occurrences (from the mid-15th *c.* BCE) are recorded in the Po Basin, in northern Italy. The only millet dated to the 16th *c.* BCE comes from Ukraine. The authors conclude that it is very unlikely that broomcorn millet reached central Europe before the mid-14th *c.* BCE.

As for foxtail millet, its arrival in northeastern France is not recorded before the 13th *c.* BCE. It was probably introduced as a weed of broomcorn millet and was cultivated later, between the 10th and 8th *c.* BCE. During the LBA and EIA, it is always represented as a minor crop, restricted to some territories (Bouby *et al.* 2017).

Commune (département)	Site	Period	Cultural chronology (BCE)	Features (*n*)	Samples (*n*)	Volume (*l*)	Charred remains (*n*)	Waterlogged remains (*n*)	Investigator (Botany/Archaeology/ Operator)
Buchères (10)	Parc logistique de l'Aube 2005-2008	EBA	Bronze A (2200-1600)	1	4	37	16		Toulemonde/Riquier/Inrap
Crévéchamps (54)	Tronc du chêne	EBA	Bronze A (2200-1600)	6	6	17	16		de Hingh/Koenig/Afan
Erstein (67)	Grasweg-PAE	EBA	Bronze A (2200-1600)	3	3	8.5	1378		Martinoli/Croutsch/ Archéologie Alsace
Wahlenheim (67)	Lotissement de Wahlenheim	EBA	Bronze A (2200-1600)	1	3	30	13		Rousselet/Croutsch/ Archéologie Alsace
Blénod-lès-Pont-à-Mousson (54)	Les longues Rayes	EBA	Bronze A2 (2000-1600)	2	16	119	179		Wiethold/Rachet/Inrap
Crévéchamps (54)	Tronc du chêne	EBA	Bronze A2 (2000-1600)	1	2	7.5	17		de Hingh/Koenig/Afan
Frouard (54)	Haut de Penotte	EBA	Bronze A2 (2000-1600)	17	17	53.3	68		de Hingh/Koenig/Afan
Frouard (54)	ZAC du Saule Gaillard I	EBA	Bronze A2 (2000-1600)	25	25	39.5	790		de Hing-Wiethold/Blouet/ SRA
Vandières (54)	Les Grandes Corvées	EBA	Bronze A2 (2000-1600)	4	4	-	6		Zech-Matterne/Koenig/ Afan-Inrap
Muttersholtz (67)	Rue des Cigognes	EBA	Bronze A2 (2000-1600)	3	3	9	6	2017	Rousselet/Pierrevelcin/ Archéologie Alsace
Pagny-Les Goings (57)	Aéroport régional Lorraine	EBA/MBA	Bronze A-B (2200-1500)	4	4	29	99		de Hing-Wiethold/Blouet/ SRA
Trémery (57)	Le Breuil/La Retienne	EBA/MBA	Bronze A-B (2200-1500)	1	1	10	9		Wiethold/Gérard/Inrap
Vignot (55)	Les Tranchons (2009)	EBA/MBA	Bronze A-B (2200-1500)	21	21	159	9		Wiethold/ Deffressigne/ Inrap
Yutz (57)	Contournement sud-est	EBA/MBA	Bronze A-B (2200-1500)	1	1	7.5	68		de Hingh/Klag/Afan
Buchères (10)	Parc logistique de l'Aube 2012-2013	EBA/MBA	Bronze A2-B (2000-1500)	1	3	30	35		Toulemonde/Parésys/Inrap
Gougenheim (67)	Gingsheimer Feld	EBA/MBA	Bronze A2-B (2000-1500)	1	1	10	2		Durand/Thomas/Inrap
Duntzenheim (67)	Rainwasen	EBA/MBA	Bronze A-C (2200-1350)	1	1	10	127		Durand/Veber/Inrap
Erstein (67)	Parc d'Activités du Pays d'Erstein	MBA	Bronze B (1600-1500)	1	1	6		11,780	Bonnaire/Croutsch/ Archéologie Alsace
Courceroy (10)	Les Dizaines	MBA	Bronze B-C (1600-1350)	1	1	15	147		Toulemonde/Lelarge/ Archéopole
Duntzenheim (67)	Weingartenberg	MBA	Bronze B-C (1600-1350)	1	1	10	5		Durand/Veber/Inrap
Basse-Ham (57)	ZAC Kickelsberg	MBA	Bronze C (1500-1350)	2	2	20	7		Wiethold/Viller/Inrap
Ay-sur-Moselle (57)	Les Vélers Jacques	MBA	Bronze C (1500-1350)	1	1	20	20		Wiethold/Klag/Inrap
Blénod-lès-Pont-à-Mousson (54)	Les longues Rayes	MBA/LBA	MBA/LBA (1450-1300)	2	3	50	7		Wiethold/Rachet/Inrap
Couternon (21)	Larrey	MBA/LBA	MBA/LBA (1450-1300)	2	2	60	70		Wiethold/Labeaune/Inrap
Obernai (67)	Schulbach, Nouvel Hôpital	MBA/LBA	MBA/LBA (1450-1300)	2	4	36	29,873		Rousselet/Ferrier-Croutsch/ Archéologie Alsace
Gingsheim (67)	Steinbrünnen, Aschenbuckel	LBA1	Bronze D (1350-1200)	1	1	10	150		Durand/Michler/Inrap
Balloy (77)	La Haute Borne	LBA1	Bronze D (1350-1200)	2	4	55	1254		Toulemonde/Samzung/ Inrap

Table 3. The large archaeobotanical dataset from northeastern France used in this study.

Commune (département)	Site	Period	Cultural chronology (BCE)	Features (n)	Samples (n)	Volume (l)	Charred remains (n)	Waterlogged remains (n)	Investigator (Botany/Archaeology/ Operator)
Erstein (67)	Parc d'Activités du Pays d'Erstein	LBA1	Bronze D (1350-1200)	1	1	9		3250	Bonnaire/Croutsch/ Archéologie Alsace
Erstein (67)	Grasweg-PAE	LBA1	Bronze D (1350-1200)	1	1	6		876	Martinoli/Croutsch/ Archéologie Alsace
Sézannes (51)	Maison de santé	LBA1	Bronze D (1350-1200)	1	6	52	617		Daoulas/Godard/Inrap
Hérange (57)	Gross Eichholz	LBA1	Bronze D (1350-1200)	1	12	225	370		Wiethold/Lafosse/Inrap
Jury (57)	ZAC de la Passerelle	LBA1	Bronze D (1350-1200)	1	1	10	9		Wiethold/Mangin/Inrap
Ay-sur-Moselle (57)	Les Vélers Jacques	LBA1	Bronze D (1350-1200)	3	3	32	40		Wiethold/Klag/Inrap
Meistratzheim (67)	Foegel	LBA1	Bronze D (1350-1200)	6	7	59	252		Wiethold/Veber/Inrap
Noyen-sur-Seine (77)	Carrière A2C	LBA1	Bronze D (1350-1200)	1	1	10	63		Toulemonde/Le Clézio/ Evéha
Courceroy (10)	Les Dizaines	LBA1	Bronze D/Hallstatt A1 (1350-1100)	6	6	>30	38	978	Toulemonde/Lelarge/ Archéopole
Réau (77)	Centre pénitencier	LBA1	Bronze D/Hallstatt A1 (1350-1100)	3	5	59	112		Toulemonde/Boulenger/ Inrap
Réau (77)	Parc d'activités de l'A5	LBA1	Bronze D/Hallstatt A1 (1350-1100)	2	12	95	5212		Pradat/Froquet/Inrap
Vinneuf (89)	Le Chatelot	LBA1	Bronze D/Hallstatt A1 (1350-1100)	2	2	20	7		Toulemonde/Issenmann/ Inrap
La Saulsotte (10)	Le Vieux Bouchy	LBA1	Bronze D/Hallstatt A1 (1350-1100)	3	3	30	22		Toulemonde/Peake/Inrap
Breuil (80)	Sole de l'épinette, Sole du Bois Marotte	LBA1	Bronze D/Hallstatt A1 (1350-1100)	1	1	?	24		Derreumaux/Baudry/Inrap
Entzheim et Geispolsheim (67)	Entzheim 2006	LBA1	Bronze D/Hallstatt A1 (1350-1100)	?	2	10	1383		Schaal/Landolt/Archéologie Alsace
Sainte Apollinaire (67)	Sur le Pré de Crot 1	LBA1	Bronze D/Hallstatt A1 (1350-1100)	2	2	59.6	131		Wiethold/Labeaune/Inrap
Bernolsheim/Mommenheim (67)	Plateforme Départementale d'Activités	LBA1	Bronze D/Hallstatt A1 (1350-1100)	1	1	40	14		Rousselet/Leprovost/ Archéologie Alsace
Warcq (8)	Bois de Charnois	LBA1	Hallstatt A1 (1200-1100)	1	2	17	20		Toulemonde/Roseau/CG Ardennes
Buchères (10)	Parc logistique de l'Aube 2005-2008	LBA1	Hallstatt A1 (1200-1100)	3	3	28	34		Toulemonde/Riquier/Inrap
Marolles-sur-Seine (77)	Croix Saint Jacques	LBA1/ LBA2	Hallstatt A1 (1200-1100)	1	1	?	546		Pradat/Peake/Inrap
Warcq (8)	Bois de Charnois	LBA1/ LBA2	Hallstatt A1-A2 (1200-1000)	1	1	9	10		Toulemonde/Roseau/CG Ardennes
Courceroy (10)	Les Dizaines	LBA1/ LBA2	Hallstatt A1-A2 (1200-1000)	5	7	80	196		Toulemonde/Lelarge/ Archéopole
St Dizier (52)	Zone de référence 2012	LBA1/ LBA2	Hallstatt A1-A2 (1200-1000)	1	1	20	8		Toulemonde/Bocquillon/ Inrap
Saint Pierre du Perray (91)	TW 2008 et CSP 2010	LBA1/ LBA2	Hallstatt A1-A2 (1200-1000)	6	22	153	1307		Toulemonde/ Saron-Wagner/Inrap
Varennes-sur-Seine (77)	Le Volstin	LBA1/ LBA2	Hallstatt A1-A2 (1200-1000)	1	1	10	27		Toulemonde/Noury/Evéha
Réau (77)	Parc d'activités de l'A5	LBA1/ LBA2	Hallstatt A1-A2 (1200-1000)	10	22	228	1896		Pradat/Froquet/Inrap
St Dizier (52)	Zone de référence 2014	LBA1/ LBA2	Hallstatt A (1200-1000)	6	6	38	728		Toulemonde/Bocquillon/ Inrap
Berru (51)	La Maladrerie	LBA1/ LBA2	Hallstatt A (1200-1000)	1	1	10	44		Toulemonde/Spies/Inrap

Commune (département)	Site	Period	Cultural chronology (BCE)	Features (n)	Samples (n)	Volume (l)	Charred remains (n)	Waterlogged remains (n)	Investigator (Botany/Archaeology/ Operator)
Cernay-lès-Reims (51)	Le Bas de la Noue Saint Rémy	LBA2	Hallstatt A2 (1100-1000)	55	55	550	237		Daoulas/Rabaste/Inrap
Dieulouard (54)	Rue des Trappiers	LBA2	Hallstatt A2 (1100-1000)	1	1	2	70		Wiethold/Mangin/Inrap
Varois-et-Chaignot (21)	Le Pré du Plancher	LBA2	Hallstatt A2 (1100-1000)	4	5	180	87		Wiethold/Labeaune/Inrap
Vergigny (89)	La Grande Folie	LBA2	Hallstatt A2 (1100-1000)	1	1	20	495		Wiethold/Afan
Erstein (67)	Parc d'Activités du Pays d'Erstein	LBA2	Hallstatt A2 (1100-1000)	2	4	38	591	2660	Bonnaire/Croutsch/ Archéologie Alsace
Furdenheim (67)	Gruen, complexe judo-basket	LBA2	Hallstatt A2 (1100-1000)	2	4	10	424		Rousselet/Pierrevelcin/ Archéologie Alsace
Noyen-sur-Seine (77)	Carrière A2C	LBA2	Hallstatt A2 (1100-1000)	1	2	18	1762		Toulemonde/Le Clézio/ Evéha
Vinneuf (89)	Le Chatelot	LBA2	Hallstatt A2-B1 (1100-900)	3	6	53	588		Toulemonde/Issenmann/ Inrap
Courceroy (10)	Les Dizaines	LBA2	Hallstatt A2-B1 (1100-900)	8	9	79	240	1342	Toulemonde/Lelarge/ Archéopole
Bréviandes (10)	Zac St Martin	LBA2	Hallstatt A2-B1 (1100-900)	1	1	20	36		Toulemonde/Laurelut/ Inrap
Buchères (10)	Parc logistique de l'Aube 2005-2008	LBA2	Hallstatt A2-B1 (1100-900)	11	14	219	1511		Toulemonde/Riquier/Inrap
Pont-Sainte-Marie (10)	Rue Fernand Jaffiol	LBA2	Hallstatt A2-B1 (1100-900)	2	3	66	58		Toulemonde/ Millet/Inrap
Cormontreuil (51)	Les Grands Godets	LBA2	Hallstatt A2-B1 (1100-900)	3	5	91	72		Toulemonde/Bündgen/ GrandReims
Loisy-sur-Marne (51)	Zac de la Haute Voie	LBA2	Hallstatt A2-B1 (1100-900)	6	6	49	282		Toulemonde/Toron/Evéha
St Dizier (52)	Zone de référence 2012	LBA2	Hallstatt A2-B1 (1100-900)	1	1	20	36		Toulemonde/Bocquillon/ Inrap
Brie-Comte Robert (77)	Les-Prés-Le-Roi	LBA2	Hallstatt A2-B1 (1100-900)	9	9	90	260		Toulemonde/Peake/Inrap
Jaulnes (77)	Le Bas des Hauts Champs Ouest	LBA2	Hallstatt A2-B1 (1100-900)	6	6	120	955		Toulemonde/Peake/Inrap
Marolles-sur-Seine (77)	Ferme de la Muette	LBA2	Hallstatt A2-B1 (1100-900)	7	10	100	101		Toulemonde/Ferrier/Evéha
Noyen-sur-Seine (77)	Le Nord du Bois du Chêne	LBA2	Hallstatt A2-B1 (1100-900)	16	33	492	2025		Toulemonde/Nallier/Inrap
La Saulsotte (10)	Le Vieux Bouchy	LBA2	Hallstatt A2-B1 (1100-900)	3	3	43	46		Toulemonde/Peake/Inrap
Saint-Maure (10)	Culoison	LBA2	Hallstatt A2-B1 (1100-900)	3	3	28	15		Daoulas/Chauvin/Inrap
Blignicourt (10)	Les Voies de Brienne	LBA2	Hallstatt A2-B1 (1100-900)	5	6	58	318		Daoulas/Chauvin/Inrap
Les Grandes Chapelles (10)	La Taverne	LBA2	Hallstatt A2-B1 (1100-900)	3	10	38	6		Daoulas/Chauvin/Inrap
Ruvigny (10)	Proche l'Eglise	LBA2	Hallstatt A2-B1 (1100-900)	1	2	16	24		Daoulas/Roms/Inrap
Troyes (10)	Preize	LBA2	Hallstatt A2-B1 (1100-900)	1	3	26	7		Daoulas/Deborde/Inrap
Lieusaint (77)	Zac du Levant	LBA2	Hallstatt A2-B1 (1100-900)	7	19	163	1891		Pradat/Baguenier/Inrap
Basse-Ham (57)	ZAC intercommunale	LBA2	Hallstatt A2-B1 (1100-900)	7	12	165	888		Wiethold/Tikonoff/Inrap
Pévange (57)	Derrière le Pâtural	LBA2	Hallstatt A2-B1 (1100-900)	1	1	10	60		Wiethold/Viller/Inrap

Commune (département)	Site	Period	Cultural chronology (BCE)	Features (n)	Samples (n)	Volume (l)	Charred remains (n)	Waterlogged remains (n)	Investigator (Botany/Archaeology/ Operator)
Coincy (57)	La réserve, Les Terres de Fer	LBA2	Hallstatt A2-B1 (1100-900)	1	1	10	1		Wiethold/Bernard/Inrap
Volstroff (57)	Les résidences de Volstroff	LBA2	Hallstatt A2-B1 (1100-900)	3	8	77	80		Wiethold/Brénon/Inrap
Guénange (57)	Carrière GSM	LBA2	Hallstatt A2-B1 (1100-900)	1	1	10	100		Wiethold/Viller/Inrap
Belleville-sur-Meuse (55)	La Pièce des vingt jours	LBA2	Hallstatt A2-B1 (1100-900)	1	1	10	212		Wiethold/Ramel/Inrap
Vignot (55)	Les Tranchons (2006)	LBA2	Hallstatt A2-B1 (1100-900)	2	2	29	9		Wiethold/Lefebvre/Inrap
Varois-et-Chaignot (21)	Le Pré du Plancher	LBA2	Hallstatt A2-B1 (1100-900)	11	12	226	1087		Wiethold/Labeaune/Inrap
Marly (57)	Le Clos des Sorbiers	LBA2	Hallstatt B1 (1000-900)	15	15	?	69		de Hingh/Klag/Afan
Yutz (57)	Contournement sud-est	LBA2	Hallstatt B1 (1000-900)	7	7	18.5			de Hingh/Klag/Afan
Art-sur-Meurthe (54)	L'Embanie – La Prairie de la Roanne	LBA2	Hallstatt B1 (1000-900)	1		7	70		Wiethold/ Deffressigne/ Inrap
Erstein (67)	Parc d'Activités du Pays d'Erstein	LBA2	Hallstatt B1 (1000-900)	3	4	38	494		Bonnaire/Croutsch/ Archéologie Alsace
Wissous (91)	Zone S/O de l'aéroport d'Orly	LBA2	Hallstatt B1 (1000-900)	3	3	23	1836		Toulemonde/Quenez/Inrap
Marly (57)	La Grange-aux-Ormes	LBA2	Hallstatt B1 (1000-900)	4	5	25	15		Wiethold/Tikonoff/Inrap
Longvic/Ouges (21)	Les Quétignières	LBA2	Hallstatt B1 (1000-900)	8	8	160	427		Wiethold/Labeaune/Inrap
Varois-et-Chaignot (21)	Le Pré du Plancher	LBA2	Hallstatt B1 (1000-900)	3	3	60	367		Wiethold/Labeaune/Inrap
Berru (51)	La Maladrerie	LBA2/ LBA3	Hallstatt B1-B2 (1000-800)	1	1	11	9		Toulemonde/Spies/Inrap
Flévy (57)	Zac de la Fontaine des Saints	LBA2/ LBA3	Hallstatt B1-B2 (1000-800)	1	1	5		132	Wiethold/Petitdidier/Inrap
Mondelange (57)	PAC de la Sente	LBA2/ LBA3	Hallstatt B1-B2/3 (1000-750)	3	3	30	5		Wiethold/Gazenbeek/Inrap
Changis-sur-Marne (77)	Les Pétreaux et La Pelle à Four	LBA3	Hallstatt B2 (900-800)	4	7	35	35		Zech-Matterne/Lafage/ Inrap
Bazancourt (51)	Sur les Petits Poissons	LBA3	Hallstatt B2/3 (900-750)	44	72	717	1867		Toulemonde/Desbrosses/ Inrap
Buchères (10)	Parc logistique de l'Aube 2012-2013	LBA3	Hallstatt B2/3 (900-750)	8	14	127	436		Toulemonde/Parésys/Inrap
Balloy (77)	La Haute Borne	LBA3	Hallstatt B2/3 (900-750)	3	6	95	112		Toulemonde/Samzung/ Inrap
Biaches (80)	Canal Seine Nord fouille 13	LBA3	Hallstatt B2/3 (900-750)	4	4	23	133		Toulemonde/Baudry/Inrap
Varennes-sur-Seine (77)	Le Volstin	LBA3	Hallstatt B2/3 (900-750)	3	7	65	1092		Toulemonde/Noury/Evéha
Réau (77)	Centre pénitencier	LBA3	Hallstatt B2/3 (900-750)	6	6	81	174		Toulemonde/Boulenger/ Inrap
Pont-sur-Seine (10)	Gué Dehan zone 2	LBA3	Hallstatt B2/3 (900-750)	12	14	60	10,951		Schaal/Collas/Eveha
Pont-Marnay-sur-Seine (10)	La Gravière	LBA3	Hallstatt B2/3 (900-750)	8	9	111	64		Bonnaire/Fournand/Inrap
Beaumont-sur-Vesles (51)	Les Hauts de Chaillot	LBA3	Hallstatt B2/3 (900-750)	1	4	65	93		Zech-Matterne/Lamotte/ Inrap
Bussy-Lettrée (51)	Vatry Mont Lardon site 16	LBA3	Hallstatt B2/3 (900-750)	17	21	242	458		Zech-Matterne/Bailleux/ Inrap

Commune (département)	Site	Period	Cultural chronology (BCE)	**Features (*n*)**	**Samples (*n*)**	**Volume (*l*)**	**Charred remains (*n*)**	**Waterlogged remains (*n*)**	Investigator (Botany/Archaeology/ Operator)
Marly (57)	La Grange-aux-Ormes	LBA3	Hallstatt B2/3 (900-750)	4	6	56	2383		Wiethold/Tikonoff/Inrap
Trémery (57)	Le Breuil/La Retienne	LBA3	Hallstatt B2/3 (900-750)	2	21	161	178		Wiethold/Gérard/Inrap
Villeneuve-la-Guyard (89)	Les Champs Boissier	LBA3	Hallstatt B2/3 (900-750)	1	1	15	166		Wiethold/Afan
Changis-sur-Marne (77)	Les Pétreaux et La Pelle à Four	LBA3/EIA	Hallstatt B3 (900-750)	56	61	305	1849		Zech-Matterne/Lafage/ Inrap
Villiers-sur-Seine (77)	Le Gros Buisson	LBA3/EIA	Hallstatt B2/3-C1 (900-620)	17	17	285	16,260		Toulemonde/Peake/Inrap
Plancy-l'Abbaye (10)	Saint Martin	LBA3/EIA	Hallstatt B2/3-C1 (900-620)	6	7	67	93		Toulemonde/Moreau/Inrap
Buchères (10)	Parc logistique de l'Aube 2005-2008	LBA3/EIA	Hallstatt B2/3-C1 (900-620)	52	66	992	4914		Toulemonde/Riquier/Inrap
Lesmont (10)	Pôle Scolaire	LBA3/EIA	Hallstatt B2/3-C1 (900-620)	8	29	251	453		Toulemonde/Sanson/Inrap
Matignicourt-Goncourt (51)	Les Brouillards	LBA3/EIA	Hallstatt B2/3-C1 (900-620)	2	7	113	99		Toulemonde/Richard/Inrap
Saint Léonard (51)	La Croix Chaudron	LBA3/EIA	Hallstatt B2/3-C1 (900-620)	5	8	100	128		Toulemonde/Bündgen/ GrandReims
Saint-Martin-sur-le-Pré (51)	Rue des Castors	LBA3/EIA	Hallstatt B2/3-C1 (900-620)	3	3	27	28		Toulemonde/Garmond/ GrandReims
Thillois (51)	La Croix Rouge	LBA3/EIA	Hallstatt B2/3-C1 (900-620)	8	16	120	211		Zech-Matterne/Riquier/ Inrap
Réau (77)	Centre pénitencier	LBA3/EIA	Hallstatt B2/3-C1 (900-620)	3	4	47	31		Toulemonde/Boulenger/ Inrap
Saint-Maure (10)	Culoison	LBA3/EIA	Hallstatt B2/3-C1 (900-620)	10	10	90	450		Daoulas/Chauvin/Inrap
Vitry-sur-Seine (94)	Collège Monod	LBA3/EIA	Hallstatt B2/3-C1 (900-620)	1	14	241	21,597		Derreumaux/Maret/SA 94
Ville Saint Jacques (77)	Le Fond des Vallées/ Le Bois d'Echalas	LBA3/EIA	Hallstatt B3-C1 (900-620)	5	8	52	256		Toulemonde/Issenmann/ Inrap
Jaulnes (77)	Le Bas des Hauts Champs Ouest	LBA3/EIA	Hallstatt B3-C1 (900-620)	4	5	100	132		Toulemonde/Peake/Inrap
Florange (57)	Petit Biterfeld	LBA3/EIA	Hallstatt B3-C (900-620)	1	1	4	270		Wiethold/Franck/Inrap
Ley (57)	Le Grand Meix	LBA3/EIA	Hallstatt B3-C (900-620)	1	1	10	99		Wiethold/Mangin/Inrap
Sainte-Apollinaire (21)	Sur le petit Pré 1	LBA3/EIA	Hallstatt B3-C (900-620)	12	12	435	574		Wiethold/Labeaune/Inrap
Changis-sur-Marne (77)	Les Pétreaux et La Pelle à Four	LBA3/EIA	Hallstatt B3-C (900-620)	26	27	135	222		Zech-Matterne/Lafage/ Inrap

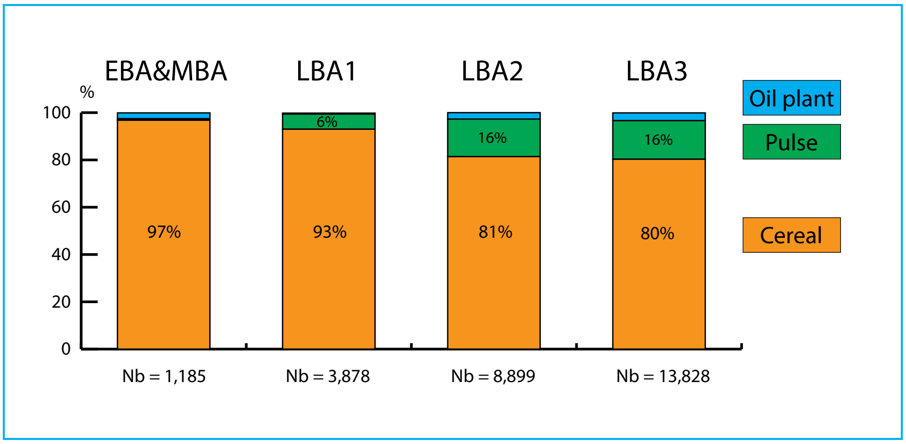

Figure 6. Proportions (in %) of the main categories of crops from the Early Bronze Age and Middle Bronze Age (EBA and MBA) settlements compared with the Late Bronze Age (LBA) settlements, divided by phases, calculated from the total number (nb) of charred grains in all sites of one phase. Mass finds are excluded from the calculations.

Discussion: Changes in agriculture and subsistence economy during the Late Bronze Age

Beside the introduction of millets, what else is new in the crop husbandry practices and subsistence economy of the LBA? The rare data for the EBA and MBA make comparisons difficult, but we did manage to collect convincing information that suggests more radical changes than just adding a new crop.

A flexible and resilient crop husbandry regime for an improved control of yields

The crop spectrum of the LBA includes a larger number of plants than that of the previous periods. It could feature up to nine cereals (hulled barley (*Hordeum vulgare* ssp. *vulgare*), bread wheat (*Triticum aestivum* s.l.), hard wheat/rivet wheat (*T. durum/turgidum*), emmer (*T. dicoccum*), einkorn (*T. monococcum*), spelt (*T. spelta*), Timopheev's wheat (*T. timopheevii* s.l.) – formerly known as 'new' glume wheat (cf. Czajkowska *et al.* 2020) – broomcorn millet (*Panicum miliaceum*) and foxtail millet (*Setaria italica*)); five pulses (grass pea (*Lathyrus cicera/sativus*), lentil (*Lens culinaris*), pea (*Pisum sativum*), bitter vetch (*Vicia ervilia*) and celtic bean (*Vicia faba* var. *minor*)); and three oil plants (gold-of-pleasure (*Camelina sativa*), flax (*Linum usitatissimum*) and opium poppy (*Papaver somniferum*)). Not only the crop spectrum, but also crop production and organisation changed. Pulses were more and more commonly cultivated and during LBA2 they became ubiquitous. For this period and the following one, they represent 16% of the charred grains in assemblages, compared with being almost completely absent from Early and Middle Bronze Age contexts (Fig. 6). At least 9 out of 10 rural settlements cultivated legumes alongside cereals. Oil plants were also much more frequent, especially gold-of-pleasure. They are recorded in one of three settlements during LBA2 and LBA3. Altogether, evidence for plant cultivation during the EBA-MBA is poor, with an average of only 2 different crop species per settlement (and a maximum of 5), and it sharply increases during the LBA, corresponding to an average of 6 crops per settlement, for a median of 5 and a maximum of 15. Most LBA farms cultivated a larger and more diversified set of crops than did farms during the earlier phases of the Bronze Age.

A larger crop spectrum meant more complexity but also more flexibility in crop management. Most of the new plants introduced and/or cultivated, such as millets, pulses and gold-of-pleasure, were summer crops. Because they are frost intolerant, they had to be sown in the spring, whereas hulled wheats were mainly sown in winter. This allowed a better distribution of fieldwork throughout the year and it permitted inclusion of catch-up crops, especially millets, which are fast-growing plants. When winter crops failed, one could still sow millet in June and harvest it in September. Another greatly appreciated technical characteristic of millet in case of bad harvest years is that for 1 grain of millet sown, 200 are harvested (Sigaut 1995). This is 16 to 50 times higher than in wheat. This meant that almost the entire harvest of millet could be consumed; one did not need to save a substantial part of it for future sowing.

If we sum up the characteristics of the new crop husbandry regime of the LBA, we have all the elements of a resilient and sustainable system, able to maintain soil fertility and therefore yields. It includes crop diversity, with 17 available crop species and evidence that indeed up to 10 or 11 species were cultivated in a given year in one settlement (Toulemonde 2013). Hardy plants with a low demand in manure (namely hulled wheats and barley) were selected as staple crops. The focus was not on high-yield plants, such as bread wheat. What mattered was the performance in difficult times and places, in case of drought, frost or poor soils. Flexibility, with summer and winter crops and catch-up crops, was another characteristic of the LBA system.

Moreover, many of the cultivated plants complement each other agronomically, making possible (likely?) maslins (of different species of wheats), rotations (pulses/cereals), or associations of plants (pea or celtic bean and gold-of-pleasure). Gold-of-pleasure also offered the possibility of controlling weeds when cultivating pulse crops, thanks to its horizontally spreading root system. This once well-known and then forgotten characteristic is being rediscovered in modern organic farming (Rozier 1821-1823; de Carné-Carnavalet 2011; Mellon and Bollot pers. comm.).

Manuring was possible in two ways. As mixed farming – crop and animal husbandry – was the rule in northeastern France (Auxiette *et al.* 2015; Auxiette and Toulemonde 2018; Toulemonde *et al.* 2018), some animal manure was available, but it may not always have been sufficient. The rotation of cereals with abundantly cultivated pulses and cruciferous plants, such as gold-of-pleasure, could have also helped maintain fertility and nutrient levels. Thanks to a symbiotic association with bacteria of the genus *Rhizobium*, pulses can fix atmospheric nitrogen in the soil, while gold-of-pleasure is rich in potassium, of which some pulses, such as celtic beans, are in high demand (de Carné-Carnavalet 2011).

All these characteristics are strategies to secure production and help farming resilience. They seem to have been successfully applied, because the population size rose sharply during the LBA. Analyses of weed flora needs in terms of nutrients using a nitrogen indicator for the French territory (Julve 1998), similar to that of Ellenberg (1988) for central Europe, are available for groups of settlements from different parts of the Champagne and Île-de-France regions, dated to the LBA and EIA (Toulemonde 2013). They indicate that during the nine centuries of the LBA and EIA (1350-475 BCE), when the same farming system was in use, there was no significant decrease in soil fertility.

This multiple cropping system, with its summer and winter crops, also entailed intensive farming year-round. Millets and pulses are plants that require regular care. The cultivation of millet only succeeds through repeated hoeing and weeding, meaning a high investment in labour at different times of the cycle, and especially during field preparation, the growth period and the harvest (Sigaut 1995). This significant labour cost was even the cause of its abandonment in some French regions in the 19th century (Bonnain 1995). The intensive fieldwork required throughout the year to take care of this broad diversity of plants with different growing periods and needs could only be provided by a sedentary population. If a nomadic life was practised during the EBA and MBA, this was no longer an option with the crop husbandry regime of the LBA. Consequently, domestic and agricultural features, such as storage pits and granaries, became much more visible and land use increased and diversified, including farming of the plateaus and chalklands alongside river valleys (see above, section on archaeological background).

Gathering: A less critical resource

As crop production increased and diversified, gathering became less crucial than it had been in previous phases of the Bronze Age. During the EBA, consumption of acorns (*Quercus* sp.), a major wild source of carbohydrates, was quite important (Coquillat 1959; Vencl 1985, 1996; Karg and Haas 1996). In Lorraine, charred acorns are even considered as an index fossil for this period. There are many examples of EBA features filled with charred acorns. The settlement at Richemont-Berg VI yielded 348 acorns from a posthole dated to the end of the EBA-beginning of the MBA; at Frouard-Zac du Saule Gaillard, 722 acorns were discovered in the fills of postholes dated to the 20th-17th *c.* BCE (de Hingh 2000, 94); and at Yutz-Contournement sud-est, a storage pit from the beginning of the EBA yielded 50 charred acorns (de Hingh 2000, 115).

During the LBA, the gathering of acorns declined in northeastern France (Bouby *et al.* 2017). In the Upper Seine Valley, although oaks were less ubiquitous than during the EBA-MBA, they were still available near settlements, and their wood was commonly used (Leroyer 2012; Chaussé *et al.* 2019). Acorn is, however, only the third most important collected wild resource, far behind hazelnut (*Corylus avellana*) and sloe (*Prunus spinosa*) (Toulemonde 2013). It seems that farming resources were at that stage sufficient to feed the population.

An overview of changes in agriculture and European convergences

The arrival of broomcorn millet in northeastern France coincides with the development of a new farming system, characterised by global strategies to secure production. This system sustained an increase in population and activities during the LBA. As glimpsed in the demographics – sluggishness then surge – changes in diet and farming practices during the LBA are proved to be a European phenomenon, which occurred at a varying pace depending on the region (*e.g.* Stika and Heiss 2013; Valamoti 2016; Bouby *et al.* 2017; Effenberger 2018; Liu *et al.* 2018; Reed 2020). It was widespread to the point of being described as '*the third food revolution*' (Kneisel *et al.* 2015b). Not all references in the archaeobotanical literature can be cited here, but it is intriguing to note that in many places across Europe, from southern Italy to Bohemia, and in northeastern France, acorns are an index fossil of the EBA. They become less frequent in LBA contexts in northern Europe (Kneisel *et al.* 2015a), while gathering continues in Mediterranean regions, where it may have concerned *sempervirens* oak species, which produce fruit with lower tannin levels (Bouby 2014; Peche-Quilichini *et al.* 2020).

More common trends in LBA farming strategies in Europe have been listed by Kneisel *et al.* (2015a). Many of them, such as the increase in crop diversity, the spread of millets, the more widespread use of pulses, the emergence of gold-of-pleasure, *etc.*, can also be observed in northeastern France. Results of the analyses of weed flora demands for nitrogen in southwestern Germany using a similar indicator to the one used for northeastern France show no significant change in soil fertility during the LBA and EIA, indicating a sustainable farming system, as observed in Champagne and Île-de-France, and suggesting the use of fertilisers (Rösch *et al.* 2015).

It is tempting to link the demographic surge of the LBA to the adoption of a new agriculture, which seemed to offer all the guarantees for a sufficient crop production and a balanced diet (Rosenstock *et al.* 2015). However, one should first understand the reasons for the apparent sluggishness of demography observed in northeastern France from the Late Neolithic to the end of the MBA. Before that period, during Early Neolithic and Middle Neolithic, other farming systems had also been successful (Bouby *et al.* 2018).

Farming, processing and uses of millet

Ethnohistory and ethnobotany teach us that, in a not-so-distant past, before being entirely replaced by maize in the 1960s, broomcorn millet was cultivated as a minor crop on every farm of the département of Vendée in western France, as well as in other areas (Hörandner 1995). Farming and processing techniques were specific to the plant due to its characteristics, which are quite different from those of other cereals (Hongrois 1995; Sigaut 1995; Lundström-Baudais *et al.* 2002). Millet was used to feed humans and poultry. People consumed it as a daily dish, but it was also on the menu for harvest festivals and wedding meals in rural areas (Hongrois 1995; Touzeau 1995). In other parts of Europe, in Portugal or Hungary for example, feasts and collective celebrations, such as carnivals, funerals, festivals of the dead, *etc.*, also featured millet in traditional dishes (Barboff 1995; Kisbán 1995). Considering this documentation, what can archaeology and archaeobotany teach us about the farming and social practices of a more distant past?

Farming and processing techniques

During the LBA, broomcorn millet was cultivated on every small farmstead, regardless of the type of soil. It does not seem that poor soils were preferred, as remains are more frequent and abundant in the fertile Seine Valley than on the chalklands of Champagne (Toulemonde 2013). We have no clues as to how millets were harvested. There is no existing study on agricultural tools for the LBA and EIA in northeastern France, due to the finds being so scarce (Toulemonde *et al.* 2017). Copper alloy sickles appear at the end of the Bronze Age (14th-13th *c.* BCE), but it is difficult to link them to millet more than to other cereals. Moreover, these tools disappear during the EIA, a period when millet is still intensively cultivated. Evidence on storage conditions is just as poor. The first mass finds of millets date to LBA3, and more have been discovered from the EIA, but none of them are of charred stock preserved in situ. Sometimes mixed with other cereals, they come from fills of waste pits (Villiers-sur-Seine; Peake 2020) or from middens (Pont-sur-Seine-Le Gué Déhan; Collas *et al.* 2018).

The dehusking of millet seems to be a mandatory step before consumption, as their glumes are siliceous and hard to digest. It is not clear if this was systematically done in ancient times for some specific contexts (Jacquat 1989; Boenke 2003; Behre 2008), however ethnobotany, ethnohistory and the history of techniques from all over the world always refer to millet dehusking, or at least to the removal of the hulls in one way or another (Comet 1992; Hörandner 1995; Murty and Kumar 1995; ICRISAT and FAO 1996; Lundström-Baudais *et al.* 2002; Lundström-Baudais 2010; Hamon and Le Gall 2013; Moreno-Larrazabal *et al.* 2015; Bhandari *et al.* 2020). This is sometimes facilitated by the heating of the grains, a treatment also practised worldwide for broomcorn millet, although it does not seem necessary for foxtail millet (Lundström-Baudais *et al.* 2002). Charred lumps of aggregated kernels of millet in their glumes were discovered all over the settlement area of Villiers-sur-Seine, suggesting recurrent processing or food preparation (Auxiette *et al.* 2015). Experiments have shown that, if not the only explanation, heat treatment prior to dehusking is a more likely hypothesis for these aggregates than the cooking of porridge (Toulemonde 2014). Finds of aggregates of entire kernels of millet on the perforated deck of specific ovens (known as Sévrier-oven types) have also been linked to heat treatment (Coulon 2015). These discoveries were made in the Alps, but the same type of oven was also found at the settlement of Buchères, Champagne.

Daily dish, festive dish

As testified by its ubiquity in the assemblages from LBA and EIA settlements, broomcorn millet was most probably consumed as an everyday meal. More information on diet is given by stable isotope studies of carbon and nitrogen ($\delta^{13}C$ and $\delta^{15}N$). For northeastern France, these studies are just emerging. LBA funerary contexts from the site of Barbuise, Champagne, have been studied and compared with the nearby Neolithic contexts at Gurgy, Burgundy. Stable isotope analyses were performed on bone and tooth collagen and apatite from eight humans and five domestic animals dating to ca. 1300 BCE. Results indicate the consumption of ^{13}C-enriched food by humans and some animals (dog and pig) during the LBA, compared with the Neolithic. The nitrogen ratio is lower, suggesting a diet based more on plants than before (Goude *et al.* 2016). These results are in line with the archaeobotanical studies.

Millet not only contributed to the daily diet, it was also part of festive menus. The multidisciplinary study of the site of Villiers-sur-Seine has demonstrated that collective feasting was a regular feature at this fortified settlement (Auxiette *et al.* 2015; Auxiette and Peake 2020; Peake 2020). Large quantities of meat from animals slaughtered at specific times of the year were consumed during these celebrations. Abundant millet remains are associated with animal bones (Toulemonde 2020). For these festive meals, the cereal was perhaps prepared in a different way than the daily meal, symbolising this ceremony or ritual, as was the case in other societies where millet was a traditional crop (Barboff 1995; Bonnain 1995).

There is evidence that broomcorn millet, important for the living, also accompanied the dead as a funerary offering. The rich elite grave with weapons found in the Tumulus 'Géraud' at Saint-Romain de Jalionas, département of Isère, French Alps, contained an LBA3 bronze situla filled with dehusked grains of broomcorn millet (Verger and Guillaumet 1988; plant macrofossils – Wiethold unpublished data).

After the Bronze Age, at a time when archaeobotanical studies show a sharp decline in the consumption of millet (Toulemonde *et al.* 2017; Zech-Matterne *et al.* 2017), the plant still played a role in some rituals. Evidence for this comes from southern Burgundy, where dozens of ceramic vessels dated to the Late Iron Age and the Roman period (prior to the 1st *c.* CE) have been recovered from the Saône River. The vessels have standardised shapes and some of them contained the remains of a charred organic matter in which entire kernels of broomcorn millet were visible. Because of their location, in fords or ports, these finds have been interpreted as cereal offerings to the gods, either as porridge or as beer (Marinval and Bonnamour 2010). Other evidence comes from the settlement of Warcq-la Sauce, in the French Ardennes. A rich chariot burial dating to the 2nd *c.* BCE included a food-related deposit with five different pottery vessels. The biochemical analysis performed on all vessels revealed traces of miliacin, with significant concentrations in three of them, leading to interpret them as the containers for food or beverage offerings made from millet (Saurel *et al.* 2021).

These offerings of millet are surprising for the periods when the cereal seemed to be no longer in vogue. An ethnobotanical survey evokes a similar case for the 19th century in southern France, where millet, which had been replaced by maize in the human diet, was still eaten as a ceremonial meal '*to ensure good relations between the community of the dead and that of the living*' (Bonnain 1995).

Overall conclusions and outlook

An overview of Bronze Age archaeobotanical data from northeastern France was combined with a series of radiocarbon dates obtained on charred caryopses of broomcorn millet. Some remains could not be dated due to the low carbon content, while others proved to be younger than expected. Results obtained so far suggest that millet did not arrive in the area before the 14th *c.* BCE, which is consistent with the conclusions of the recent AMS-radiocarbon dating programme carried out to track the arrival of millet on a European level (Filipović *et al.* 2020).

The introduction of this summer crop is at the heart of a new farming system, characterised by global strategies to secure production and maintain soil fertility. The surge in demographics that followed in northeastern France and in other parts of Europe was therefore sustained by a new diet. Millets were indeed the emblematic plant of food identity at the end of the European Bronze Age. In northeastern France, they contributed to the everyday diet and were also an important part of collective celebrations. Never again have they played such a predominant role in the human diet. They started to decline during the Late Iron Age, from the 2nd *c.* BCE onwards, when innovations in farming tools led to the extension of cultivated areas and the development of a more specialised agriculture (Zech-Matterne and Brun 2016; Toulemonde *et al.* 2017).

Research perspectives on the role of millets in prehistoric France are numerous. They should first include a new series of radiocarbon dating to consolidate and refine results in relation to the introduction of these cereals, by tracking at a regional level their spread from the neighbouring countries (southern Germany, Switzerland, northern Italy) across the current French territory. Stable isotope studies are developing, and several have already been undertaken within the framework of a collective research project whose goal is to track mobility and changes/social differentiation in paleodiet at the transition between the MBA and LBA in the Upper Seine Valley (PCR BronzPal, led by Rebecca Peake, Inrap). Concerning the food evidence, plenty of material is available in the form of aggregated kernels of millet from various contexts, as described in this article. In the future, it could serve as the basis of a major project, aimed at combining experimentation on beer making and other food preparations with scanning electron microscope (SEM) analysis of these remains.

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On-site to off-site: A multidisciplinary and multiscale consideration of the 13th to 11th century BCE transformation in northern Germany

Ingo Feeser, Stefanie Schaefer-Di Maida, Stefan Dreibrodt, Jutta Kneisel, Dragana Filipović

Abstract

Older and more recent excavations in the Mang de Bargen micro-region of northern Germany have revealed traces of local human activities, starting from the Late Neolithic (ca. 2200 BCE) and continuing, through the Bronze Age and Early Iron Age, to the Roman Iron Age (1st century BCE). This paper focuses on the Late Neolithic and Bronze Age occupation, when the site was used mainly for funerary activities. Near- and on-site palaeo-environmental investigations revealed that the local environment was changing during this period. The fundamental shift in burial rites during the 13th to 11th centuries BCE coincided with a fundamental change in land-use practices. This probably included an intensification of use of open, agricultural land associated with a shift from woodland to grassland pasturage. A number of crops typical of Late Neolithic and Bronze Age agriculture in northern Germany were in use at Mang de Bargen. A comparison of the developments at the local scale (based on both on- and near-site data) with the archaeological, archaeobotanical and palaeo-environmental evidence from a regional (Schleswig-Holstein, Germany) and a supra-regional (northern Germany) scale (using off-site data) reveals similar and coinciding changes in material culture, burial rites and land-use patterns. The changing land-use practices in northern Germany during the last centuries of the 2nd millennium BCE are also reflected in the diversification of the crop spectrum, including the beginning of cultivation of broomcorn millet (*Panicum miliaceum*). This supports the idea that the 13th to 11th centuries BCE were the time of far-reaching societal transformation. Substantial changes occurred in many forms of material expression (settlement architecture, layout and size; utilitarian objects), as well as in ideology (mortuary practice), technology (raw materials and techniques), trade and exchange (intensified circulation of goods), and the food economy (new crops and domesticates).

The 13th to 11th century BCE transformation in northern Germany

The period covering the 13th to 11th centuries BCE was an exceptionally dynamic one in the cultural history of northern Germany. On the basis of the recently produced absolute dates (Schaefer-Di Maida 2020), it is considered as the transition from the Older (Period Ib-III, 1700-1100 BCE) to the Younger Bronze Age (Period IV-VI, 1100-530/500 BCE), which starts in the second half of Period III (around 1200 BCE) in the regional archaeological periodisation (cf. Fig. 4). The transition brought a number of changes and innovations in the location and size of settlements, treatment of the dead, access to and choice of raw materials, tool and weapon type preference, and the size of the population (Feeser *et al.* 2019; Kneisel *et al.* 2019). The changes were substantial and far-reaching; the period is, therefore, regarded as a time of societal transformation evident in multiple aspects of life.

The archaeological evidence indicating these large-scale developments at around 1200 BCE can be summarised as a series of up- or downward trends in different archaeological datasets reflecting some major areas of human activity: social, technological, ideological and economic. Through systematisation and chronological alignment of these numerous on-site and off-site datasets from the Bronze Age in northern Germany, Kneisel *et al.* (2019) were able to identify several important general trends from about 1200 BCE onwards, relative to the previous periods. These are:

- a decrease in house size;
- an increase in the number of houses, settlements and settlement pits;
- the emergence of so-called storage-pit fields;
- already from 1500 BCE, increased human pressure on the landscape resulting from population growth;
- lower amounts of amber; and
- a sharp drop in the number of metal axes and sickles and, somewhat later, of swords and daggers.

In the 13th or 12th century BCE, a new cereal crop arrived in the region, probably from the south or southeast (Filipović *et al.* 2020a) – broomcorn millet (*Panicum miliaceum*). The earliest occurrences include large deposits, such as those at Rullstorf (site No. 5, county of Lüneburg, Lower Saxony; Kirleis 2003) and Badegow (site No. 19, county of Ludwigslust-Parchim, Mecklenburg-Vorpommern; Saalow *et al.* 2014), as well as many contemporaneous cases where smaller amounts of grains were discovered (Filipović *et al.* 2020a, Supp. Dataset). Radiocarbon dates produced directly on broomcorn millet grains suggests that this innovation spread very quickly across northern Germany. The start of millet cultivation was, potentially, a major agricultural change at the transition from the Older to the Younger Bronze Age. In northern Germany, this period is also marked by the beginning of the use, or increase in the use, of some other crops, such as pulses and oil/fibre plants.

Approaching the research questions

At least some of these synchronous and spatially overlapping trends were intertwined, or one caused the other. For instance, the intensified trade and exchange network, usually understood as distributing metal, metal objects and cultural influences, probably also served as a mechanism for the diffusion of crops. The new cultivar (broomcorn millet) may have led to changes in the ways the land was used for agricultural and other purposes. There may have been new tools and techniques employed in food production.

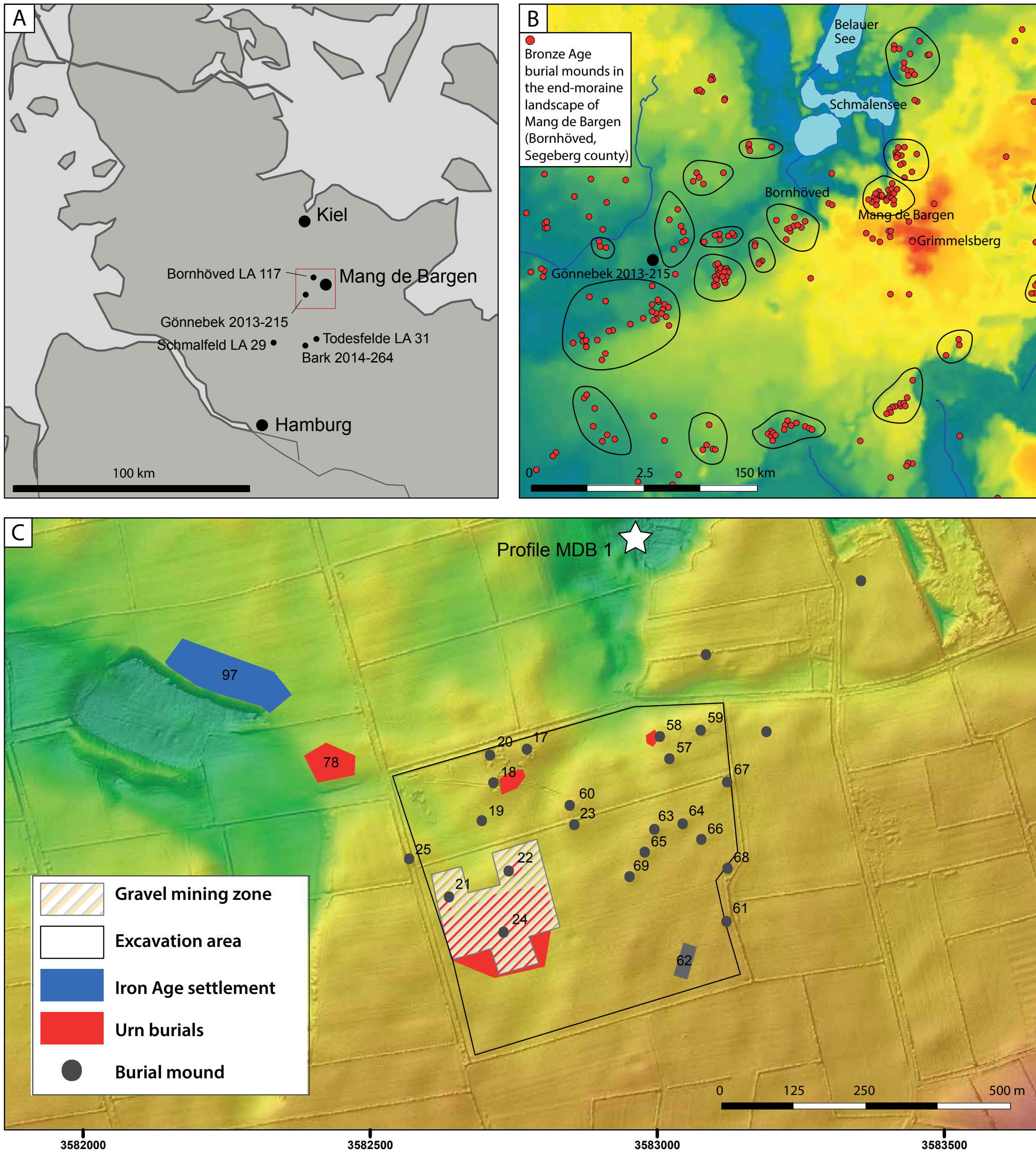

Figure 1. Location of Mang de Bargen and additional sites and geographic locations mentioned in the text. A: Map of Schleswig-Holstein showing location of the site of Mang de Bargen and other archaeobotanically analysed sites in the wider Mang de Bargen region mentioned in the text, and indicating the area shown in Fig. 1B (red rectangle). B: Map of the area around the site of Mang de Bargen, showing burial mounds (red dots) and clusters of burials (black lines); the cluster Mang de Bargen is shown in detail in Fig. 1C. C: Map showing the distribution of burial locations at Mang de Bargen (the numbers refer to the LA-numbers mentioned in the text).

Despite the good archaeological knowledge of this period, some key aspects remain elusive. For instance, how was the increasing human pressure on the environment exerted? Was a greater area needed to accommodate cultivation of the new crop? Did this increase the value of the land suitable for cropping and, possibly, create tensions in society? The demand for wood fuel presumably increased due to the new burial ritual; would this have been reflected in the landscape?

These and similar questions are important, as their answers can clarify the interconnections between changes in the environment and society and thus elucidate their knock-on effect. They cannot be addressed using a single line of evidence; they are also unlikely to be clarified to the same level of detail at the local to regional to supra-regional scales. Therefore, we take a multidisciplinary approach and look at the datasets produced by archaeological, palaeo-environmental and archaeobotanical analyses. We consider them separately, and then we combine them at different scales.

The local scale is here represented by the site of Mang de Bargen, in Schleswig-Holstein, Germany (Fig. 1). The results of the archaeological, palaeo-environmental and archaeobotanical analyses that have recently been carried out there have now been published (Feeser *et al.* 2020; Filipović *et al.* 2020b; Schaefer-Di Maida 2020; Kneisel *et al.* in prep.), meaning that we can use the final data and that the archaeological context and dating of the different materials have been fully reconstructed. We take the area of Schleswig-Holstein, and in particular the eastern younger morainic region, for which generally similar and synchronous cultural developments can be anticipated during the Bronze Age (cf. Schaefer-Di Maida 2020), as representing the regional scale of investigations. It includes Lake Belau, from which one of the palaeo-environmental archives discussed here derives (see below), as well as a number of other archaeological sites that are of similar age as Mang de Bargen (Fig. 1). Northern Germany is our supra-regional scale, and it serves as the wider geographical context for our observations made at lower scales. In parallel, we use some observations valid for all of northern Germany to inform our understanding of the developments at the regional and local levels.

This multidisciplinary and multi-scalar approach has three advantages. First, it allows us to compensate for the low availability or resolution of some of the data (*e.g.* archaeobotanical), which is an inevitable consequence of the nature of the studied archives and their differential rate of preservation. As will be shown below, not all of the selected evidential strands offer the same amount of detail, be it qualitative or quantitative, within and between the spatial scales. Second, it enables us to articulate the observations made from the different forms of data and to devise hypotheses on the cause-and-effect relationships between the changes seen in different aspects of the environment and human behaviour. Third, we can move between the scales, that is, use the site-based information to inform the supra-regional picture, and *vice versa*.

Mang de Bargen: Location and history of research

The site of Mang de Bargen (also called Mank den Bargen) is located about 2 km east of the town of Bornhöved, in the county of Segeberg, in the state of Schleswig-Holstein. It is situated between the Grimmelsberg end-morainic ridge (ca. 83 m asl) in the southeast and the Bornhöved lake chain in the northwest (Fig. 1B). The northwestern slope of the Grimmelsberg is composed of several morainic tops dating from the last Ice Age. The end-morainic landscape is covered by a variety of soil types, such as luvisols, cambisols and brown soil, underlain by a glacier-accumulated substrate made up of sand, gravel and clay lenses. The base of slopes is covered in colluvium. Along the lakes and ponds, one finds gleys and peat (Piotrowski 1991; Dreibrodt *et al.* 2009).

A number of burial mounds were constructed on the slopes of the Grimmelsberg ridge and along its foot during the Late Neolithic and the Bronze Age (Fig. 1B), most of them grouped in clusters of 3-30. Mang de Bargen itself, which represents a cluster of about 20 burial mounds (with 76 burials), has the highest concentration of these features. In the pre-Roman Iron Age and succeeding periods, an Urnfield cemetery (LA 115) located adjacent to the barrow area developed, and it preserved remains of 201 cremations. A little farther to the northwest, ca. 750 m away from the burial zone, are a settlement from the Iron Age (LA 97) and a small Urnfield cemetery from the Younger Bronze Age (LA 78), as yet unexcavated but known from surveys.

The Mang de Bargen mounds (Fig. 1C) were recorded as early as the 1960s, within a regional archaeological survey (Schwerin von Krosigk 1976). In 2004-2005 and 2014, the Archaeological Heritage Department of Schleswig-Holstein carried out rescue excavations prior to the expansion of a local gravel pit. With the exception of one mound (LA 57), all burial mounds visible on the surface, as well as the pre-Roman Iron Age urnfield, were investigated. Some of the burials were heavily disturbed, and only traces of these were discovered. Others were almost entirely destroyed and offered no evidence of former barrows or graves.

Parallel to the archaeological fieldwork in 2005, the Ecology Centre of CAU Kiel conducted investigations of the soil cover around the burial mounds in order to determine the degree of vegetation openness based on colluvial formations (Dreibrodt *et al.* 2009, 481-491). Previous work on the reconstruction of the vegetation and occupation history of the Bornhöved lake chain had taken place in the 1980s and 1990s within two research projects (the Bundesministerium für Bildung und Forschung-funded project 'Ökosystemforschung Bornhöveder Seenkette' and the Deutsche Forschungsgemeinschaft-funded project 'Neolithisierung in Schleswig-Holstein'). As part of these programmes, a high-resolution pollen diagram was produced from Lake Belau, offering insight into the regional human impact on the landscape (Wiethold 1998; Dörfler *et al.* 2012; Dreibrodt and Wiethold 2015).

Mound LA 57 was excavated in 2017, by the Collaborative Research Centre (CRC) 1266 (subproject D3), Kiel University (Schaefer-Di Maida 2020; Kneisel *et al.* in prep.). The magnetic prospection of the cemetery was performed by the Institute of Geosciences in Kiel. Additional magnetic prospections and test excavations were carried out in the wider surroundings of the cemetery (Kneisel *et al.* 2017). Also in the context of the CRC 1266, the history of the Mang de Bargen palaeo-environment was reconstructed, based on the analysis of sediment samples taken on-site – from the archaeological contexts – and the study of a short peat sequence from the area 300 m north of the site (subproject F2). The latter represents a so-called near-site archive, with local and extra-local pollen as the dominant components (*sensu* Moore *et al.* 1991). The analysis of the macro-botanical remains was also part of the research done within the CRC 1266 (subproject F3).

Prehistoric burial activity at Mang de Bargen

The relative chronological attribution of the artefacts and the absolute dating of cremated bones and charcoal show that the burial activity at Mang de Bargen started in the Late Neolithic, at ca. 2200 BCE, and lasted until the mid-1st century BCE. From the Late Neolithic until the start of Bronze Age Period III (ca. 1300 BCE), the burial activity involved the formation of grave mounds (barrows), under and within which the deceased were inhumated. Each mound covered a single primary burial in its centre, but some also enclosed secondary burials placed in the upper layers or in the periphery of the mound. Only a small, selected ('privileged') part of the community was buried in the barrows (*e.g.* 10% according to Kristiansen 2018, 110). The rest of the community may have received flat graves; these are, however, difficult to trace archaeologically. In the central grave, the deceased was laid in an oak-log coffin placed upon a stone-built base or surrounded by a row of stones. This construction was then covered with one or more heaps or layers of earth, creating the core and the mantle of the mound.

Only a few burials investigated at Mang de Bargen derived from the Late Neolithic phase of its use (Fig. 2), such as those at LA 63 and LA 64 (Schaefer-Di Maida 2020). Almost no burials were recorded for the period of transition from the Neolithic to the Bronze Age, that is, Bronze Age Period I (1750-1500 BCE). Either the degree of use

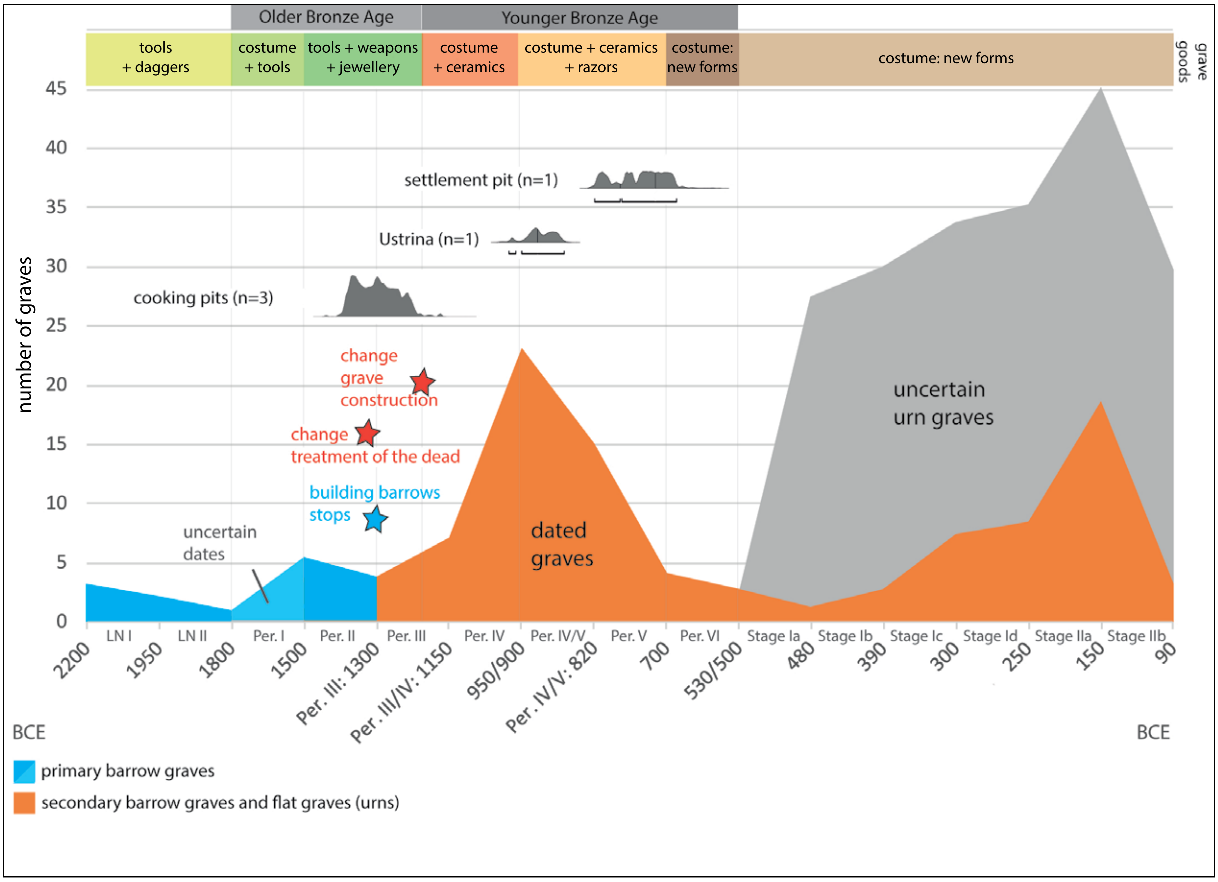

Figure 2. Chronological sequence and nature of the cultural developments at Mang de Bargen, reconstructed from the archaeological evidence.

of the site was much lower during this phase, or there was a gap in its occupation altogether. Bronze Age Period II (1500-1300 BCE) witnessed a considerable rise in the burial activity at Mang de Bargen and was the main phase of barrow construction.

The final barrow was built around 1300 BCE, marking the end of this funerary practice. This last barrow also contained the earliest cremation burial at the site, thus clearly documenting the shift from inhumation to cremation, which happened all over Schleswig-Holstein at about this time. Subsequently, from the middle of Bronze Age Period III (around 1200 BCE) onwards, the pre-existing barrows and their immediate surroundings at Mang de Bargen were re-used for secondary burials. These were exclusively cremations.

The burial activity that incorporated the new ritual was relatively low up until 1200 BCE. From this point on, it increased rapidly, and the number of burials peaked at 950/900 BCE (Fig. 2). Afterwards, the number of graves decreased, and it remained very low during Bronze Age Period VI (700-530/500 BCE). Another surge in burials began shortly before the transition to the pre-Roman Iron Age (530/500 BCE). This was mostly due to the start of the use of the urn cemetery (LA 115) located next to the grave mound area of the site, from ca. 530/500-480 BCE.

The cultural transformation of the 13th to 11th centuries BCE at Mang de Bargen

The archaeological evidence indicates a gradual change in burial rites from 1300 BCE onwards. Whereas at around 1300 BCE the treatment of the dead changed, *i.e.* from inhumation to cremation, the method of grave construction, *i.e.* the erection of grave mounds, continued unchanged. The repertoire of grave goods did not change either;

it continued to consist of tools, weapons and pieces of jewellery. There were also some new, non-funerary elements introduced at this time, though, and these are the so-called cooking pits. They were found in the immediate vicinity of Mang de Bargen, arranged in circles and dated to approximately 1300 BCE (Schaefer-Di Maida 2020).

From 1200 BCE (start of the Younger Bronze Age), the grave construction at Mang de Bargen changed fundamentally. The deceased were now exclusively cremated. Their remains were buried in urns placed within stone circles or were laid directly on a bed of stone. Burial took place within the pre-existing mounds or along their margins. More people were buried here in the last centuries of the 2nd and early centuries of the 1st millennium BCE than in any of the previous phases of use of the site (Fig. 2). For example, up to 35 secondary burials have been detected around a single mound (LA 57). From a practical point of view, the more intensive use of the site could have simply been because urn or directly buried cremation graves required less space than a single-grave barrow, and therefore more graves could be placed in the area. Also, the amount of resources needed, such as construction materials (wood, soil) and human labour (for the mound building, but also for the transport of earth and vegetation sods; cf. Schunke 2018), may have been higher for the creation of barrows than for the execution of cremation funerals. On the other hand, considerable resources and labour were also required for the cremation burials, *i.e.* for the collection of wood, construction of the funeral pyre, and transport of the stones used for lining/encircling the graves. Falkenstein suggests that the amount of labour invested in cremation burials would have been similar to that invested in building tumuli (Falkenstein 2012, 336). He goes on to suggest that the time required to collect (enough) wood for the pyre would have been comparable to the time needed to raise a mound 7 m in diameter (Falkenstein 2017, 80-81). The diameter of the burial mounds at Mang de Bargen generally exceeds 20 m, so constructing these mounds would, following these calculations, have taken much more resources and energy expenditure than cremation funerals.

The 12th century BCE transformation in the burial ritual at Mang de Bargen entailed a new repertoire of grave goods. Tools, weapons and jewellery were replaced by dress ornaments and pottery. Overall, grave good inventories appear less diverse, almost standardised. This, together with the simple, uniform burials perhaps suggests that the members of the community now received more equal funerary treatment. Indeed, the period of burial mound construction has been described as the time of chiefs, warrior elites and pronounced social stratification (Jensen 1982; Kristiansen 1987, 1991; Earle 1991, 2002; Vandkilde 1996, 2006). The dramatic change in the burial ritual and other aspects of life in the Younger Bronze Age may point to a major societal change, a transformation of the social structure, apparently from non-egalitarian to (more) egalitarian.

Plant use at Mang de Bargen: The archaeobotanical perspective

In order to retrieve evidence of prehistoric plant use at Mang de Bargen, archaeobotanical sampling was employed at 11 burial locations, and at one location (LA 116) that comprised remains of different Younger Bronze Age features (pits, ovens, hearths) reflecting activities whose character – whether residential or funerary – could not be clearly distinguished. An assortment of archaeological contexts of interest to the researchers were sampled at these locations: graves, pits, cooking pits, hearths and an oven. The number of samples taken at each of the locations depended on the presence and number of such clearly defined contexts. The samples, measuring, on average, 8-9 litre in volume, were floated manually using buckets and a 0.3 mm geological sieve. All plant remains encountered are in

TAXON			LA 63	LA 64	LA 23	LA 69	LA 115	LA 57	LA 116
		Site	LA 63	LA 64	LA 23	LA 69	LA 115	LA 57	LA 116
		Type of site	Burial	Burial	Burial	Burial	Burial	Burial	Settlement
		Period	Late Neolithic		BA Period I-II			BA Period II-III	BA Period V-VI
	Number of analysed features		2	1	2	2	1	21	8
	Volume of analysed samples (l)		16	18	14	25	6	348	38
TAXON	Weight of wood charcoal (g)		2.5	1.3	20.2	4.2	75.7	73.7	25.1
Crops	**plant part**	**common name**							
Hordeum vulgare	grain	barley	3	1				8	8
Triticum cf. *monococcum*	grain	einkorn						1	
Triticum monococcum/dicoccum	grain	einkorn/emmer						1	
Triticum dicoccum	grain	emmer	1					9	
Triticum dicoccum	glume base	emmer						5	
Triticum aestivum/durum/turgidum	grain	free-threshing wheat		1				1	
Triticum spelta	glume base	wheat						1	
Triticum sp.	grain	wheat	2					4	
Cerealia indeterminata	grain	non-millet cereal	1	1				21	5
cf. *Cerealia indeterminata*	grain	cereal							1
Panicum miliaceum	grain	broomcorn millet							2
Wild plants	**plant part**	**common name**							
Alnus sp.	catkin fragment	alder						1	
Bromus sp.	fruit	brome grass			1				
Calluna vulgaris	fragment of flower	heather						2	
Carex sp., *tricarpellate*	nutlet	sedge						3	
Carpinus betulus	seed	common hornbeam					1	1	
cf. *Mentha* sp.	seed	mint				1			1
Chenopodiaceae	seed	goosefoot family						2	
Chenopodium album	seed	fat hen						13	
Chenopodium sp.	seed	goosefoot						1	
Coenococcum geophilum	sclerotium	soil fungi						40	
Corylus avellana	nutshell fragment	hazelnut						3	
Fabaceae	seed	legumes						2	
Hypericum cf. *perforatum*	seed	St. John's wort						1	
Persicaria lapathifolia agg.	nutlet	pale persicaria							1
Persicaria lapathifolia/maculosa	nutlet		1		1			1	
Persicaria maculosa	nutlet	lady's thumb						1	2
Phleum pratense s.str.	fruit	timothy grass	1						

Table 1 (continued on opposite page). Results of the archaeobotanical analysis of different locations and contexts at Mang de Bargen.

		Site	LA 63	LA 64	LA 23	LA 69	LA 115	LA 57	LA 116
		Type of site	Burial	Burial	Burial	Burial	Burial	Burial	Settlement
		Period	Late Neolithic		BA Period I-II			BA Period II-III	BA Period V-VI
	Number of analysed features		2	1	2	2	1	21	8
	Volume of analysed samples (l)		16	18	14	25	6	348	38
TAXON	**Weight of wood charcoal (g)**		2.5	1.3	20.2	4.2	75.7	73.7	25.1
Plantago lanceolata	seed	ribwort plantain						8	
Poa cf. *annua*	fruit	annual bluegrass							1
Poaceae	fruit	grasses			1			8	3
Poaceae	culm node	grasses						1	
Poaceae	culm fragment	grasses						49	
Polygonaceae/Cyperaceae	nutlet							1	
Polygonum aviculare agg.	nutlet	common knotgrass						1	
Polygonum convolvulus	nutlet	black bindweed						4	
Polygonum convolvulus/aviculare	nutlet							1	
Quercus sp.	acorn fragment	oak	3					1	
Rubus idaeus	seed	raspberry						1	
Rubus spec.	seed							1	
Rumex acetosella agg.	endosperm	sheep's sorrel		16					
Rumex obtusifolius s.l.	nutlet	bitter dock						1	
Schoenoplectus tabernaemontani	nutlet	great bulrush	1						
Scirpus cf. *mucronatus*	nutlet	bog bulrush						1	
Solanum nigrum	seed	black nightshade					1		
Vicia sp., small-seeded	seed	vetch	3	1	2			2	
Viola sp.	seed	violet				1		1	2
Indeterminate									
bud				16	1		1	4	
fragment of flower								1	
fragments of cone				1					
fragments of leaf/needle							1		
fragments of stem								7	5
fruit/bread fragments				11				2	
indeterminate seed (eroded)			4	1	8	6	3	72	4
indeterminate vegetal matter	fragments		23	16	13	53		348	129
parts of rhyzomes and culm bases					1				
spores			23	17	12	3	100	1220	25
cf. animal droppings			1		1		2	7	
cf. insect								1	

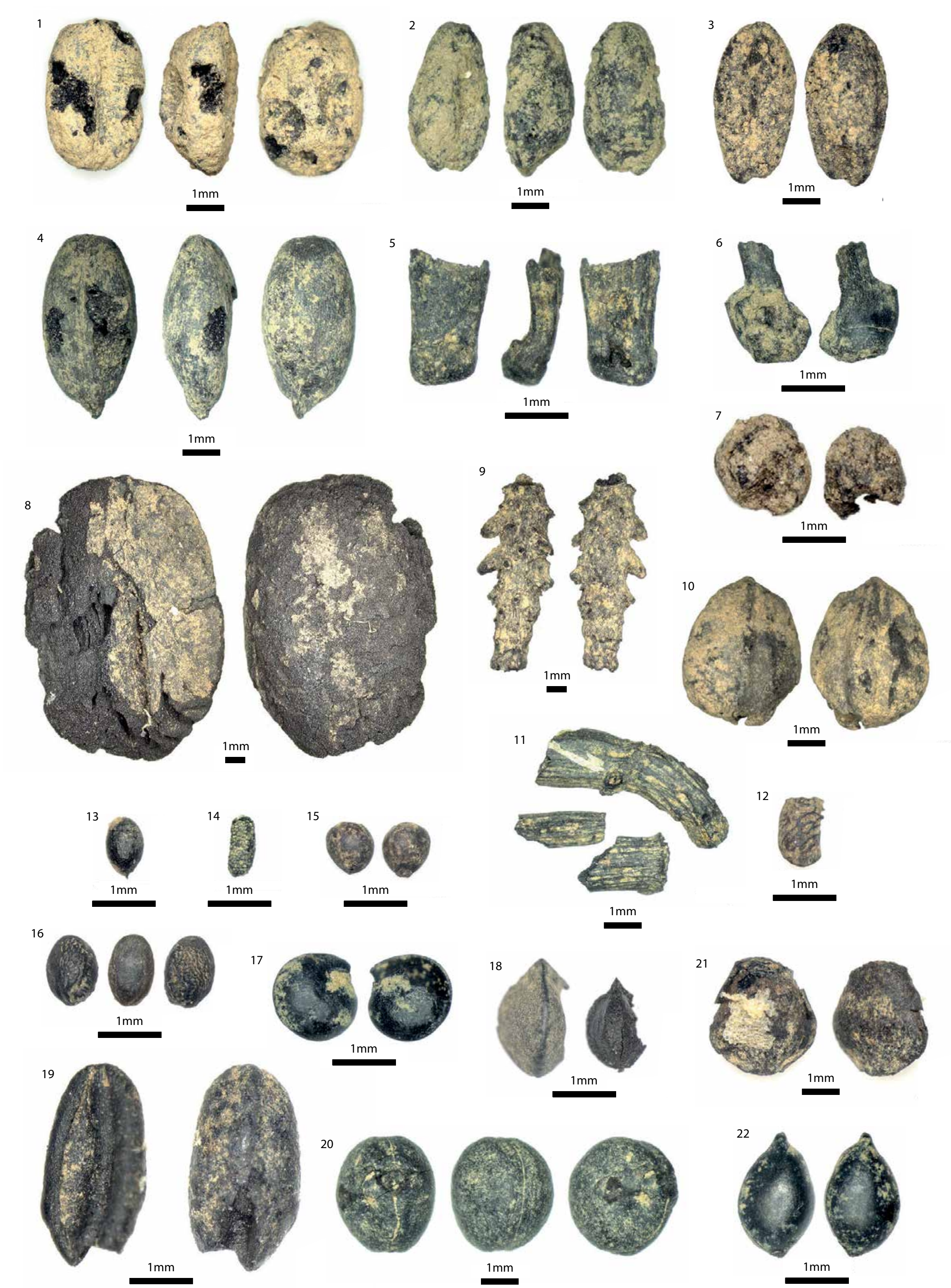

Figure 3. Selected archaeobotanical remains from Mang de Bargen (photo: Dragana Filipović, Tanja Reiser): 1. Free-threshing wheat or spelt grain (LA 57); 2. Free-threshing wheat or emmer grain (LA 57); 3. Emmer grain (LA 57); 4. Barley grain (LA 57); 5. Spelt glume base (LA 57); 6. Emmer glume base (LA 57); 7. Broomcorn millet grain (LA 116); 8. Acorn cotyledon (LA 57); 9. Alnus *sp. catkin (LA 57). 10.* Carpinus betulus *seed (LA 115); 11. Rhizomes, possibly* Arrhenatherum *(LA 57); 12.* Rubus *seed fragment (LA 57); 13.* Phleum *fruit (LA 63); 14.* Hypericum *cf.* perforatum *seed (LA 57); 15.* Viola *seed (LA 57); 16.* Brassicaceae *seed (LA 69); 17.* Chenopodium album *seed (LA 57); 18.* Fallopia convolvulus *seed and endosperm (LA 57); 19.* Plantago lanceolata *seed (LA 57); 20.* Vicia *seed (LA 57); 21.* Scirpus mucronatus *seed (LA 57); 22.* Carex *seed (LA 57).*

Crop taxa	Late Neolithic	Bronze Age Period I-II	Bronze Age Period II-III	Bronze Age Period V-VI
Barley	X		X	X
Emmer	X		X	
Free-threshing wheat	X		X	
Spelt			X	
Einkorn			X	
Broomcorn millet				X

Table 2. Presence/absence of crop taxa in the different phases of occupation of Mang de Bargen.

a charred state, and the majority of them represent fragments of wood charcoal. Detailed archaeobotanical data are available for LA 23, LA 57, LA 63, LA 64, LA 69, LA 115 and LA 116 and are given in Table 1 (Filipović *et al.* 2020b).

Despite the large number of samples processed, only a very small non-wood plant assemblage was recovered, composed of poorly preserved parts of crops and wild plants (Table 1; Fig. 3). The assemblage is, nonetheless, quite diverse. Crops are represented by grains of barley (*Hordeum vulgare*), grains and chaff of emmer (*Triticum dicoccum*), grains of free-threshing wheat (*T. aestivum/durum*) and einkorn (*T. monococcum*), grains and chaff of spelt (*T. spelta*) and grains of broomcorn millet. Finds of barley and emmer are the most frequent. The seeds identified as *Vicia* sp. may belong to potentially cultivated common vetch (*Vicia sativa*). The assemblage of wild plants from Mang de Bargen is also diverse and consists of seeds and fragments of nuts, nutshell, culms, rhizomes and tubers. Some of the remains belong to edible parts of trees and bushes, such as oak (*Quercus*), common hazel (*Corylus avellana*) and blackberry (*Rubus idaeus*), and they may represent traces of food. Seeds of fat hen (*Chenopodium album*), knotgrass (*Polygonum aviculare*), pale persicaria (*P. lapathifolium*), sheep's sorrel (*Rumex acetosella*), black nightshade (*Solanum nigrum*) and others document the presence of arable weeds in the assemblage. The vegetative plant parts (stems, culm bases, stolons/rhizomes) may represent traces of plants used as kindling for cremation or domestic fires. Some of these remains perhaps come from false oat-grass (*Arrhenatherum elatius* ssp. *bulbosum*), which was documented at some other sites in this region as well as throughout northwestern and north-central Europe (*e.g.* Bornhöved LA 117 [Kneisel *et al.* in prep.] and Gönnebek 2013-215 [Effenberger 2018a]; see Roehrs *et al.* 2013).

Plant remains were found in both burial and non-burial contexts, suggesting that the plants were used and/or became charred in different locations across the site. Another possibility is that there was general mixing of the material from different contexts due to recurrent digging and redepositing of soil to cover the graves. Thus, for instance, crop-processing waste (cereal chaff, arable weed seeds) was found in both settlement and burial pits, but cleaning of the grain before use may have taken place elsewhere – perhaps away from both residential and funerary areas. Due to the long-term and apparently intensive use of the site through later prehistory, it was expected that plant materials dating from different periods of occupation would have become mixed together in the archaeological layers. Therefore, a selection of plant remains were submitted for radiocarbon dating (Schaefer-Di Maida 2020), allowing their approximate age to be established. Using a combination of absolute dates and contextual or stratigraphic information, the plant remains are here broadly attributed to individual phases of occupation/use of Mang de Bargen. This provides an overview of the presence/absence of different crop taxa through time (Table 2).

The largest diversity of crop species was noted at LA 57, which is where the number of sampled contexts was the highest (22, compared with <10 at other locations; see Table 1). Interestingly, just three Late Neolithic contexts yielded traces of three crop taxa, whereas the five Bronze Age Period I-II contexts did not contain any crop remains. Based on this, the impressions is that there was no or little crop cultivation or consumption at or around Mang de Bargen during Bronze Age Periods I and II. This is very much in line with the absence of human activity at the site during Bronze Age Period I, as inferred from the archaeological evidence (see above).

Some crop species were in use at Mang de Bargen in both the Late Neolithic and the later phases of the Bronze Age, namely barley, emmer and free-threshing wheat. Although wheat remains were not confirmed for the final phases of the Bronze Age, they may be present in the category 'Cerealia indeterminata' (indeterminate cereal grain) (Table 1). Broomcorn millet finds from Mang de Bargen derived from the Younger Bronze Age. Only two grains were found, both at LA 116, in a pit dated to the 8-6th century BCE. Broomcorn millet arrived in and spread across northern Germany in the 13th-12th centuries BCE (Effenberger 2018a; Filipović *et al.* 2020a) and may have been available to the Mang de Bargen occupants already from this time onwards.

For the purpose of radiocarbon dating, a small collection of wood charcoal fragments, extracted from inhumations or cooking pits from locations LA 23, LA 57, LA 64 and LA 116, has been identified. A fragment of birch (*Betula*) wood from LA 64 was dated to the second half of the 3rd millennium BCE (the Late Neolithic). Several fragments of oak (*Quercus*) and hazel (*Corylus*) wood from LA 23 and LA 57 derived from the second half or the end of the 2nd millennium BCE (Schaefer-Di Maida 2020).

Trends in local land use through time: The palaeo-environmental evidence

On-site investigations

Pedological and sedimentological analyses on samples taken just east of barrow LA 57 revealed a fossil soil covered by three colluvial layers (Fig. 4). Based on the optically stimulated luminescence (OSL)-dates, the fossil soil horizon (fAh) dates to the Late Neolithic (Kneisel *et al.* in prep.), and the colluvial material has been accumulating on top of it from the Iron Age onwards. Palynological analysis has been carried out for the fAh horizon and the earliest colluvial layer (M1); the results are summarised in Table 3. The predominance of subfossil pollen grains of herbaceous land plants (72% excluding fern spores) along with the presence of cereal-type pollen, partly in clumps, indicates that the site was used for agriculture probably already during the Late Neolithic. The findings of fused birch pollen could point to the existence of fallow land and the beginning of regeneration of woody vegetation near LA 57. Despite the possibility of taphonomic enrichment of fern spores due to selective preservation (Havinga 1984), the comparatively high proportion of spores of spotted fern (*Polypodium vulgare*) and common viper's tongue (*Ophioglossum*), both of which prefer a low-nutrient environment, could indicate nutrient-impoverished soil conditions (cf. Feeser and Dörfler 2016, 2019), which is not unlikely given the generally sandy soils in the area.

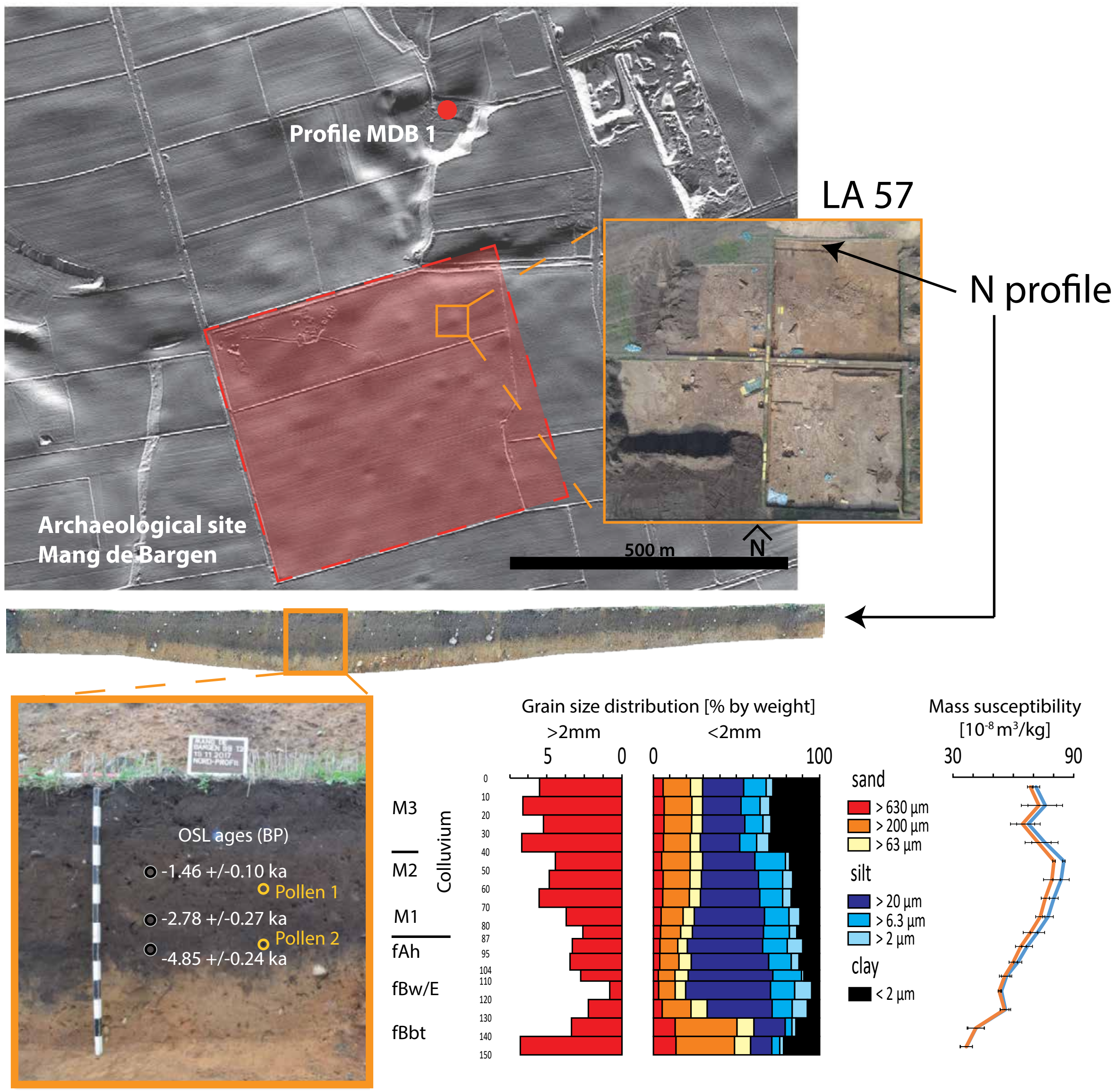

Figure 4. Pedological, sedimentological and palynological analyses of a soil profile from the archaeological layers at LA 57. Results of the analysis of pollen samples Pollen 1 and 2 are given in Table 3.

Site	LA 57	LA 57
Context	N-Profil	N-Profil
Sample	Pollen 1	Pollen 2
Labnr.	22152	22153
Volume (ml)	7	8
Weight (g)	6.05	10.11
Added markers	19223	19223
Counted markers	12	597
Trees and shrub taxa		
Alnus	-	2
Betula	-	13/6/-
Corylus	-	5
Pinus	-	5
Quercus	-	3
Tilia cordata-type	1	1
Dwarf shrub taxa		
Calluna	1	14
Non-arboreal pollen taxa		
Asteraceae p.p.	1	4
Bidens-type	1	-
Cerastium-type	-	1
Geranium	1	1
Wild grass-type	7	18/8/2
Hornungia-type	-	2
Liguliflorae	5	48
Plantago lanceolata-type	-	1/8/-

Site	LA 57	LA 57
Ranunculus acris-type	-	1
Sinapis-type	-	4
Succisa	-	2
Cultivars		
Avena-type	-	1
Cerealia-type indet.	5	21/4/-
Hordeum-type	-	4
Unidentified		
Corroded indet.	11	122
Varia indet.	-	1
Spores		
Botrychium	-	4
Ophioglossum	-	30
monolete fern spore (-perine)	-	19
Polypodium vulgare	1	5/-/1
Pteridium	2	26
Sphagnum	-	2
Non-pollen palynomorphs		
Botryococcus	-	1
Pseudoschizaea	1	51
HdV-201: *Xylomyces*	-	1
HdV-214: *Debarya-type*	-	1
HdV-461	-	62
Microcharcoal		
Particles (>37 um)	50	6495

Table 3. Results of palynological analysis of soil samples from Mang de Bargen LA 57. Indicated are the counts for the different micro-fossil taxa. Where multiple numbers are given, they refer to number of subfossil grains/number of subfossil pollen grains in clumps/number of well-preserved, probably modern, grains.

Near-site investigations

In order to find suitable deposits for palaeo-ecological investigations in the immediate vicinity of Mang de Bargen, test gouge coring in a small, wet, seasonally flooded depression ca. 300 m northwest of Mang de Bargen was carried out in 2017. The core, labelled MDB1, was extracted using an 80 mm Usinger piston corer. It revealed the presence of peat deposits, lying under a 1.2 m thick modern sand layer. At 2.15 m below the surface, the piston hit an oak log, which impeded further coring.

The peat section of profile MDB1 was continuously subsampled in 1 cm thick slices for palynological and geochemical analyses, as well as for loss-on-ignition examination. The dating of the core is based on three radiocarbon dates on terrestrial plant material and the detection of two cryptotephra layers (Hekla 3 and 4) with their corresponding age estimates from the nearby Lake Belau (cf. Dörfler *et al.* 2012). The chronology of the investigated sequence covers the interval between ca. 3200 BCE and 650 CE, with an average resolution of ca. 40 years per sample.

Given the small size of the depression, and its location in the immediate vicinity of the site, the majority of the pollen grains are understood to have derived from the local and 'extra-local' vegetation, *i.e.* from a radius of a few hundred metres around the archaeological site. This near-site pollen archive enabled a detailed reconstruction of the local land-use history for the entire period of occupation of Mang de Bargen.

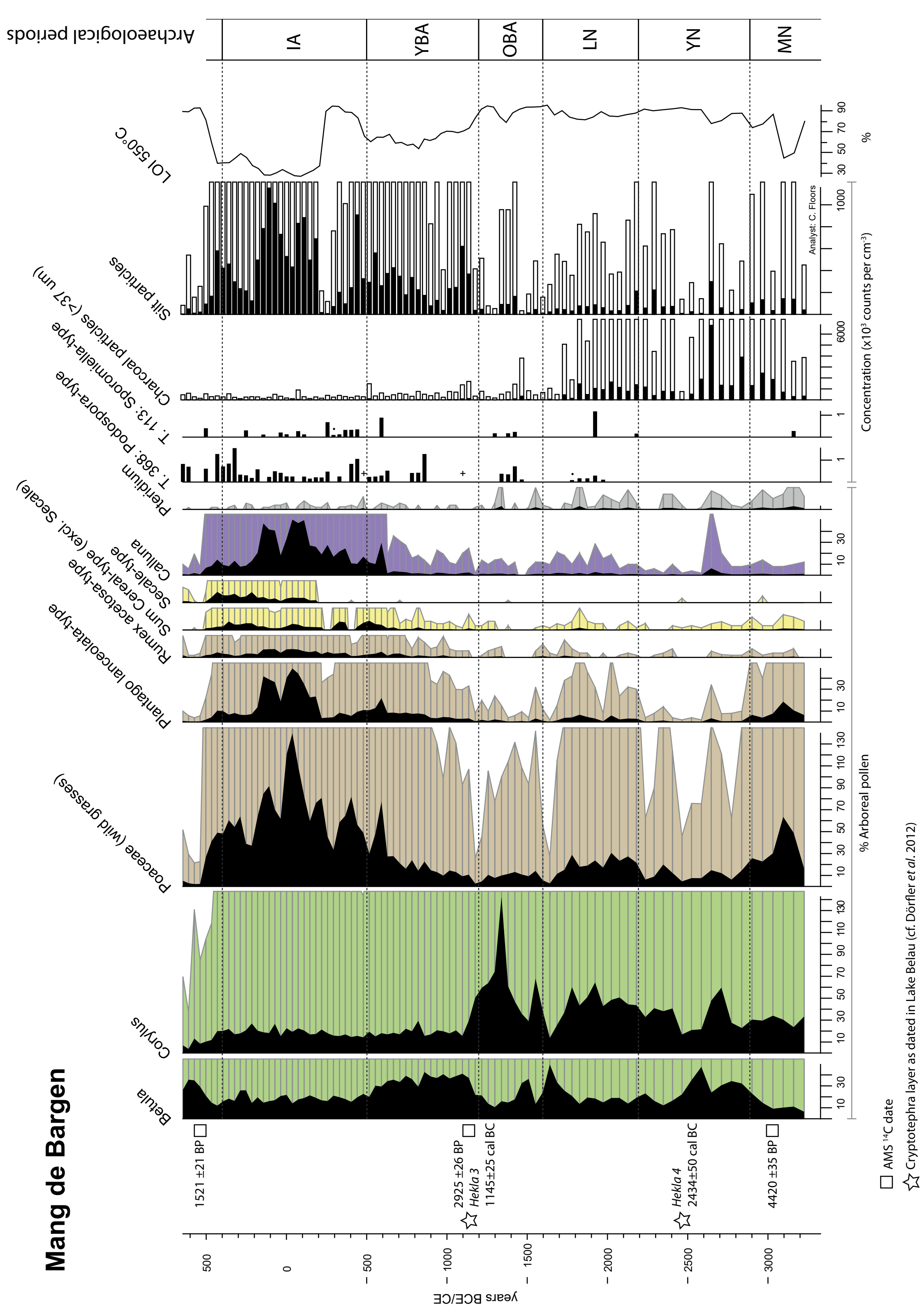

Figure 5. Selection of palynological and sedimentological taxa and parameters from the near-site profile (MDB 1). Middle Neolithic (MN), Younger Neolithic (YN), Late Neolithic (LN), Older Bronze Age (OBA), Younger Bronze Age (YBA), Iron Age (IA).

Figure 5 shows the percentages of selected palynological and sedimentological proxies recorded in the MDB1 profile. Birch (*Betula*) and hazel (*Corylus*) are light-demanding trees, and their presence can reflect woodland openness. Birch, as a pioneer tree, is generally indicative of woodland regeneration, pointing to the existence of relatively open, early stage secondary woodlands. Birch grows quickly on land left fallow, and this land can be used for forest pasturing. The growth of hazel, on the other hand, is generally promoted by opening of the woodland and can therefore point to woodland disturbance. Further evidence of woodland disturbance at Mang de Bargen is provided by the presence of *Pteridium* spores. Bracken (*Pteridium aquilinum*) is a fern favoured by opening of the canopy and is often regarded as an indicator of clearance through burning or woodland pasturing. The former can also be inferred based on the high quantities of micro-charcoal particles in the sediment.

Among the non-arboreal pollen (NAP) types at Mang de Bargen, there are standard anthropogenic indicators (cf. Behre 1981), including *Plantago lanceolata*-type and *Rumex acetosa*-type; both of these were also registered in the charred seed assemblage from this site (Table 1). They are understood as reflecting anthropogenic open landscape and agricultural areas, respectively. Ribwort plantain (*Plantago lanceolata*), for example, is an indicator not only of pastoral activities or grassland, but also of arable activities and associated fallow land (Behre 1981; Brinkkemper and van Wijngaarden-Bakker 2005; Kirleis 2019, 76-77). The rising values for *Calluna* possibly signal increasing soil depletion in the anthropogenic parts of the landscape and the associated spread of heather (*Calluna vulgaris*). The amounts of cereal-type pollen can be used to infer the presence and importance of arable farming. Animal grazing/browsing is documented by non-pollen palynomorphs relating to fungi growing on animal dung – so-called coprophilous fungal spores – such as *Sporomiella*-type (HdV-113) and *Podospora*-type (HdV-368) (cf. Feeser and O'Connell 2009; Baker *et al.* 2013).

Another proxy for local land-use activity causing soil erosion is the minerogenic content of the peat, reconstructed based on the results of the loss-on-ignition at 550°C (LOI550), where low values indicate lower organic content of the sediment, and on the concentration of silt particles in the pollen samples.

Changing land-use and cultural practices at Mang de Bargen: A multidisciplinary perspective

Here we integrate the results of different analyses (palaeo-environmental, archaeobotanical, archaeological) and use them to chart the history of local land use at Mang de Bargen. The fluctuation over time in the quantities of different taxa in the pollen record demonstrates changes in the vegetation forms and/or their extent around the site as a result of low *vs*. high degree of human impact. Beyond this quantitative aspect of prehistoric human activity at Mang de Bargen, the pollen and sedimentological archives allow us to also infer a qualitative aspect – the *nature* of the activity – and changes in it over time.

The near-site pollen diagram (Fig. 5) opens at ca. 3300 BCE and shows a period of increased human activity up until ca. 2900 BCE, based on the quantitative representation of the indicators described above. In culture-historical terms, this time relates to the Middle Neolithic period. The surroundings of Mang de Bargen may have been used at this time, but this left no conclusive on-site archaeological evidence.

A further phase of increased land use can be palynologically inferred for the period ca. 2200-1650 BCE, overlapping with the regional Late Neolithic. There are indeed archaeological traces of human activity at Mang de Bargen during this period, in the form of burial mounds containing primary graves (see above). The archaeobotanical evidence indicates cultivation of emmer and barley and perhaps gathering of wild resources (*e.g.* acorn). That agricultural activity took place locally is demonstrated by the palynological analysis and OSL-dating of the fossil soil horizon at LA 57. These results are further supported by the presence of ard marks under at least four burial mounds (LA 18, 57, 60 and 63, cf. Fig. 1C; Schaefer-Di Maida 2020), indicating possible agricultural activities before the erection of the barrows. The finds of spores of coprophilous fungi in the near-site profile MDB1 show that perhaps domestic animals were also kept in the site's surroundings.

There seems to have been a lull in human activity during the second quarter of the 2nd millennium BCE, as indicated by the declining values for anthropogenic indicators in profile MDB1 in the period after ca. 1750 BCE, continuing to their minimum at around 1500 BCE. The archaeological layers broadly associated with this phase did not contain evidence of crop cultivation or consumption. This is in agreement with the archaeological data from Mang de Bargen, which show a decrease or gap in burial activity from around 1700 BCE until about 1500 BCE (the period of Bronze Age Period I in Schleswig-Holstein).

At ca. 1500 BCE, barrow construction activity recommenced at the site, probably reaching maximum levels in a very short time, after which it gradually decreased until 1300 BCE, when it came to an end (Fig. 2). Based on the palynological record, this is associated with a phase of increased grazing activity (a peak in *Sporomiella*-type (HdV-113) and *Podospora*-type (HdV-368)) and low agricultural activity (only sparse records of cereal-type pollen; no archaeobotanical evidence of crops) between ca. 1500 and 1300 BCE (BA Periods I-II).

The time around 1300 BCE is when the new burial rites – cremation and, later on, placement of cremation urns into flat graves – entirely replaced inhumations and barrows at Mang de Bargen and when a sharp rise in burial activity began. The higher number of post-1200 cal BCE burials at Mang de Bargen may imply that more people lived in the area from this time onwards. However, more graves need not reflect demographic growth. In light of the large-scale social change around 1200 BCE, understood as a shift from elite-centred, highly stratified communities to egalitarian communities, it is possible that what used to be a dedicated barrow area in earlier times was now a burial place (also) open to groups previously not entitled to a grave here due to their social status (Schaefer-Di Maida 2020). Either way, the demand for wood may have surged.

The palynological data shows an increasing share of NAP from ca. 1300 BCE onwards, suggesting an increasing opening of the landscape. Local cereal cultivation regained its importance, as indicated by the increasing quantities of cereal-type pollen in the MDB1 core. Furthermore, the change in the relative proportion of woody taxa, *i.e.* a distinct decline in *Corylus* and an associated increase in most arboreal taxa, indicates a change in woodland composition and structure. Further distinct changes in the palaeo-environmental record include increased evidence for soil erosion (*i.e.* high silt particle concentration and lower LOI550) and lower fire activity (*i.e.* low micro-charcoal concentrations).

The latter seems to contradict the evidence for increasing importance of cremations in the area. But, as outlined below, the earlier higher micro-charcoal values are interpreted to primarily reflect the burning of woodland undershrub, which would produce a lot of charcoal in the catchment. Burning of wood in pyres, instead, is much more localised and probably also reaches higher temperatures and more complete combustion, which in turn results in comparatively little charcoal output (cf. Patterson *et al.* 1987; Veal *et al.* 2011).

The palynological evidence for the increasing importance of cereal cultivation is corroborated by the presence of cereal remains in the coeval archaeological layers, now coming from a greater range of species (Table 2) and possibly including broomcorn millet. This in fact could support the idea of an increase in population during the Younger Bronze Age, reflected not only by an increasing number of graves, but also by a growing demand for agricultural products.

The presented results therefore refine the picture of agricultural history at Mang de Bargen presented by Dreibrodt *et al.* (2009), who found no evidence for local Bronze Age agricultural activities. Based on the presence of colluvial layers, Dreibrodt *et al.* (2009) reconstructed main phases of soil erosion, and therefore local agricultural activities, for the Late Neolithic (around 2400/2200 BCE) and, in particular, the Iron Age (*c.* 250 to 400 CE). Although these two phases are in good agreement with the results from MDB1, it is conceivable that local agriculture and also soil erosion rates had already increased in the Younger Bronze Age, before reaching a maximum in the Iron Age.

At the same time in the woodlands, the decreasing importance of hazel and the associated generally lower representation of bracken points towards less disturbance. Taken together, these trends point to more intensive use of the open land at the same time when the woodlands were used more extensively. This is regarded as signalling a different form of land use from 1200 BCE onwards compared with the earlier phases recorded for the area of Mang de Bargen.

A possible explanation is that until 1300 BCE, woodland pasture was an important component. Grazing of animals and periodic cutting of trees for fuel or raw materials would have resulted in the opening of the woodland canopy and affected its structure. This form of land use would have favoured the light-demanding hazel, which constituted woodland undergrowth, and also the proliferation of the disturbance-tolerant bracken. Fire was probably used to improve the accessibility and quality of the grazed vegetation, *e.g.* by encouraging resprouting of plants and thus increasing the amount of forage (cf. Mellars 1976), and fire could have also been applied to clear the land for cultivation of crops.

After 1200 BCE, the record of coprophilous fungal spores suggests pastoral activities, but without clear evidence for woodland disturbance. This could be explained by a shift in pastoral activities to open land. Increased representation of non-arboreal pollen supports this impression; consequently, open grassland may have become the preferred, or the only available, grazing zone. A possible consequence of this intensification of pastoral activities in the open lands around Mang de Bargen is the spread of heather due to increasing soil depletion. The distinct increase in coprophilous fungal spores after 1200 BCE in profile MDB1 is associated with an increase in heather. This process seems to have reached a maximum in the two centuries before and after BCE and is in agreement with pedological investigations in the region, which found the first evidence for podsolisation during the Iron Age (Dreibrodt and Wiethold 2015).

To sum up, our results indicate that, although from an archaeological point of view Mang de Bargen was, throughout much of its history, principally the site of burial activity, parts of the land locally or in the surrounding region were used for animal grazing and crop cultivation. It seems that, with the complete shift to cremation at 1200 BCE, animal grazing was relocated from one landscape zone (forested) to another (cleared), either in response to modified agricultural practices (*e.g.* new crops and cultivation practices, a change in animal husbandry, and size of herds, a focus on secondary products) or newly emerged human needs (*e.g.* securing wood for funeral and domestic fires, construction or metallurgy), or both.

Culture and land-use changes with a special focus on the 13th to 11th centuries BCE across spatial scales

In this chapter, we place the evidence from Mang de Bargen, *i.e.* the local scale, into the broader history of land use and cultural developments by looking at the regional and supra-regional palaeo-environmental, archaeobotanical and archaeological evidence.

We take the well-dated, high-resolution off-site pollen record from Lake Belau, ca. 3.5 km north of Mang de Bargen (Wiethold 1998; Dörfler *et al.* 2012; Dreibrodt and Wiethold 2015; Fig. 1B), as representative of the regional palaeo-environmental developments (Fig. 6).

The supra-regional view of the human impact on the environment through time is provided by a combination of pollen, pedo-sedimentological and archaeological radiocarbon data (see details in Feeser *et al.* 2019). The palynological data derive from the annually laminated sediments of Lake Belau (Wiethold 1998; Dörfler *et al.* 2012; Dreibrodt and Wiethold 2015) and Lake Woserin (in Westmecklenburg; Feeser *et al.* 2016). The pedo-sedimentological data consist of records of colluvial deposits in Schleswig-Holstein and Mecklenburg-Vorpommern. The radiocarbon dates come from dozens of single- and multi-period sites in northern Germany (Dreibrodt *et al.* 2010; Hinz *et al.* 2012; Kneisel *et al.* 2013; Fig. 7). These datasets have each been amalgamated into single temporal trajectories, *i.e.* proxy curves for human environmental impact, covering much of the later prehistory of northern Germany. The synchronous trends in the three curves are taken as reflecting changes in the supra-regional population size, where the upward trend signifies an increase in the number of people living in the region, resulting in greater/more intensive use of the landscape and thus changes in the vegetation cover and an increase in soil erosion rates (Fig. 7). These trends have been termed 'boom phases' and the intervals between them 'bust phases', regarded to reflect growing and declining trends in population numbers, respectively (Feeser *et al.* 2019).

Similar to the data from the local scales, the regional and supra-regional palaeo-environmental data reveal increasing human activity in the last centuries of the 3rd millennium BCE and the first centuries of the 2nd millennium BCE (the Late Neolithic). In both the near-site pollen archive from Mang de Bargen and the pollen diagram for Lake Belau (Fig. 6), this is associated with increased evidence for cereal cultivation, clearly discernible at around 2200 BCE (see curves for cereal-type pollen), *i.e.* with the start of the Late Neolithic. Although we know from the local record MDB1 that pastoral activities increased at the same time, it seems likely that clearance of woodlands for agricultural fields was the primary contributor to the changes in the vegetation composition locally, as it was across the wider region (Feeser *et al.* 2019). Given the regular evidence of former arable activities in the soils under the burial mounds, it is unlikely that, even on a local scale, clearing in preparation for burial mound constructions played an important role in opening up the landscape. Rather, it seems that, as in other regions and previous periods, the graves were erected on former farmland, which was thus given a cultural value in addition to an economic one (Doorenbosch 2013; Feeser and Dörfler 2016, 2019).

The archaeobotanical data confirm that agriculture played an important role. Barley, emmer and, to some extent, free-threshing wheat were by this time being grown throughout northern Germany and southern Scandinavia (Kirleis *et al.* 2012; Kirleis and Fischer 2014). In the Late Neolithic, spelt wheat was also taken into cultivation. Spelt remains were discovered inside house structures at the Late Neolithic-Younger Bronze Age site of Todesfelde LA 31, located south of Mang de Bargen (Fig. 1A). Spelt grain from one of the houses, from a pit that contained a large concentration of mostly emmer grain, was dated to 2σ 2298-2135 cal BCE (KIA-49888, 3785±30 BP; Effenberger 2018a, Table 3). This is so far the earliest directly dated

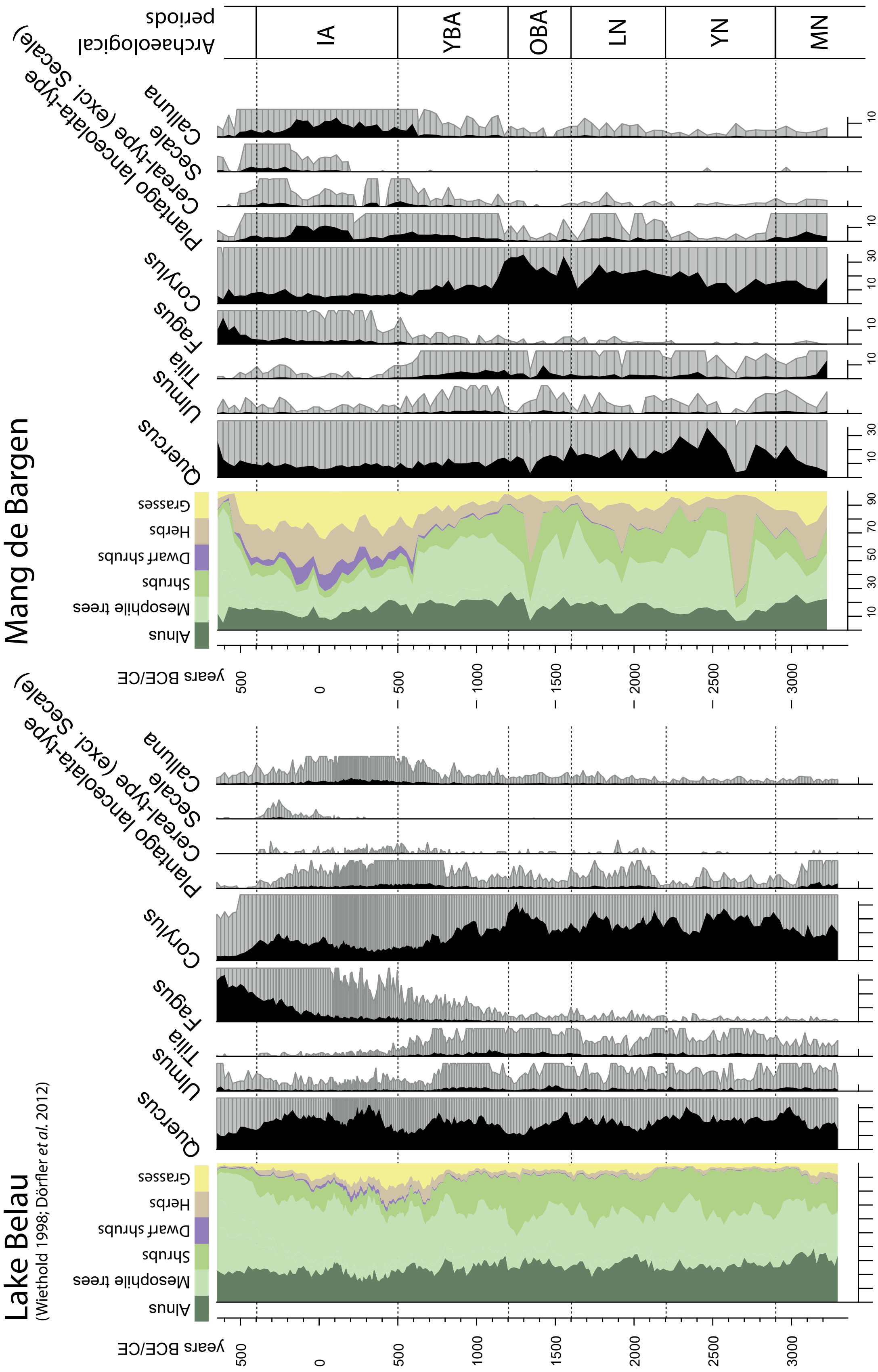

Figure 6. Comparison of selected palynological taxa (% total terrestrial pollen) from the regional profile from Lake Belau and the near-site profile (MDB1). Archaeological periods as in Figure 5.

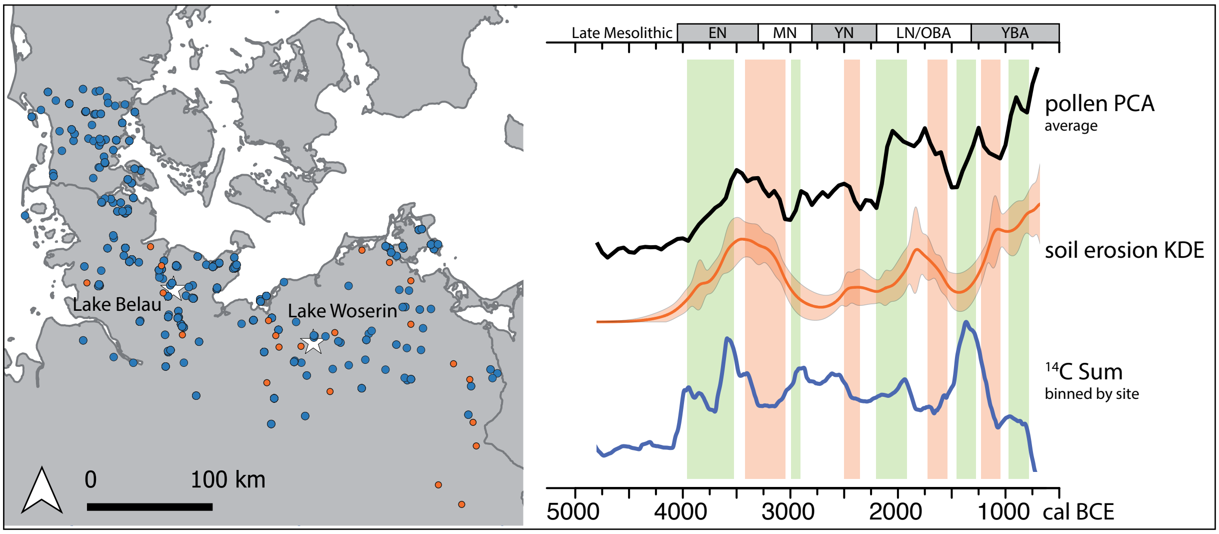

Figure 7. Evidence of supra-regional population dynamics in northern Germany and southern Jutland, Denmark, as derived from multi-proxy investigation (Feeser et al. 2019). Vertical bars indicate inferred phases of population growth (green) and decline (red). Archaeological periods as in Figure 5. The map shows the locations of the sites sampled for palynological data (stars), colluvial deposits (red dots) and archaeological radiocarbon dates (blue dots).

find of spelt in northern Germany. There are several reports of spelt wheat from Early Neolithic sites, but they have not been directly dated[1]. At Mang de Bargen, a large spelt deposit was encountered at burial location LA 18 (Alsleben pers. comm.). One grain and one spikelet fork from this deposit have been radiocarbon dated by the CRC 1266. Both returned dates falling in the period between the late 15th and early 13th century BCE – the late phases of the Older Bronze Age (grain: KIA-54920, 3116±28 BP, 2σ 1443-1296 cal BCE; spikelet fork: KIA-54921, 3085±29 BP, 2σ 1421-1269 cal BCE). At another settlement site in the region – Bark 2014-264 (Fig. 1A) – a fire pit was discovered that contained cereal remains dated to the end of the 18th or the 17th century BCE (MAMS22199, 3400±21, 2σ 1746-1635 cal BCE). The plant assemblage from the pit comprised mainly emmer and spelt glume bases (Effenberger 2018a, Tables 4, 34). Overall, the archaeobotanical evidence from northern Germany suggests that emmer and spelt were grown as a mixed (maslin) crop (Effenberger 2018a).

From the 17th century BCE onwards, the regional palaeo-environmental data, in agreement with the picture of the local cultural and environmental development, indicate a decline in human activity, reaching a minimum at around 1500 BCE (Figs. 2, 5, 6). Reduced human presence can also be inferred in the wider region from the low number of burials (Aner and Kersten 1978, 1979, 1991, 1993; Aner *et al.* 2005, 2011, 2017) or settlements associated with this period (Bronze Age Period I-II). Generally, data on Older Bronze Age settlements are very limited (cf. Meier 2013) due to insufficient research or difficulties in locating the remains in archaeological surveys. The groups of burial mounds adjacent to Mang de Bargen have been excavated only partially or not at all; moreover, some of the excavations took place in the 19th century and do not offer data of comparable resolution (*e.g.* the 'Königsbarg' burial mound, with 12 burials, was excavated in 1883 and 1888; Aner *et al.* 2011, 18).

Traces of several Late Neolithic and/or Bronze Age Period I houses have been found at the site of Schmalfeld LA 29 south of Mang de Bargen (Effenberger 2018a); however, they may be older than the 17th century BCE, since only relative chronological determination is provided. Curiously, none of the 250 archaeobotanical samples from this site contain crop remains; only fragments of hazelnut shell and acorn and blackberry seeds were found (Effenberger 2018a, 27). The fire pit at Bark 2014-264 perhaps derives from this period, judging from the date on the cereal remains from it (see above). At another recently excavated burial location in the

1 Spelt wheat chaff from an Older Bronze Age house at the site of Rothenkirchen, on the island of Rügen, gave a date of 1984-1876 cal BC (KIA-37002) (Alsleben 2019).

same region – Bornhöved LA 117 – remains of barley, emmer, free-threshing wheat, einkorn, lentil (*Lens culinaris*) and broomcorn millet were recovered, but they could be of later date. This barrow was erected in the Late Neolithic and then rebuilt or modified several times, up until the Younger Bronze Age, when cooking pits and urn graves were created on it; settlement pits were also detected here (Kneisel *et al.* in prep.). Two other archaeobotanically analysed sites in the region, Gönnebek 2013-215 and Todesfelde LA 31, yielded only few traces of domestic activity from the Older Bronze Age (Effenberger 2018a, 26-41; Kneisel *et al.* in prep.). Besides residential structures, the latter site also comprised a burial mound from the Older Bronze Age (Lütjens 2012, cited in Effenberger 2018a). Archaeobotanical samples were taken from the mound, the layer of burning at its base, the ancient ploughing horizon underlying the mound, and different layers of the ditch encircling the mound (Effenberger 2018a, 31). Small amounts of barley, emmer and spelt were found in these contexts (Effenberger 2018a, Table 21), but their age is unclear, and they may derive from different phases of use of this multi-period site. In sum, the archaeobotanical evidence from the early period of activity at Mang de Bargen fits well into the regional picture, which shows that, if production of crops was practised in the region during the Older Bronze Age, it was on a very low level, leaving only a small imprint on the vegetation and soil cover.

The locally and regionally observed decline in human activity is also reflected at the supra-regional scale, with a 'bust' phase from around 1700 BCE to the middle of the 2nd millennium BCE (Feeser *et al.* 2019). A coinciding lull in human environmental impact, generally centred at around 1600/1500 BCE, is also discernible across northern and central Germany (*e.g.* Hellmund *et al.* 2011; Jahns and Kirleis 2013; Kneisel 2013; Jahns *et al.* 2018). This period of low human environmental impact coincided with the archaeologically documented decrease in human presence/activity throughout central Europe (16th-15th centuries BCE) inferred from the decreased number of settlements from this period (Kneisel *et al.* 2012) or the 'break in archaeological cultures' seen in the radiocarbon dates (Kneisel *et al.* 2013; Risch and Meller 2015, 240). The time around 1600-1500 BCE is when the Únětice culture collapsed. This was a prominent bronze production and trade network and a major political power structure of the first half of the 2nd millennium BCE in eastern central Europe. Its demise had a knock-on effect down the line and resulted in dissolution of some local socio-economic entities, including those in the marginal zones of the trade network. Triggered by the social upheaval, a general decentralisation of economic production and political power ensued in Europe after ca. 1500 BCE (Müller and Czebreszuk 2010; Kneisel 2012, 2013; Müller 2013). In some regions, this new political vacuum was instantly filled up by emerging powers, such as the Mycenaean city-states in the Aegean (Risch and Meller 2015, 256). In northern Germany, there is no evidence of anything akin to the dissolution of social structures at this time. Despite the contemporaneous palaeo-environmental evidence of agricultural decline and population decrease around the 17th and 16th centuries BCE, the apparent 'bust' was immediately followed by a gradual increase in human presence/activity – a 'boom' from ca. 1500 BCE onwards encompassing profound socio-economic changes that culminated in the 12th century BCE.

Between 1500 and 1300 BCE, a strong increase in bronze use, bronze hoarding and associated trade networks can be observed. This further coincides with a rise in the construction of grave mounds. This increase in monumentality and economic expenditure (raw materials, labour distribution and expense) is visible at the local and regional scales. In addition, changes in the spectrum of grave goods are recognisable for this phase, which reveal differentiation in terms of the grave furnishings. On the one hand, a clear difference can be observed between the flat graves without grave goods and the in part richly furnished grave mounds. On the other hand, differences among the burial mounds are also visible, too. This concerns not only the number of grave goods, which can vary between none and more than nine grave goods, but also the repertoire (Schaefer-Di Maida 2020). Although isolated grave goods involving weaponry are already known from Period I, the frequency and diversity of such grave goods increases distinctly. This is argued to reflect the highlighting of individual personal identity beyond death. These deceased, often termed warrior elites (Vandkilde 1996, 2006; Earle 2002, 363), are indicative of a strong social stratification, which is generally regarded to reflect the emergence of so-called chiefs based on kinship structures (Jensen 1982; Kristiansen 1987, 1991; Earle 1991). Another important aspect during this phase is the emergence and establishment of the three-aisle house structure and thus the enlargement of houses and the use of byre-dwellings. With this change in house construction, a change in the way of living and the household can be assumed.

Despite sporadic first evidence for cremation burials in Schleswig-Holstein from ca. 1500 BCE onwards, it is only around 1300 BCE that a widespread regional change in the treatment of the dead, from inhumation to cremation, can be observed, including at Mang de Bargen (Schaefer-Di Maida 2020). The changed burial ritual can be understood as a local reflection of the general supra-regional ideological shift in mortuary behaviour that took place with the spread of the Urnfield phenomenon across Europe in the last centuries of the 2nd millennium BCE (*e.g.* Falkenstein 2012). A similar sequence of changes, including the shift to new burial rites at the regional scale, can be inferred from the barrows, although this is reliant on relative, not absolute chronology (Aner and Kersten 1978, 1979, 1991, 1993; Aner *et al.* 2005, 2011, 2017). In contrast to the steady amounts of prestige goods and the continuous construction of burial mounds or secondary burials, the amount of other goods in the graves was decreasing, which may further indicate a divergence in the social structure. Only with the full dominance of urn graves, from Bronze Age Period IV (1100-900 BCE) onwards, can a general decline in the quantities of grave goods be observed, indicating a shift towards a more egalitarian social organisation (Kneisel *et al.* 2019).

Changes also took place in other aspects of life, such as house construction. Starting from the 13th century, the house size was generally smaller, and single-, two- and three-aisled structures were built, perhaps with differing and multiple functions. Schaefer-Di Maida (2020) suggests that the likely smaller number of people now needed for grave construction, on the one hand, and the smaller house sizes in Schleswig-Holstein, on the other, may together indicate the development of smaller household communities around 1200 BCE. Hereby it is conceivable that a reorganisation on the household level may reflect or have brought about changes in subsistence practices.

A recent archaeological survey of the area within a 50 km radius of Lake Woserin confirmed that, following the apparent bust in the Older Bronze Age, human presence/activity increased again around the 12th century BCE, as demonstrated by the reappearance of graves and finds of material culture. Coincidently, intensified land use is evident from the higher rate of soil erosion at Lake Woserin (Fig. 7), causing a distinct increase in minerogenic input in the lake sediments from ca. 1200 cal BCE onwards (Feeser *et al.* unpubl. data). This goes hand in hand with the evidence for cultivation of a remarkably wide spectrum of crops in northern Germany in the final centuries of the 2nd millennium BCE and early in the 1st millennium BCE (Effenberger 2018a, 2018b; Filipović *et al.* 2019). In addition to the cultivars that had been grown since the Neolithic – emmer, barley, free-threshing wheat, spelt wheat – the cereal spectrum of the Younger Bronze Age included broomcorn millet and possibly oat (*Avena sativa*) and rye (*Secale cereale*). Leguminous and oil/fibre crops seem to have become much more prominent in this period. Common pea (*Pisum sativum*), lentil, flax/linseed (*Linum usitatissimum*) and poppy (*Papaver somniferum*) may have been grown from the Older Bronze Age or the Late Neolithic, whereas faba bean (*Vicia faba*) and gold-of-pleasure (*Camelina sativa*) were introduced here at the end of the 2nd millennium BCE. The use of wild plants seems to have increased towards and after the turn of the millennium (Effenberger 2018a, Fig. 35). It focused on some previously unused or less-used resources, such as acorns, and perhaps also large-grained grasses growing as crop weeds, for instance rye brome (*Bromus secalinus*) and common wild oat (*Avena fatua*), both of which are relatively abundant in the archaeobotanical assemblages from this period (*e.g.* Behre 2008; Effenberger 2018a; Filipović *et al.* 2019).

On a supra-regional scale, the archaeobotanical data therefore show that, after the apparent regional break or decline in the use/cultivation of crops in the centuries preceding the 12th century BCE, the degree of agricultural activity increased, relying on the suite of crops known previously, but now with the addition of broomcorn millet (Table 2; Effenberger 2018a, 26-32, 66-69, 2018b; Filipović *et al.* 2020a). The diversification of the crop spectrum seems to have been associated with a change in land-use practices, as suggested by the local and regional palaeo-environmental data. Around 1200 cal BCE and after at Lake Belau, a decline in *Corylus* is observed, along with a gradual rise in the representation of *Calluna*, which is almost identical to the local signal from Mang de Bargen (Fig. 6). Thus the changes in land use as reconstructed for Mang de Bargen probably represent a local manifestation of the region-wide developments in agropastoral activities and woodland exploitation around the beginning of the Younger Bronze Age – as has already been proposed by Overbeck (1975, 468) for all of northwestern Germany.

Summary and conclusions

Previous and more recent excavations in the Mang de Bargen micro-region of northern Germany revealed a series of archaeological features, mostly burials, from the Late Neolithic, the Bronze Age and the Early Iron Age. Near- and on-site palaeo-environmental investigations revealed that the local environment was changing during the course of the site's occupation. Archaeobotanical analysis identified the use of a number of crops typical of Late Neolithic and Bronze Age agriculture in northern Germany, reflecting the general process of diversification of the plant resource base in the late 2nd millennium BCE. The findings offer on-site and off-site perspectives on the local cultural and associated environmental dynamics. Whereas the burials document long-term ritual use of the site, on-site domestic activity has been archaeologically confirmed only for the very late phase of the Bronze Age occupation or later, based on the traces of the Early Iron Age settlement. However, the presence of crops and associated weeds in both early and late periods of site use suggests that processing and perhaps also consumption of crops took place on-site. That the arable fields may have been located in the area is further indicated by the palynological evidence from on- and near-site palaeo-environmental records. Animal herding was also practised in the site's surroundings from very early on, as attested in the near-site palaeo-environmental record.

The shift in the funerary custom in the 13th-11th centuries BCE and the subsequent 'boom' in burial activity at Mang de Bargen coincide with a number of other changes in human lifeways including subsistence and land-use practices. Not only did the observed changes in the ritual and economic spheres of life probably take place at about the same time, they were also intertwined or causally related. Coinciding evidence for social restructuring and associated changes in landscape exploitation on the regional and supra-regional scale suggest that the local developments reflect and parallel developments on a much larger spatial scale.

This supports our idea that the multidisciplinary reconstruction of environmental and cultural change at Mang de Bargen can be used to improve our understanding of the wider socio-environmental transformation in the period between the 13th and 11th centuries BCE in northern Germany. We therefore suggest that the specific activities identified as drivers of changes in land use locally are pertinent to the reconstruction of the regional and supra-regional developments.

The quantification of on-site (archaeological) and near-site anthropogenic indicators at Mang de Bargen documents high-intensity use of the site and the surrounding area from around 1200 BCE onwards. The qualitative evidence points to specific human actions and their possible consequences. Cremation burials are a testament to the cutting and collection of wood for the purpose of building and fuelling funeral pyres. A changing demand for wood – not just for funeral and domestic fires, but also for construction or metallurgy – could have been one reason for changes in woodland management or usage. The proliferation of open land in the surroundings was a result of intensified land use, at least partly resulting from the shift from woodland to grassland pasture. Further, despite their poor preservation and low quantity, the archaeobotanical remains document processing and consumption of a wide range of crops in the last centuries of the 2nd millennium BCE. At least some were cultivated or processed near the site, as suggested by the presence of cereal-type pollen in the near-site core. Indeed, broomcorn millet cultivation, which started in northern Germany around 1200 BCE, would have allowed expansion onto previously uncultivated soils (*e.g.* those that would have been waterlogged in cold seasons), thus increasing human impact on the landscape. Expanding and more intensive use of areas under arable farming could have driven soil erosion and depletion, especially if the same land was used for both animal keeping and crop growing – for instance in a system where fallowing was practised and animals were grazed on fallow fields or where farming of the same fields extended throughout the year, for example, with wheat in winter and broomcorn millet in summer, as occurs in multi-cropping regimes described ethnographically by, for instance, Buttler (1999).

The societal transformation of the 13th-11th centuries BCE in northern Germany entailed fundamental changes in cultural practices, such as the shift in burial rites, changes in the number and layout of settlements and houses, innovations and new developments in agropastoral production, and a significant increase in the number of people residing in this part of Europe from this period onwards (Feeser *et al.* 2019; Kneisel *et al.* 2019). The transformation represented an interplay of different, interconnected social and economic factors. The synchronous patterns we see in the palaeo-environmental records from a range of spatial scales capture the imprint on the landscape left by this transformation. This process is best discernible at the local scale. At Mang de Bargen, we have been able to directly link changes in the on-site and off-site cultural practices through the reconstruction of the potential impact on the environment of the shift in burial customs and intensified food production. The present study, therefore, highlights the potential of combining complementary data from different spatial scales and disciplines to improve our understanding of socio-environmental transformations.

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SECTION 2: APPROACHING MILLET CULTIVATION AND CONSUMPTION THROUGH HIGH-END MICROSCOPY, CHEMISTRY AND ETHNOGRAPHY

Putting millet into a culinary context: Organic residue analysis and the identification of *Panicum miliaceum* in pottery vessels

Edward A. Standall, Oliver E. Craig, Carl Heron

Abstract

Broomcorn millet (*Panicum miliaceum*) is a cereal of global significance. From domestication in East Asia, to translocation across Eurasia, this species significantly influenced subsistence strategies and agricultural systems, presenting a new way of life for many communities. Previous research has focused on the investigation of this species in terms of subsistence, yet few studies have explored the cultural implications of its translocation and adoption in prehistory. By investigating the incorporation of broomcorn millet into cuisine, archaeologists are able to examine nuanced cultural practices and infer the significance of this species to past peoples and cultures. To explore subtle and complex uses of this cereal, in culinary contexts, researchers are applying organic residue analysis (ORA) and the biomarker approach to detect miliacin, a discrete compound concentrated in *P. miliaceum* caryopses. This paper summarises the motivations, methods, and benefits of ORA, in the investigation of *P. miliaceum*, and presents a review of previously published studies that attempt to elucidate past cultural activities incorporating broomcorn millet. In doing so, this paper outlines current limitations in the interpretation of 'millet residues' in pottery vessels and details areas of future research that are necessary to better explore the uses of broomcorn millet in archaeological contexts.

Introduction

Broomcorn millet (*Panicum miliaceum*) is thought to have been domesticated in northeastern China around 6000 BCE (Zhao 2011), although the chronology and nature of the domestication process remain topics of significant debate (Miller *et al.* 2016; Leipe *et al.* 2019; Stevens *et al.* 2020). Broomcorn millet is among the earliest domesticated cereals globally and represents an important developmental driver of early societies in China. It spread relatively slowly across China, but expanded rapidly westwards, across Eurasia, in the third and second millennium BCE (Frachetti *et al.* 2010; Motuzaite-Matuzeviciute 2013; Spengler *et al.* 2018; Leipe *et al.* 2019; Filipović *et al.* 2020). Agricultural communities, of eastern and western traditions, likely converged around the northeastern terminus of the 'Inner Asian Mountain Corridor' (IAMC) at the beginning of the third millennium BCE, with probable evidence for *P. miliaceum* in Kazakhstan from ca. 2700 cal BCE (Hermes *et al.* 2019) and direct evidence of wheat (*Triticum* spp.) in China from ca. 2600 cal BCE (Long *et al.* 2018). The adoption of a new cereal is neither passive nor mundane and may occur concurrently with cultural, social and economic change. Therefore, the means and motives of cereal translocation have caused considerable debate, from which one dominant question arises: *'Why move starchy cereals?'* (Lightfoot *et al.* 2013).

Archaeobotanical evidence indicates that broomcorn millet was incorporated into various cropping regimes in Europe (Kapcia and Mueller-Bieniek 2019; Mueller-Bieniek *et al.* 2019) and ecological opportunism, for either economic gain or food security, represents a compelling motive for its adoption (Jones *et al.* 2011). Furthermore, environmental limitations potentially provide an explanation as to why some communities did not adopt this species (Miller 2015; Miller *et al.* 2016). However, neither provides a universal explanation for the adoption and rejection of broomcorn millet across Eurasia, as is evident from archaeobotanical (Miller *et al.* 2016; Valamoti 2016) and isotopic (Lightfoot *et al.* 2013; Wang *et al.* 2017; Hermes *et al.* 2019) investigations.

Cultural and social motivations for the introduction of new cereals are emphasised by Boivin *et al.* (2012). Millet would have enriched culinary practices and cuisine, providing a different taste and texture from western cereals. These characteristics may correspond with ideas of exotica, prestige, and conspicuous consumption. Conversely, new species may be perceived negatively and either shunned or proscribed within and between communities. Indeed, attitudes may differ on either a localised social scale or more broadly on a cultural scale. The exotic nature of introduced products may result in their incorporation into either new or existing cultural frameworks that are influenced by either internal or external factors. Furthermore, the perception and uses of a new foodstuff are subject to change over time. However, it is important to consider how cultural ideas and practices are represented in the archaeological record and whether our investigative techniques are sufficient to elucidate them.

Reconstructing *P. miliaceum* use in cuisine

One method of understanding the role and perception of foodstuffs in prehistory is by investigating the culinary context of their use. The selection, preparation and consumption of different foods is culturally mediated and deeply rooted in individual and group identity (Hastorf 2017). Separation and combination of different products, in daily meals and celebratory events, may demonstrate their significance and meaning. However, the intricate scale of analysis required to study culinary activity necessitates consideration of the material culture employed in the manipulation, processing, cooking, and consumption of foodstuffs. Indeed, understanding the role of pottery containers, where archives of food preparation and consumption are preserved microscopically and at the molecular level, is integral to enhancing knowledge of cultural practices.

A direct association between millet and material culture, in this case pottery vessels, is challenging to establish. Impressions in pottery, thought to be made by millet caryopses and interpreted as evidence for cultivation of *P. miliaceum*, are often erroneously identified (An *et al.* 2019). There are very occasional caches of millet caryopses (*e.g.* Reed and Drnić 2016) and processed millet foods, such as noodles (Lu *et al.* 2005; Gong *et al.* 2011), that are preserved in either intact or near-intact pottery vessels. Microscopy has been used to identify millet grains in charred surface deposits adhering to pottery vessels, with observations supported by isotope analysis (Miyata *et al.* 2007). Additionally, starch grains and phytoliths, recovered from the surface of pottery vessels, as well as other objects such as grinding stones, have been used to identify millet residues (Yang *et al.* 2012a, b; Dal Corso *et al.* 2017; Liu *et al.* 2020). However, arguably the most promising development, in the identification of processing *P. miliaceum* in ceramic vessels, is the application of combined molecular and isotopic analysis (Heron *et al.* 2016).

The aim of this paper is to review and evaluate the role of organic residue analysis (ORA) in detecting *P. miliaceum* processing in pottery vessels. Emphasis is placed on the molecular characterisation of lipid residues in ceramic-absorbed and visible surface deposits (*e.g.* charred 'foodcrusts'). We review and critically assess recent findings of *P. miliaceum* residues and evaluate some of the current limitations of ORA in the identification of broomcorn millet. Finally, we explore areas of new research that are needed to take these enquiries forward.

Organic residue analysis

The analysis of organic residues, extracted from ceramic fabrics and charred surface deposits, is a well-established analytical approach, contributing to a range of enquiries including manufacturing technology and typology, subsistence, cuisine, population movement, cultural interaction, and past environments (Roffet-Salque *et al.* 2017). Organic residues are characterised through the application of several analytical techniques, including gas chromatography-mass spectrometry (GC-MS), elemental analysis – isotope ratio mass spectrometry (EA-IRMS), and gas chromatography-combustion-isotope ratio mass spectrometry (GC-C-IRMS). These three techniques enable the identification of individual compounds absorbed in ceramics and preserved in surface deposits, bulk carbon and nitrogen isotope analysis of surface deposits, and compound-specific carbon isotope analysis of individual molecules absorbed in ceramic and surface deposit residues. These techniques have enabled the characterisation of a wide range of plant and animal products (Roffet-Salque *et al.* 2017). However, the detection of cereals has proven difficult, compared to animal and resinous plant products, as they contain a relatively low abundance of lipids and produce few diagnostic 'biomarker' compounds (Colonese *et al.* 2017; Hammann and Cramp 2018). Notable exceptions include two widely cultivated C_4 plants, maize (*Zea mays*) and broomcorn millet, that have been identified in archaeological ceramics, following analysis of authentic and experimental samples (Reber and Evershed 2004; Reber *et al.* 2004; Heron *et al.* 2016).

The effectiveness of isotopic techniques in the identification of *P. miliaceum* processing varies according to geography. Western Eurasia is dominated by C_3 plants, therefore, as a C_4 plant, broomcorn millet is isotopically distinct from most native carbon sources (Lightfoot *et al.* 2013; Wang *et al.* 2017). However, it is not possible to distinguish between isotopic enrichment derived from either broomcorn millet, other C_4 plants, marine products, or terrestrial animals that have consumed ^{13}C-enriched resources (Lee-Thorp 2008). Combined archaeobotanical and zooarchaeological analysis, in addition to isotopic analysis of human and other animal remains, may exclude potential sources of ^{13}C enrichment (*e.g.* Chakraborty *et al.* 2020), yet there are limitations to this approach. Therefore, in many scenarios, molecular characterisation by ORA is imperative.

Identification of *P. miliaceum* processing in archaeological ceramics is based on the detection of a discrete organic molecule, miliacin (Figure 1), together with evidence of ^{13}C enrichment (Heron *et al.* 2016). This approach is based on the

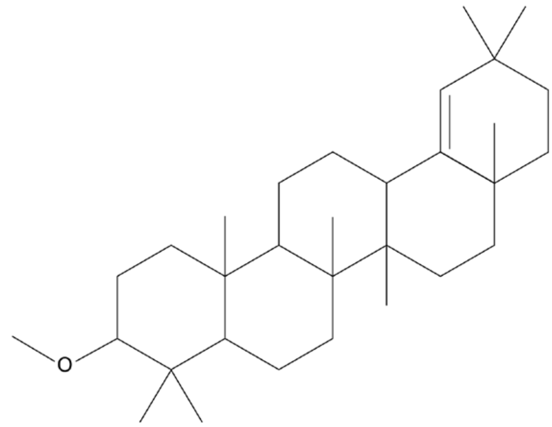

Figure 1. Structure of miliacin (olean-18-en-3β-ol).

detection of miliacin in sedimentary samples, particularly pollen cores and pit fills, applied to detect areas of past cultivation and storage of broomcorn millet (Jacob *et al.* 2008; Motuzaite-Matuzeviciute *et al.* 2016; Courel *et al.* 2017). Miliacin (olean-18-en-3β-ol) is a pentacyclic triterpene methyl ether (PTME) concentrated in the caryopses of *P. miliaceum*. Species in the genera *Panicum*, *Pennisetum*, *Paspalum*, *Digitaria*, *Chionocloa*, *Eragrostis*, *Glyceria*, and *Microstegium* are also reported to produce miliacin, in varying abundance, in addition to other PTMEs (Jacob *et al.* 2005; Bossard *et al.* 2013). Therefore, while miliacin dominates (c. 90%) the PTME fraction of broomcorn millet, when examining archaeological samples, it is important to note that the compound is not exclusive to this species (Bossard *et al.* 2013). In prehistoric European contexts, known sources of miliacin are limited to *Digitaria sanguinali*s (Ohmoto *et al.* 1970), a native species commonly known as hairy crabgrass, and *P. miliaceum* (Jacob *et al.* 2008; Bossard *et al.* 2013; Heron *et al.* 2016). There is little evidence to suggest that *D. sanguinalis* caryopses were ever gathered, processed, and consumed in large quantities, although it may feature as a weed. Therefore, in culinary contexts, it is most likely that *P. miliaceum* processing is the source of miliacin in pottery residues. Beyond Europe, a better understanding of the presence and abundance of miliacin in plants may be required. *P. miliaceum* is distinguishable from foxtail millet (*Setaria italica*), as it does not produce miliacin (Bossard *et al.* 2013). The expansion of foxtail millet cultivation into Europe is less clear, due to difficulties in distinguishing it from wild varieties and its presence as a potential weed in broomcorn millet agriculture, although some abundant finds have been reported (Reed and Drnić 2016).

Experiments have shown that miliacin is mobilised in water and absorbed into ceramic matrices when *P. miliaceum* caryopses are cooked in pottery vessels (Heron *et al.* 2016). However, the abundance of absorbed miliacin is a fraction of that present in caryopses (Bossard *et al.* 2013). Further experiments are necessary to explore the mobilisation, absorption, and retention of miliacin, during *P. miliaceum* processing, in addition to studies focused on the impact of concurrent and sequential processing with other foods, as has been investigated for other cereals (Hamman and Cramp 2018; Miller *et al.* 2020). The effect of different processing methods, *e.g.* boiling and fermentation, on the transfer and recovery of miliacin should also be investigated. Finally, the survival potential of miliacin in archaeological materials should be explored. In lieu of further experimental and archaeological research, it is not possible to compare the frequency and abundance of miliacin to other compounds identified in organic residues and it is premature to interpret an absence of miliacin as an absence of broomcorn millet processing.

Identification of broomcorn millet by organic residue analysis of pottery vessels: A brief review

Heron *et al.* (2016) investigated millet processing in Bronze Age and Iron Age ceramics from Bruszczewo (Poland) and Bronze Age ceramics from Majeon-ri (Korean Peninsula). At Bruszczewo, bulk isotope analysis of Early Bronze Age (EBA) and Late Bronze Age/Early Iron Age (LBA/EIA) charred surface deposits identified ^{13}C enrichment, in the latter period, indicative of C_4 plant input. Comparable ^{13}C enrichment was observed in compound-specific carbon isotope analysis of a single LBA/EIA sample examined by GC-C-IRMS. Furthermore, the lipid profile of this residue was consistent with a plant origin and a trace of miliacin was observed. In combination, these data securely identify *P. miliaceum* processing in pottery vessels at Bruszczewo and support the chronology of its introduction and adoption at the site (Kroll 2010). Miliacin was also identified in absorbed ceramic residues from Majeon-ri, although no surface deposits were available for analysis. The results indicate that *P. miliaceum* caryopses were processed in ceramic vessels at both sites, forming charred surface deposits at Bruszczewo and absorbed ceramic residues at Majeon-ri. Further analysis is currently underway at Bruszczewo to investigate absorbed ceramic residues. The presence of broomcorn millet residues confirms direct consumption by humans, opening new avenues into detecting culinary practices incorporating this cereal. Furthermore, this study demonstrates the ability of ORA methods in understanding the prevalence of *P. miliaceum* processing and temporally tracking its adoption in Europe.

The initial report by Heron *et al.* (2016) has prompted several subsequent investigations of potential millet residues, albeit applying slightly different methodologies. Common to most of these investigations is the use of GC-MS to detect miliacin in absorbed ceramic residues (Fig. 2). Bulk carbon and nitrogen isotope analysis is infrequently undertaken due to the relative scarcity of charred surface deposits. Additionally, compound-specific carbon isotope analysis has yet to be applied routinely to detect C_4 plant influence.

Isaksson and Nilsson (2018) report GC-MS analysis of 12 sherds from the LBA cemetery at Maciejowice (Poland). Miliacin was identified in four samples and is attributed to *P. miliaceum* processing. This interpretation is supported by the local chronology of this species (Kapcia and Mueller-Bieniek 2019; Filipović *et al.* 2020) and scorch marks on vessel exteriors, that indicate cooking. The presence of broomcorn millet residues in burial contexts potentially demonstrates the inclusion of this species in cultural activities as either a staple food or product with greater significance. Further analysis of residues, from cemeteries and settlements, in the surrounding region may elucidate the role of this species.

Ganzarolli *et al.* (2018) identified miliacin in 26 of 45 Late Antique and Early Medieval Age (6th-10th century) ceramic sherds from Padova (Italy). Miliacin was either the only, or the dominant, PTME observed in these 26 samples and its abundance was low, relative to other lipid constituents, in all but one sample. This is typical of residues produced during *P. miliaceum* processing (Figure 3 shows an example from Bruszczewo). However, one sample contained a higher than usual abundance of miliacin, potentially demonstrating either different processing or preservation conditions. This enabled determination of the compound-specific carbon isotope value of the compound (−20.5‰), confirming a ^{13}C-enriched, *i.e.* C_4 plant, origin.

Kučera *et al.* (2019) detected miliacin in the soil content of a complete vessel, placed in a Corded Ware culture cremation grave (ca. 2707-2571 cal BCE), from Držovice (Czech Republic). Miliacin was not observed in either the ceramic fabric of this vessel or the soil contents of nearby vessels. Therefore, Kučera *et al.* (2019) suggest that broomcorn millet was stored in the jug and deposited in the grave,

Figure 2. European sites wherein miliacin has been identified in ceramics (filled circles) and soils/sediments (open circles). 1. Vix-Mont Lassois (Rageot et al. 2019a) 2. Lake Paladru (Simonneau et al. 2013) 3. Lake le Bourget (Jacob et al. 2008) 4. Obernai (Courel et al. 2017) 5. Heuneburg (Rageot et al. 2019b) 6. Padova (Ganzarolli et al. 2018) 7. Bruszczewo (Heron et al. 2016) 8. Držovice (Kučera et al. 2019) 9. Maciejowice (Isaksson and Nilsson 2018) 10. Zanovskoe (Motuzaite-Matuzeviciute et al. 2016).

perhaps as an offering. However, this interpretation is not supported by the current chronology of *P. miliaceum* translocation across Eurasia (Frachetti *et al.* 2010; Spengler *et al.* 2018; Hermes *et al.* 2019; Leipe *et al.* 2019). Indeed, Direct AMS-dating of over 100 European millet caryopses has produced no evidence for the presence of this species in Europe prior to the 2nd millennium BCE (Motuzaite-Matuzeviciute *et al.* 2013; Filipović *et al.* 2020). Therefore, either the source or date of the miliacin observed in this study requires reconsideration. The analysis of soil fills of pottery vessels is unlikely to be a reliable approach without supporting evidence from either charred surface deposit/absorbed ceramic residues or archaeobotanical analysis.

Rageot *et al.* (2019a, b) report the observation of miliacin in their analysis of over 200 vessels from the Early Celtic sites at Vix-Mont Lassois (France) and Heuneburg (Germany) respectively. Miliacin was not observed in any imported wares, likely suggesting that broomcorn millet was neither imported nor processed in these vessels. Miliacin is observed in locally produced vessels, yet it is less prevalent in high-status areas and in later periods, at both sites, where Mediterranean influence is more pronounced. Furthermore, it is completely absent in late occupation high-status areas at Heuneburg (Rageot *et al.* 2019b). The data indicates a shift in the perception of *P. miliaceum* by the Celtic elite, at both sites, but persistence of subsistence practices, that include broomcorn millet, among lower status individuals (Rageot *et al.* 2019a, b). The observed decline of *P. miliaceum* among elite groups correlates with a higher abundance of Mediterranean vessels, associated with wine consumption (Rageot *et al.* 2019a). Miliacin is observed in both domestic and fine wares at Vix-Mont Lassois and Heuneburg, indicating varied processing and consumption contexts (Rageot *et al.* 2019a, b). However, at Vix-Mont Lassois, miliacin is most commonly observed in drinking type vessels, potentially indicating the consumption of a millet-based beverage. The co-occurrence of miliacin and beeswax in eight fine handmade bowls, in addition to the presence of bacterial hopanoids in half of these vessels, led the authors to propose the consumption of a fermented beverage (beer) containing *P. miliaceum* (Rageot *et al.* 2019a). Distinguishing cooked and fermented millet products is highly desirable. However, further experimental and archaeological research is necessary to prove such distinction is possible.

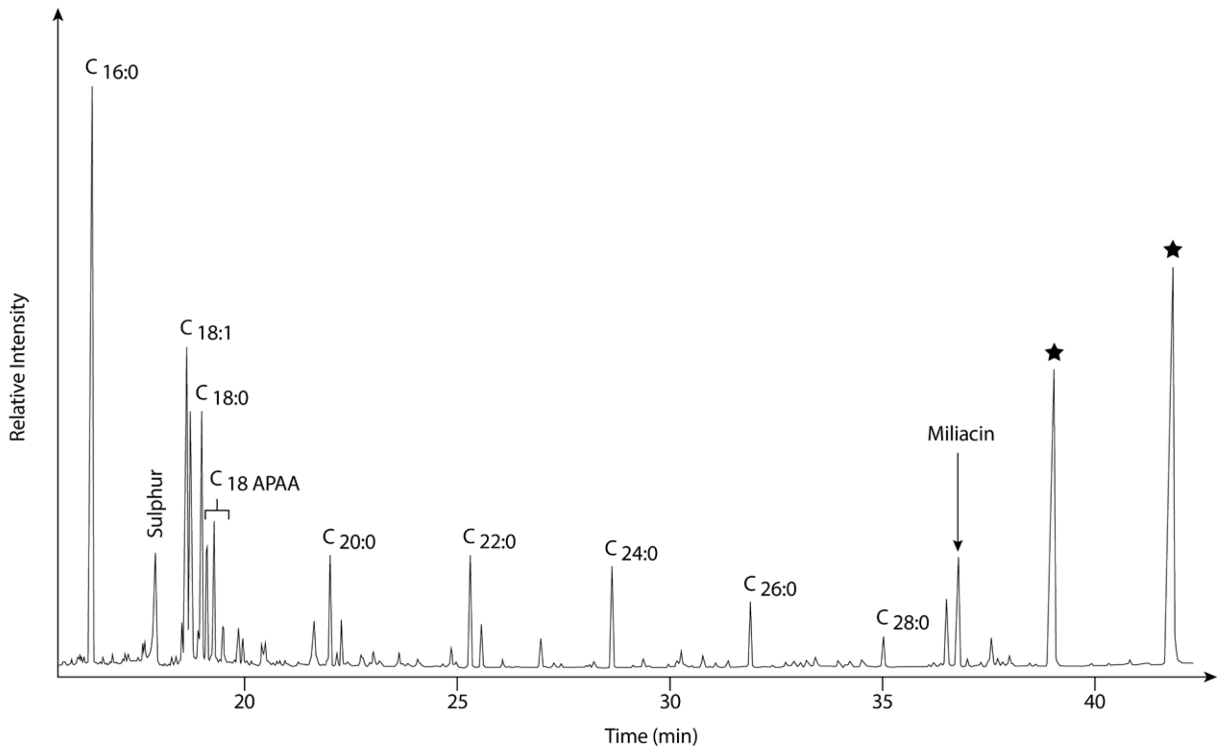

Figure 3. Partial total ion chromatogram of a charred 'foodcrust' from Bruszczewo that contains a low abundance of miliacin, relative to dominant fatty acids, $C_{16:0}$ (palmitic) and $C_{18:0}$ (stearic). ☆ Internal C34 and C36 alkane standards.

Junno *et al.* (2020) present ORA data, from Hamanaka 2 (Rebun Island, Japan), that is characteristic of marine product processing, including ^{13}C enriched palmitic ($C_{16:0}$) and stearic ($C_{18:0}$) acids and abundant aquatic biomarkers. The ^{13}C enrichment from marine products is likely to mask a contribution of C_4 plant lipids to residues, therefore, this study is reliant on miliacin to detect *P. miliaceum* processing. A single sample analysed contained miliacin and was interpreted as evidence for the earliest identification of *P. miliaceum* in the region. Cultivation of this species is known among Okhotsk communities on the island of Hokkaido, yet there is presently no archaeobotanical evidence for its presence in the region of Hamanaka 2 (Leipe *et al.* 2017). This data may demonstrate early processing of *P. miliaceum*, and the integration of Hamanaka 2 into long-distance exchange networks (Junno *et al.* 2020). However, to confirm this theory, greater sampling of local flora and vessels from Hamanaka 2 and other Okhotsk sites is necessary to track and trace the appearance of miliacin and *P. miliaceum* throughout the region.

Chakraborty *et al.* (2020) present absorbed ceramic residue data from Kotada Bhadli (Gujarat, India). Samples demonstrate varying degrees of lipid ^{13}C enrichment, that may derive from the processing of either C_4 plants or C_4-fed animal products. Miliacin is not observed in any of the residues analysed, despite *P. miliaceum* cultivation in the region at this time. Therefore, the authors contend that broomcorn millet was not directly processed in the vessels (Chakraborty *et al.* 2020). However, it is debatable whether an absence of miliacin in pottery residues can be used to rule out the processing of *P. miliaceum*, as aspects of miliacin release, transfer, absorption, accumulation, and preservation are uncertain.

Next steps in the study of millet processing in archaeological ceramics

The detection of residues from processing *P. miliaceum*, in association with material culture, provides a rare opportunity to investigate the introduction, adoption, uses and role of a single crop. The criteria underpinning the detection of broomcorn millet processing, proposed by Heron *et al.* (2016) at Bruszczewo and Majeon-ri are as follows:

- Elevated bulk carbon isotope values in charred surface deposits (foodcrusts), consistent with a C_4 plant influence.
- Identification of miliacin (olean-18-en-3β-ol methyl ether) in either charred surface deposits or ceramic-absorbed residues.
- Elevated carbon isotope values in *n*-alkanoic (fatty) acids and miliacin, if available in sufficient quantities, consistent with C_4 plant influence.

These three criteria have not been met in most applications reviewed above since the preservation of charred surface deposits is rare in many archaeological contexts, hence bulk isotope analysis is not possible. Further complications arise and may underestimate the occurrence of broomcorn millet in pottery vessels. Firstly, miliacin may be present at levels that are below the detection limit of GC-MS, especially in cases where broomcorn millet was processed as a minor constituent in a vessel. Furthermore, our current understanding of the uptake and preservation of this compound, in archaeological ceramics, is limited. Secondly, the mixing of isotopically diverse foods may either mask or diminish the C_4 isotope signal imparted during the processing of *P. miliaceum*, complicating the interpretation of bulk and compound-specific isotope data.

Further experimental research is necessary to investigate and understand these issues. The transfer of miliacin, from seed to archaeological material, under different processing conditions, *e.g.* boiling and fermentation, in addition to its preservation, during multiple cooking events and deposition under different burial conditions, require detailed experimental studies. Furthermore, while the dominance and overall abundance of miliacin in broomcorn millet caryopses provides a degree of confidence in assigning the compound to *P. miliaceum*, reliance on the detection of miliacin is likely to remain the subject of debate, due to its occurrence in other plant species. Therefore, extensive sampling of reference materials is also strongly advised. Finally, an examination of the impact that *P. miliaceum* processing has on carbon isotope values of surface deposits and absorbed ceramic residues, by EA-IRMS and GC-C-IRMS, would help understand isotopically complex datasets.

The detection of miliacin may prove useful in the identification of *P. miliaceum* processing in other materials, *e.g.* grinding stones. The compound has also been detected in coprolites, providing evidence of direct consumption (Zhang *et al.* 2020). Therefore, exciting opportunities exist to expand the detection of this cereal to new fields.

There is much to be gained by pursuing the study of culinary activities, from single cooking events to entire cuisines. Large-scale studies, assessing substantial numbers of specific vessel types, are necessary to examine the contribution of *P. miliaceum* to food processing and consumption patterns and move our understanding beyond simple presence/absence observations of the crop in antiquity.

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Tracing millet through biomarker analysis in archaeological sites in alluvial plains: The first miliacin data from the northern Italian Bronze Age

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Abstract

Broomcorn millet has been attested by the biomarker miliacin in the archaeological sediments at the *terramara* site of Fondo Paviani (ca. 1350-1100 BCE), in the Po River valley, northern Italy. This molecule is typical of *Panicum miliaceum* and it was absent in the other modern panicoid grasses analysed for reference in this study. We present the results of investigation of on-site sediments and, together with the available archaeobotanical and isotopic records, incorporate them into the picture of millet consumption and cultivation during the Late Bronze Age in the Po valley.

Introduction

Background on millet and miliacin studies

In the present study, we explore the potential of biomarker analysis in archaeological stratigraphic features. We focus on the biomarker miliacin, a pentacyclic triterpene methyl ether (PTME), currently considered a promising indicator to complement studies on crop diversity in archaeological contexts. The interest in miliacin lies in its ability to trace the presence of a specific crop, namely broomcorn millet (*Panicum miliaceum*), even in the absence of unambiguous botanical evidence (Dubois and Jacob 2016). This method has recently received increased attention, corresponding to that given to the early adoption of millet outside its region of domestication in northern China (Liu *et al.* 2009, 2012), which is indicative of an expansion in contacts, materials and know-how. This topic has gained the attention of many scholars, as testified by the present volume and by the rich literature derived from more than a decade of archaeobotanical research in central Asia and Europe (*e.g.* Hunt *et al.* 2008; Motuzaite-Matuzeviciute *et al.* 2013; Miller *et al.* 2016; Filipović *et al.* 2020).

Broomcorn millet as a crop did not reach Europe together with the 'Neolithic package of founder crops' composed of emmer, einkorn, wheat and barley (*e.g.* Rottoli and Castiglioni 2009a; Zohary and Hopf 2012; Rottoli and Pessina 2016; Kirleis 2019; Liu *et al.* 2019). In contrast to these large-grained cereals, which were domesticated in the Fertile Crescent, broomcorn millet belongs to a group of small-grained cereals, usually referred to as millets, which includes drought-resistant species with short growing cycles. In Europe, the first evidence for millets from prehistoric archaeological contexts concerns *Panicum miliaceum* and *Setaria italica* (foxtail millet). A recent dating programme of charred broomcorn millet caryopses from European prehistoric sites established that it diffused as a crop in Europe during the Bronze Age, starting from the 16th century BCE (Filipović *et al.* 2020). Currently, it seems that northern Italy, together with Ukraine, was one of the first regions of Europe where millet cultivation was adopted (Dal Corso *et al.* 2022).

The adoption of a new crop for alimentary purposes has multiple and possibly overlapping cultural implications, ranging from forward planning (*i.e.* increasing diversity of cultivars as a means to overcome possible crop failures) to short-term human adaptability (*i.e.* the need to react to ongoing adverse conditions). In addition, millet, as a fast-growing crop, could indicate the adoption of more mobile settlement strategies, or contacts with more mobile human communities, as well as the use of only periodically available land (Motuzaite-Matuzeviciute *et al.* 2013, 2016; Ventresca Miller *et al.* 2020; Dal Corso *et al.* 2022). The study of early millet adoption, therefore, has multifaceted implications for archaeological research, especially as there are multiple ways to trace millet in archaeological contexts, as described below.

Millet consumption can be traced through carbon and nitrogen stable isotope analysis (*e.g.* Tafuri *et al.* 2009, 2018; Lightfoot *et al.* 2013) conducted on human and animal bones, and they can reveal consumption of millet as staple food or fodder. This method is based on the fact that broomcorn millet uses the C4 photosynthetic pathway and is the first such crop in Europe. Thus, the method is particularly appropriate for studies of prehistoric societies in temperate environments poor in wild panicoids and other wild or cultivated C4 plant species, *i.e.* where the C4 plant signal identified isotopically can be attributed to millet as a crop. Plant macro-remain analysis is the usual way to detect crops in archaeology. It is made difficult by the fact that millet grains are small and require significant effort to be recovered. In older investigations, the absence of millet remains may be more a reflection of insufficient sampling and processing strategies (*e.g.* too-large mesh sizes, no flotation) rather than of their genuine absence. Furthermore, unless the grains are fused together (in 'clumps'), their small size makes millet grains more prone to contaminating underlying, unrelated archaeological features, requiring radiocarbon dating to detect temporally misattributed specimens. In the case of pollen analysis, the morphology of millet pollen grains is usually considered insufficiently diagnostic to avoid confusion with wild, non-economic grass species (Beug 2004). Attempts to detect millet cultivation by means of pollen analysis therefore remain limited (*e.g.* Cremaschi *et al.* 2016). Phytolith analysis represents a promising research direction in the distinction of *Panicum miliaceum* (Lu *et al.* 2009; Out and Madella 2016), yet it remains a relatively niche research field in temperate environments (*e.g.* in Italy; Dal Corso *et al.* 2017), which would benefit from the analysis of more wild plants. Given the limitations of the micro- and macro-botanical evidence, any independent data source represents a useful addition to confirm the presence of early millet adoption and cultivation.

In the present paper, our research question is whether it is feasible to use sedimentary miliacin as a molecular tracer of *Panicum miliaceum* at Bronze Age sites of the Po River valley in northern Italy. In this way, we aim to contribute to the reconstruction of the history of this crop in a very dynamic period and region of Europe.

Miliacin in modern plants and archaeological studies

Miliacin (olean-18-en-3β-ol methyl ether) is a PTME and is found in high concentrations in the seeds of *Panicum miliaceum*. The value of miliacin as a marker for the presence of millet depends primarily on its unequivocal association with millets in a given study area. Bossard *et al.* (2013) investigated the miliacin content of *Setaria italica* and of multiple *Panicum* and *Pennisetum* species. Miliacin was detected in all *Panicum* species analysed, while it was sparsely present in *Pennisetum*. It was not detected in *Setaria italica*, in contrast with earlier, independent findings (Lu *et al.* 2009). Bossard *et al.* (2013) also tested the presence of miliacin in the green mould *Chaetomium olivaceum* reported by Smetanina *et al.* (2001) and found none. Few other plants are currently known to be a source of miliacin. A possibly non-exhaustive list (sourced from Ohmoto *et al.* 1970; Connor and Purdie 1976, 1981; Bossard *et al.* 2013) includes *Eragrostis ferruginea* (Thunb.) P. Beauv., *Glyceria acutiflora* Torr and different *Chionochloa* species, among others. Most of the species mentioned so far are not native to Europe (Pyankov *et al.* 2010) and they are therefore not relevant to discussing agricultural dynamics in northern Italy during the Bronze Age. In this context, *P. miliaceum* is the most abundant cereal among the known miliacin-producing taxa. Two aspects support the use of sedimentary records of miliacin in some contexts to track past millet agricultural use: the high concentration of miliacin in the grain of *P. miliaceum* relative to other PTMEs and to other grasses, and the high biomass that cultivated broomcorn millet possesses relative to other potential plant sources.

The same inferred relationship between *P. miliaceum* and miliacin has been used as a basis to detect millet cultivation and processing at multiple European sites from the Bronze Age onwards (Jacob *et al.* 2008; Heron *et al.* 2016; Motuzaite-Matuzeviciute *et al.* 2016; Courel *et al.* 2017). Based on previous studies, where sedimentary archives of miliacin have been found in conjunction with a high concentration of other PTMEs (*e.g.* at a Brazilian lake – Jacob *et al.* 2005), the compound cannot be used as a biomarker for *P. miliaceum*. In contrast, miliacin was the sole detectable PTME in the sediments from lake Le Bourget in France (Jacob *et al.* 2008, 2009), lakes Ledro and Paladru in Italy (Simonneau *et al.* 2013), and in Ukrainian palaeosols thought to have been cultivated for *P. miliaceum* (Motuzaite-Matuzeviciute *et al.* 2013). In conjunction with other evidence, the presence of miliacin in these cases was interpreted as an indicator of the cultivation of *P. miliaceum* in the catchment area.

In this study, we analysed modern grains of *P. miliaceum* as well as grains from other panicoid grass species possibly occurring in Italy. We investigated their miliacin content in order to compare the results with sedimentary miliacin content from the archaeological contexts described here.

Archaeological setting

The archaeological sediment analysed in this study originates from different contexts. First, we sampled two Bronze Age sites. The first site is the pile-dwelling of Bande di Cavriana (Mantua), located within a now-drained lake south of Lake Garda in northern Italy. Sediment samples from different cores from Cavriana (CAV 4-11-12-15, described in Zanon *et al.* 2019) were processed with a 500µm sieve, yielding no evidence of millet caryopses. Despite the absence of millet macro-remains, the finds of millet at other northern Italian prehistoric sites (Rottoli and Castiglioni 2009a, 2009b) and the methodological approach used at lake Le Bourget

(Jacob *et al.* 2008) suggested that testing the samples for miliacin could provide information on the possible millet cultivation close to Cavriana.

The samples for miliacin analysis came from an off-site sediment core (CAV 4) taken in the former lake basin and used for palaeoenvironmental investigation (Zanon *et al.* 2019). In the core, deposits were present that partly dated to the Bronze Age occupation related to the pile-dwelling (Zanon *et al.* 2019). Miliacin was not detected in any of the CAV 4 samples. Therefore, the results presented here focus exclusively on the second site studied, the *terramara* of Fondo Paviani near Verona (Fig. 1).

The Terramare culture

The Terramare culture developed in the central Po valley between the transition from MBA1 to MBA2 and the end of RBA[1] (first half of the 16th to ca. mid-12th century BCE) (Cardarelli 2010; Cupitò and Leonardi 2015). It had direct links with the cultural developments in the first part of the MBA in the northern Po valley. In this early phase, mainly pile-dwellings (*palafitte* in Italian) are known, as was the case during the preceding Early Bronze Age Polada culture (Cupitò and Leonardi 2015; Leonardi *et al.* 2015). The Terramare culture is characterised by settlements of subquadrangular layout surrounded by a fortification system consisting of an earthen rampart and a moat; these settlements are called *terramare (*singular *terramara)* (Bernabò Brea *et al.* 1997; Cardarelli 2010; Cupitò 2012; Cupitò and Leonardi 2015). One of the most important and distinctive traits of the culture is the advanced skills in water management and land reclamation (*e.g.* Balista and De Guio 1997; Cremaschi *et al.* 2006, 2016; Bernabò Brea and Cremaschi 2009). Contemporaneous cemeteries are often found near *terramare* settlements, and are characterised by both inhumations and cremations in the northern Po valley and only by cremations in the southern Po valley (*e.g.* De Marinis and Salzani 1997; Cardarelli and Tirabassi 1997; Cupitò and Leonardi 2015). The communities practiced a mixed food economy, relying on both crop cultivation and herding of domesticated animals for subsistence (Nisbet and Rottoli 1997; Riedel 1997; Mercuri *et al.* 2006; Carra 2009; De Grossi Mazzorin 2009, 2015; Rottoli and Castiglioni 2009a, 2009b; Berto and Rottoli 2015; Bertolini *et al.* 2015; Cremaschi *et al.* 2016; Dal Corso 2018). During its more than 400 year long duration, particularly during its final phase, the Terramare culture – specifically the area of the so-called Valli Grandi Veronesi polity (Balista and De Guio 1997; Cupitò and Leonardi 2015; Cupitò *et al.* 2015a) – functioned as the main cultural hub connecting Europe and the Mediterranean world. Thanks to its geographical position, the Terramare area was at the centre of a dense net of routes of exchange and circulation of raw materials (first of all copper and amber), involving north-central Europe, the Alps, peninsular Italy, the Aegean and the Levant (Bellintani 1997, 122-126; Carancini and Peroni 1997; Cardarelli 2010, 452; Bettelli *et al.* 2015, 2017; Cupitò and Dalla Longa 2015; Cupitò and Leonardi 2015; Cupitò *et al.* 2020, 299-301).

The *terramara* of Fondo Paviani was occupied from the advanced MBA to the first phases of the FBA (ca. mid-14th to 11th century BCE; Cupitò *et al.* 2015a). The site is located in the Valli Grandi Veronesi lowlands, in the lower plain north of the Po River. This is a subsiding portion of the Po valley, characterised by Pleistocene alluvial ridges and incised valleys, crossed during the Holocene by spring-fed rivers (Nicosia *et al.* 2011). After a first occupation phase, in which the site was surrounded by a possible palisade and a shallow moat, in the RBA (between the 13th and the

1 Abbreviations for the Bronze Age periods and phases in northern Italy: EBA=Early Bronze Age; MBA=Middle Bronze Age; RBA=Recent Bronze Age; FBA=Final Bronze Age. Further subphases and their correspondence with radiocarbon dating follow Pacciarelli (2001), Cardarelli (2010) and Leonardi *et al.* (2015): EBA1=ca. 2200-1800 BCE; EBA2=ca. 1800-1650 BCE; MBA1=ca. 1650-1550 BCE; MBA2=ca. 1550-1450 BCE; MBA3=ca. 1450-1350/1300 BCE; RBA1=ca. 1350/1300-1200; RBA2=1200-1150 BCE; FBA1-2=ca. 1150-1000 BCE; FBA3=ca. 1000-950/925 BCE.

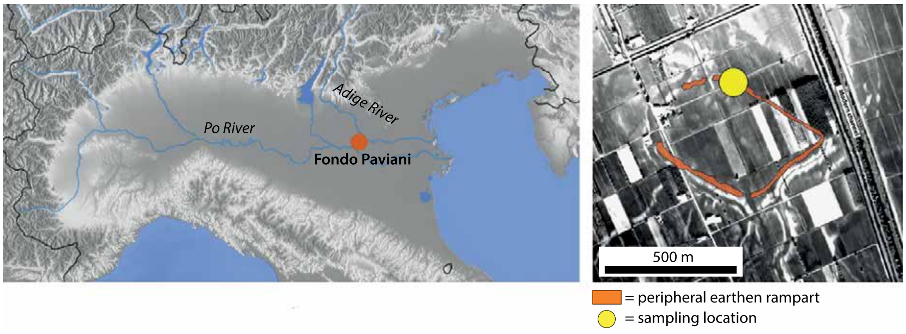

Figure 1. Location of the site of Fondo Paviani, ca. 40 km southeast of Verona, Italy.

beginning of the 12th century BCE), a peripheral earthen rampart was erected (Balista *et al.* 2012; Cupitò *et al.* 2015a; Dal Corso *et al.* 2017; Dal Corso 2018; Dalla Longa *et al.* 2019). Outside of the rampart, a water basin derived from a senescent branch of the spring-fed Menago River bordered the site, functioning as a large moat (Dal Corso *et al.* 2017; Dal Corso 2018; Dalla Longa *et al.* 2019).

This fortified settlement is one of the largest in the Terramare area. Its construction must have involved the exploitation of existing river channels and alluvial ridges and a partial modification of the surrounding landscape (Deiana *et al.* 2020). In the RBA2, in the first half of the 12th century BCE, the settlement was at its largest, covering ca. 16-20 ha. Typological and archaeometric studies of ceramic, metal, amber and glass artefacts testify that Fondo Paviani was at that time an important centre within a network of contacts between the Aegean-Mycenaean and Levantine worlds (Jones *et al.* 2014; Bettelli *et al.* 2015, 2017), continental Europe, and peninsular Italy (Angelini *et al.* 2015; Cupitò *et al.* 2015a, 2015b, 2015c; Dalla Longa *et al.* 2015; Marcon and Mazzoli, 2015; Strafella *et al.* 2015; Vicenzutto *et al.* 2015). Participation in these exchange networks was probably favoured by the geographical position of the settlement and of the Valli Grandi Veronesi polity of sites depending on it. They were located on the system of spring-fed rivers (the Tione, Tartaro, Tregnone and Menago rivers) that connected the Adige River to the Po River. Fondo Paviani and its polity were thus at the core and, in the RBA, in control (Cupitò *et al.* 2020) of a route connecting north-central Europe and the Alps to the Adriatic coast and the Mycenaean and Levantine cultural worlds.

At the end of the RBA, the Terramare system was hit by a deep crisis (Cardarelli 2010). Different proxies detect environmental instability linked to hydrological and climatic changes at the end of the 2nd millennium BCE, which likely affected the Terramare socio-economic stability, although other, anthropogenic, causes, such as demographic pressure and the subsequent overexploitation of the territory and natural resources, must also be considered (Cremaschi *et al.* 2006, 2016; Cardarelli 2010; Mercuri *et al.* 2011; Ravazzi *et al.* 2012; Dal Corso 2018; Dalla Longa *et al.* 2019). We should emphasise that the crisis affected in particular the Terramare sites of the southern Po valley, for which a true collapse can be detected at the end of the RBA, in the 12th century BCE (Cardarelli 2010). The northern Po valley was also affected by the crisis but, here, a change in the settlement system occurred. There was a hyper-concentration of settlements and the development of a new settlement geometry, as well as the emergence of a culturally-influential phenomenon that is the rise of the Frattesina settlement as a central place (Cupitò and Leonardi 2015; Cupitò *et al.* 2015a, 2020).

Fondo Paviani is one of the sites that displayed resilience. The site continued to be settled until the first phases of the FBA, despite a reduction in size in the later period (Cupitò *et al.* 2015a). In the excavated portion of the site, a significant functional transformation occurred in the first phases of the FBA, in which the area used for dwelling and production was converted into arable land used for gardens (Dalla Longa 2020). Arable plots with ridge-and-furrow system have been identified in the

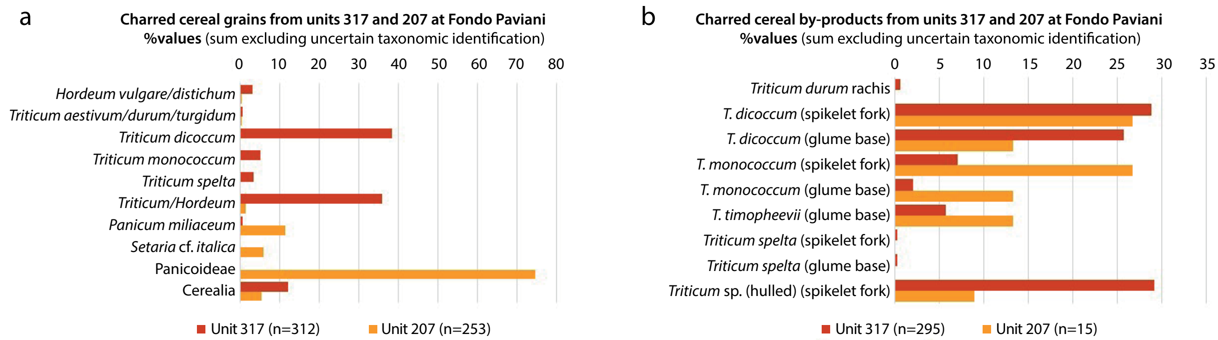

Figure 2. a. Cereal record from two refuse pits at Fondo Paviani based on charred carpological remains, in this case grains; b. crop-processing by-products from the same stratigraphic units (for Unit 317, see Berto and Rottoli 2015; for Unit 207, see Berto et al. in press).

stratigraphy by means of soil micromorphology and geochemical analysis (Nicosia *et al.* 2011; Dal Corso *et al.* 2012; Cupitò *et al.* 2015a).

Evidence of millet at Fondo Paviani

At Fondo Paviani, millet was detected as both charred carpological remains and phytoliths.

Charred cereal grains and other parts of the ears came mostly from the flotation of the fill of postholes, later used as refuse pits, within the settlement. These features date to the transition from the RBA1 to RBA2 (beginning of the 12th century BCE). The taxonomic composition of the cereal record is shown in Figures 2a (grains) and 2b (by-products). In pit fill Unit 317 (Berto and Rottoli 2015), emmer (*Triticum dicoccum*) is the dominant cereal, followed by several other hulled wheats (einkorn [*T. monococcum*], spelt wheat [*T. spelta*], 'new type' glume wheat [*T. timopheevii*]) and rare finds of free-threshing wheat and barley. Broomcorn millet is rare in Unit 317 (2 caryopses). The composition of macro-remains from another refuse pit (pit fill Unit 207; Berto *et al.* in press) is very different and shows the dominance of charred Panicoideae grains, with secure identification of broomcorn millet and foxtail millet (Fig. 2). Despite the minor presence of barley and wheats among the grains in Unit 207, the same wheat species are documented in both units (317 and 207) as glume bases and other by-products derived from the cleaning prior to food preparation. In both pits, the record is clearly dominated by cereals (emmer in Unit 317 and millets in Unit 207), probably representing lost food from an advanced stage of processing.

In the sediment from the ditch of the pre-rampart phase (sequence FP10 in Dal Corso *et al.* 2017; Dal Corso 2018) phytolith morphotypes from millet-like inflorescence were found (Fig. 3; for modern material see Lu *et al.* 2009). They are accompanied by more general phytolith morphotypes typical of (but not exclusive to) panicoid grasses, such as grass short cell bilobates, crosses and polylobates (Out and Madella 2016). These remains were particularly abundant in the ash layers in the ditch, likely coming from the dumping of rubbish before or in conjunction with levelling for the base of the peripheral earthen rampart.

In general, the cereal spectrum at Fondo Paviani shows that in the RBA, several different species were cultivated, with an important role given to micro-thermal cereals, usually growing in winter, such as hulled wheat, and drought-resistant macro-thermal cereal, or summer crops, such as millets. From the carpological remains, as well as from the phytolith evidence, we know that *Setaria italica* was also present.

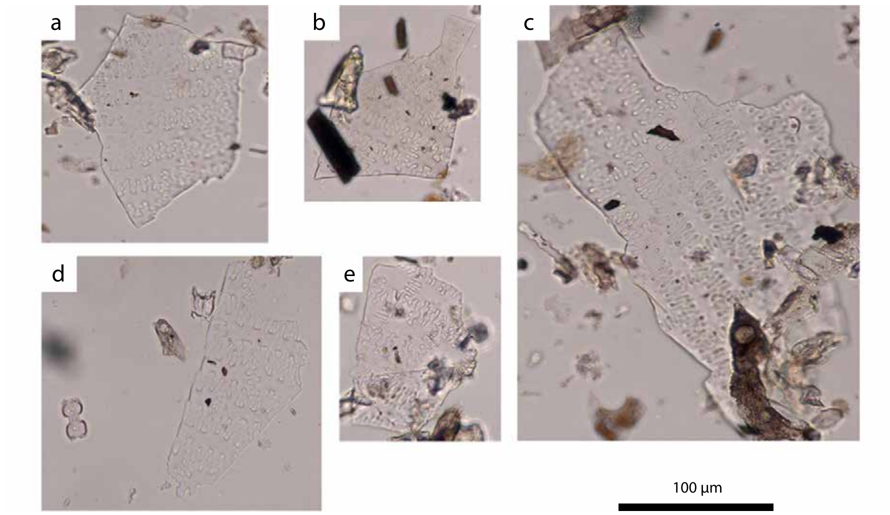

Figure 3. Micro-photographs of phytoliths from the inflorescence of Panicoideae (cf. Panicum miliaceum *glumes) found at Fondo Paviani in the ditch of pre-rampart phase, Unit 9b.*

Materials and methods

Modern samples

The investigation of possible miliacin producers has so far involved a relatively limited number of taxa. Furthermore, contrasting reports - such as those on *Setaria italica* and *Chaetomium olivaceum* mentioned above – hinder reliable determination of all possible miliacin sources. In order to address this issue by generating additional data, we tested the miliacin content of modern grains belonging to a subset of taxa within the grass subfamily Panicoideae. We focused on hulled grains because of the outer waxing layer present on glumes, where miliacin could be found. Grains of *Panicum miliaceum* were tested in order to evaluate the reliability of the extraction procedure from grains. *Setaria italica* and *Echinochloa crus-galli* were selected due to their documented presence in northern Italian Bronze Age plant assemblages (Tafuri *et al.* 2018). Additional species (*Setaria viridis* and *Echinochloa frumentacea*) were included thanks to the easy access to modern reference material.

Archaeological material from Fondo Paviani

For the present study, 16 sediment samples were analysed (Fig. 4; Table 1). Samples 1-8 originate from the area of the peripheral shallow ditch of the pre-rampart phase. Samples 9-14 come from a posthole, later used as waste pit and filled with charred plant remains, including mostly cereals and cereal by-products (Berto and Rottoli 2015). This waste pit fill (Unit 317, see above) is datable to the RBA, more specifically, to the transition from a late phase of the RBA1 to the RBA2 (Dalla Longa 2020). Finally, samples 15 and 16 were collected from two extensive layers which formed in the open and included trampled palaeo-surfaces located in the same excavation trench as the posthole (Nicosia *et al.* 2011).

Sediment samples measuring ca. 20 g each were collected during fieldwork in 2010, conducted as collaboration between the universities of Kiel and of Padova. The sampling was carried out on freshly cleaned sediment surfaces, with metal tools (knife, spoon) that were washed with water and dried with paper towels between the samples. Dry samples were stored at room temperature in sterile plastic bags labelled on the outside. In the case of the ditch fill, a monolith in a plastic frame was collected and stored in the cold storage at Kiel University (Dal Corso *et al.* 2017; Dal Corso 2018). From each sample, a 1 cm^3-subsample of sediment was taken in 2015, in a laboratory at Kiel University.

Stratigraphic unit	Interpretation	Description	References
Ditch of the pre-rampart phase			
Unit 2001	Base of the rampart	Extended silty deposit without archaeological materials	Dal Corso *et al.* 2017 (Unit D1); Dal Corso 2018
Unit 9a	Ditch fill with domestic waste	Silt and organic debris, including charcoal and some archaeological materials	Dal Corso *et al.* 2017 (Unit D2); Dal Corso 2018
Unit 9b	Ditch fill with ashes	Discontinuous ash, charcoal and sand lenses	Dal Corso *et al.* 2017 (Unit D3); Dal Corso 2018
Unit 9c	Ditch fill with domestic waste	Silty loam deposit with charcoal and archaeological materials (*e.g.* potsherds)	Dal Corso *et al.* 2017 (Unit D4); Dal Corso 2018
Unit 9c	Ditch fill with ashes	Ash lens with abundant wood charcoal	Dal Corso *et al.* 2017 (Unit D5); Dal Corso 2018
Unit 2038	Natural fluvial substrate	Calcareous silty clay alluvial deposit	Dal Corso *et al.* 2017 (Unit D7); Dal Corso 2018
Refuse pit fill 317			
317a	Waste pit fill, uppermost portion	Silty loam deposit with very abundant charred cereals and charcoal	Unpublished
317b	Waste pit fill, central portion	Silty loam deposit with very abundant charred cereals and charcoal	Unpublished
317c	Waste pit fill, central portion	Silty loam deposit with very abundant charred cereals and charcoal	Unpublished
317d	Waste pit fill, lower portion	Mostly charred cereals and by-products	Berto and Rottoli 2015, Fig. 1
321	Waste pit fill, upper eastern portion	Silty loam deposit with very abundant charred cereals and charcoal	Unpublished
322	Waste pit fill, upper eastern portion	Silty loam deposit with very abundant charred cereals and charcoal	Unpublished
Cultural layers			
19a	Uppermost portion of the anthropogenic deposit detected in the extensive layers which formed and were trampled in the open; intra-site gardening/cultivation of arable plots still active in the last phase of settlement (first phases of FBA) but reworking sediments and archaeological materials from the precedent phase (RBA2)	Clay-loam deposit with frequent highly fragmented 2-5 mm artefacts (charcoal, pottery, burnt sediment), wavy top boundary derived from agricultural practice	Nicosia *et al.* 2011 (top of Unit 4, Horizon 4Aant1)
19b	Central portion of the anthropogenic deposit detected in the extensive layers which formed and were trampled in the open; dwelling layers of human occupation (RBA2)	Silty clay-loam deposit with artefacts of different size classes (charcoal, pottery, burnt sediment, bones, shells)	Nicosia *et al.* 2011 (central part of Unit 4, Horizon 4Aant2)

Table 1. Description of the litho-stratigraphic units sampled for biomarker analysis at the site of Fondo Paviani.

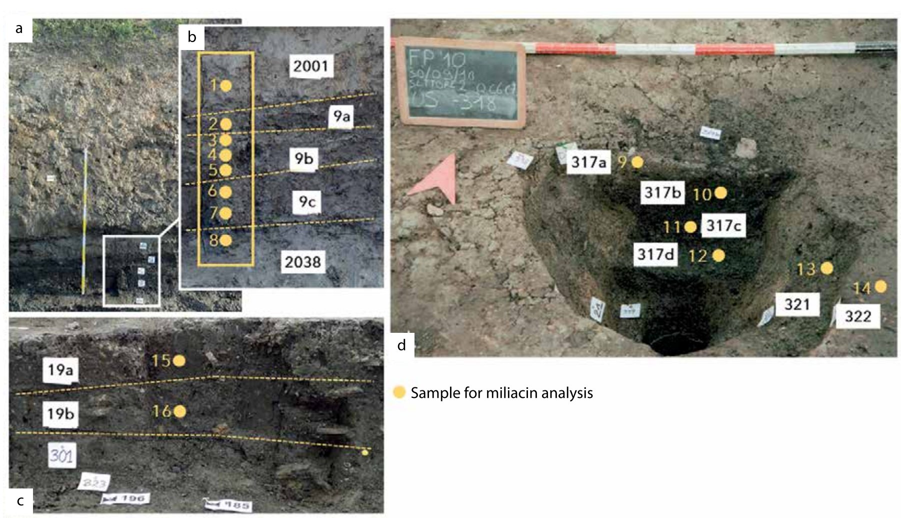

Figure 4. Field photographs of the archaeological features that have been sampled for miliacin analysis at Fondo Paviani, 2010 campaign. a. the ditch of pre-rampart phase; b. detail of the section of the ditch shown in 4a that was successively sampled with a monolith; c. cultural layers from the excavation trench; d. refuse pit fill 317 and other fill units.

Miliacin extraction

Authentic miliacin was kindly provided by Jérémy Jacob. The methods for miliacin extraction from modern grains and sediment samples follow those presented in Bossard *et al.* (2013). Fresh modern grains from a range of species were obtained from botanical gardens in Germany. Lipids were extracted by ultrasonication (3×) using dichloromethane (DCM):isopropanol (2:1) and the extracts were combined. The total lipid extract was separated into neutral, acidic and polar fractions on a Pasteur pipette filled with aminopropyl-bonded silica. The neutral fraction was collected after elution with DCM:isopropanol 2:1. The neutral fraction was separated using flash chromatography on silica (activated at 120°C for 24 h, then deactivated with H_2O at 5% by wt.) into aliphatic and aromatic hydrocarbons, ethers, esters and ketones, and alcohols by sequential elution with solvent of increasing polarity. All fractions were dried under a stream of N_2 and stored at −20°C until the analysis using gas chromatography-mass spectrometry (GC-MS). In order to quantify the miliacin in the extracts, a known amount of 5*α*-cholestane was added as internal standard prior to GC-MS. Miliacin was detected by GC retention time and mass spectrometry (Heron *et al.* 2016).

Results

Miliacin sources

Among all modern specimens tested, miliacin was detected exclusively in *Panicum miliaceum* (Table 2). The absence of detectable miliacin from *Setaria italica* and *Echinochloa crus-galli* is in agreement with the findings of Bossard *et al.* (2013) and Ohmoto *et al.* (1970). Results are shown in the chromatograms in Figure 5. The authentic miliacin standard shows a single peak eluting at 28.157 mins. The molecular ion (M^+) is visible at *m/z* 440 with prominent fragment ions at *m/z* 189 and 204. In Figure 5a, the authentic miliacin standard (upper) is compared with results from the modern samples *Panicum* 1 (middle) and *Panicum* 2 (lower). This confirms the presence of miliacin in the grains of this species through presence of the molecular ion (M^+) at *m/z* 440. The mass spectral data confirm the common origin for the peak. In broomcorn millet, Bossard *et al.* (2013) report yields of 297-476 µg miliacin per g^{-1} of grain and our results are not inconsistent with these yields.

In Figure 5b, the authentic miliacin standard (upper) is compared with samples of modern *Setaria viridis*, *S. italica* and *S. verticillata*. Once again, the molecular ion (M^+) at *m/z* 440 only is traced: the single peak is from the authentic miliacin, which confirms that no miliacin is present in any of the *Setaria* species analysed. Finally, in Figure 5c, the authentic miliacin standard (upper) is compared with modern samples of *Echinochloa crus-galli* and *E. frumentacea*. The molecular ion (M^+) at *m/z* 440 only is traced; the single peak is from the authentic miliacin only, confirming also in this case that no miliacin is present in the *Echinochloa* species analysed. The very minor peak eluting just before 28 minutes is common to all *Echinochloa* species. It is likely to be a similar compound to miliacin (that is, a triterpene methyl ether).

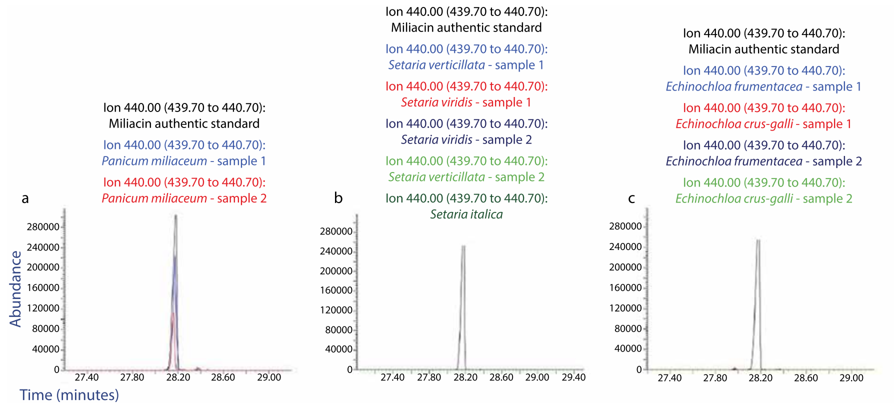

Figure 5. Extracted ion (m/z 440) chromatograms to test for the presence of miliacin in modern species of Panicoideae. a. authentic miliacin and two Panicum miliaceum *extracts; b. authentic miliacin and five* Setaria *species extracts; c. authentic miliacin and four* Echinochloa *species extracts. Only the* Panicum *samples exhibit a chromatographic peak with the same retention time and mass spectral characteristics as authentic miliacin.*

Sample	Plant species (grains)	Weight of grains extracted	Miliacin present	Yield (µg g-1)
Panicum 1	*Panicum miliaceum*	122 mg	Yes	703
Panicum 2	*Panicum miliaceum*	129 mg	Yes	380
Setaria vir 1	*Setaria viridis*	124 mg	No	-
Setaria vir 2	*Setaria viridis*	128 mg	No	-
Setaria vert 1	*Setaria verticillata*	129 mg	No	-
Setaria vert 2	*Setaria verticillata*	126 mg	No	-
Setaria it 1	*Setaria italica*	128 mg	No	-
Setaria it 2	*Setaria italica*	128 mg	No	-
Echinochloa c-g 1	*Echinochloa crus-galli*	117 mg	No	-
Echinochloa c-g 2	*Echinochloa crus-galli*	127 mg	No	-
Echinochloa frum 1	*Echinochloa frumentacea*	123 mg	No	-
Echinochloa frum 2	*Echinochloa frumentacea*	122 mg	No	-

Table 2. Results showing the presence or absence of miliacin in the modern species of Panicoideae analysed in this study.

Miliacin at Fondo Paviani

Miliacin was detected in all of the analysed sediment samples from Fondo Paviani – from the ditch fill (units 2001, 91, 9b, 9c, 2038), the pit (units 317a, 317b, 317c, 317d, 321, 322) and the two extensive layers which formed and were trampled in the open (Units 19a, 19b) (Table 3).

Discussion

Miliacin from modern reference material

From a methodological point of view, this study provides further evidence of miliacin in modern *Panicum miliaceum* grains, with yields of 380-703 µg miliacin per g-1 of grain, which is comparable to those obtained by Bossard *et al.* (2013), who report yields of 297-476 µg per g^{-1}. Miliacin is absent in the grains from the other Panicoideae here analysed, namely *Setaria* sp. (*S. italica*, *S. viridis* and *S. verticillata*) and *Echinochloa* sp. (*E. crus-galli* and *E. frumentacea*). Some of these species are attested in the archaeobotanical record from prehistoric sites in northern Italy (*e.g.* Rottoli 2001; Carra 2009; Rottoli and Castiglioni 2009a, 2009b; Perego 2015; Rottoli and Pessina 2016). Our results from the modern plant material support published data regarding the absence of miliacin in *S. italica* (Bossard *et al.* 2013).

Sample no.	Stratigraphic unit	Miliacin content (µg/g)
Ditch of the pre-rampart phase		
1	Unit 2001 cm2	<0.01
2	Unit 9a	0.70/1.12
3	Unit 9b (ash layer)	9.01
4	Unit 9b (charcoal layer)	1.34
5	Unit 9b (ash layer)	2.39
6	Unit 9c	8.34
7	Unit 9c (charcoal layer)	2.08
8	Unit 2038	2.08/2.67
Waste pit fill 317		
9	317a	6.23
10	317b	7.47
11	317c	3.88
12	317d	4.59
13	321	7.54
14	322	5.73
Cultural layers		
15	19a	1.57
16	19b	5.73

Table 3. Results showing the amount of miliacin per gram of sediment from the site of Fondo Paviani.

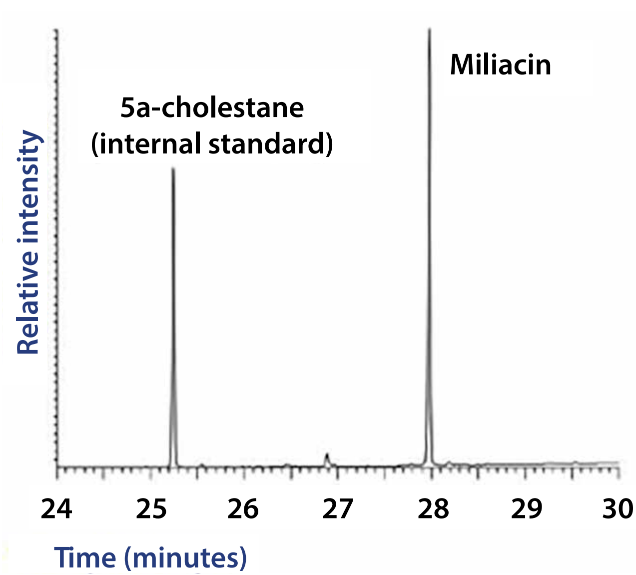

Figure 6. Partial total ion current (TIC) chromatogram showing the presence of miliacin as the sole PTME from a sample in the ditch of the pre-rampart phase, within an ash layer (Unit 9b, sample 3).

Miliacin from archaeological contexts in the floodplain

We applied miliacin extraction procedure on sediment samples from the Late Bronze Age site of Fondo Paviani in the Po valley. This is the first time that the extraction of miliacin from sediment has been undertaken in northern Italy. The feasibility of using this biomarker to attest the presence of millet in archaeological contexts in alluvial plains has been confirmed by this case study, supporting the well-known studies of lake sediments (*e.g.* Jakob *et al.* 2008, 2009; Simmoneau *et al.* 2013) and 'food crust' on ceramic containers (*e.g.* Heron *et al.* 2016).

Miliacin in the pre-rampart phase ditch: Millet consumption

The results of biomarker analysis show that miliacin can be traced in all of the samples, although with different yields. To contextualise these results, other materials in the deposit and the formation processes will be described, previously identified through the analysis of plant micro-fossils and soil micromorphology (Dal Corso *et al.* 2017) and using the archaeological data (Cupitò *et al.* 2015a).

In this study, the lowest miliacin yields came from a minerogenic unit constituting the base of the peripheral earthen rampart (sample 1). Here, miliacin is present only in traces. The next-lowest miliacin yield was from the alluvial deposit (sample 8) that forms the natural substrate under the ditch fill. In soil thin-section, this alluvial unit showed moderate porosity and few charcoal fragments (see Unit D7; Dal Corso *et al.* 2017); some sediment may thus have percolated from the anthropogenic deposits above and be responsible for the trace of miliacin. These units concern the ditch fill, where dumps of waste from routine activities are found (Units 9b, 9c; see D3-D5 in Dal Corso *et al.* 2017), together with some washed-in sediment (Unit 9a; see D2 in Dal Corso *et al.* 2017).

The highest miliacin yields in this study are found in ash lenses in the ditch fill (samples 3 and 6, 8.34 and 9.01 $\mu g\ g^{-1}$, respectively). These ashes are largely composed of phytoliths derived from chaff of pooid and panicoid cereals and from some grass leaves and stems possibly coming from cereal straw. The pollen record, which is dominated by Cerealia-type pollen (40%) and wild Poaceae pollen (over 30%), supports the phytolith record (Dal Corso *et al.* 2017). Matching the high miliacin content, there are abundant phytoliths (Fig. 3) from panicoid inflorescence comparable with that of broomcorn millet and foxtail millet (Lu *et al.* 2009). Despite being found in the ditch in a secondary deposit, the combination of a number of proxies suggest that these ashes derived from the burning of dung from domestic animals (Dal Corso *et al.* 2017; Dal Corso 2018). This practice possibly relates to the cleaning of stabling areas or from the deliberate use of dung as fuel, although wood charcoal is present too and wood was most likely the primary fuel. Further proxies indicative of herbivore dung are the abundant faecal spherulites in the thin sections, as well as the coprophilous fungal spores (*e.g. Sordaria* sp. and *Coniochaeta* sp.) and eggs of the intestinal parasite *Trichuris*. As mentioned above, the associated botanical micro-fossils show a high concentration of grass phytoliths, many still in anatomical position in multicellular aggregates, including crop processing remains, such as chaff and straw (possibly chopped or trampled, considering the cutmarks in the phytolith aggregates), abundant pollen from wild grasses, and pollen from other herbaceous plants (Dal Corso *et al.* 2017; Dal Corso 2018). The latter does not suggest human faecal material; most likely it derives from millet hulls and green forage given to herbivores. Sheep and pig are the most frequent animals in the faunal record at Fondo Paviani (De Grossi Mazzorin 2015). The presence of dung suggests that animals were likely kept inside the settlement at least in some phases of their lives, according to the seasonality of production or processing of meat or secondary products (De Grossi Mazzorin 2015).

Studies in other parts of the world suggest the practice of winter foddering of caprines with millets (*e.g.* Hermes *et al.* 2019). Further, modern uses of broomcorn millet as fodder include its mixing with barley for feeding pigs or part-grinding the grains for fattening lambs; in general, millet is considered a useful fall-back crop in case of loss of other yields (Baltensperger *et al.* 1995; Berglund 2007; Tran 2015, 2017). At Fondo Paviani, the use of broomcorn millet as fodder is seen only in some pigs exhibiting high $\delta^{13}C$ values (Tafuri *et al.* 2018).

At some sites in the low and middle Verona Plain, the primary evidence of millet consumption comes from the study of carbon and nitrogen stable isotope composition of osteological remains of humans and animals. These results stem from eight sites – both cemeteries and settlements – covering the entire EBA-RBA (Tafuri *et al.* 2009, 2018). Human remains from the settlement of Dossetto di Nogara (middle-advanced EBA1-EBA2; 1 sample) and the cemeteries of Olmo di Nogara (MBA2-RBA2; 64 samples) and Bovolone (MBA3/RBA1 transitional phase-RBA2; 21 samples) are enriched in ^{13}C, which is here attributed to the consumption of millets within a diet based on terrestrial food. Among these sites, Olmo di Nogara is a particularly useful case study for the present work because, dating from the middle phase of the MBA to the RBA2 (mid-16th to mid-12th century BCE), it is partially contemporaneous with the last occupation phase of Fondo Paviani (RBA). At this cemetery, inhumation burials prevail over the cremation burials and, in the MBA, the existence of elite is evident from the rich grave goods, with swords and daggers buried with men and parures with women, composed of pins made of bronze and amber (Cupitò and Leonardi 2005; Cupitò 2006; Canci *et al.* 2015). According to the anthropological, palaeopathological and isotopic analyses, the social differentiation seen in the grave goods is not reflected in the generally good health condition and nutrition of the individuals buried in the cemetery (Canci *et al.* 2015). The diet of all individuals, including children, contained millet, but that of women was also nitrogen rich and for this reason differed from that of the rest of the population (Tafuri *et al.* 2018). From Fondo Paviani, isotopic analysis were performed only on animal bones: cattle (5 samples), sheep (4) and pig (8) (Tafuri *et al.* 2018). Only pigs show traces of millet consumption. It is possible that crop processing waste was given to these animals, while dehusked millet grains were used as food for humans.

Reconstruction of the beginning of millet consumption in this region requires further investigation. Thus far, few millet grains have been retrieved from some Neolithic and Copper Age contexts (Rottoli and Castiglioni 2009a) and the direct radiocarbon dates for these are missing or unpublished. Among the isotopic studies of the EBA individuals from the area of Verona, an infant from Dossetto di Nogara gave indications of C4 plant consumption (Tafuri *et al.* 2018), unlike the individuals from the cemetery of Arano di Cellore, which did not show such traces (Varalli *et al.* 2016). Future investigations and dating of the EBA macro-botanical, stable isotope and archaeological records will help to better interpret this early millet evidence. The radiocarbon-dated grains of millet available to date suggest that millet was consumed from at least the MBA1 (16th century BCE, after the modelled dates in Filipović *et al.* 2020). For the MBA2 to the RBA period, there is robust isotopic evidence for millet consumption from the cemeteries mentioned above (Tafuri *et al.* 2018).

Miliacin in pit fill 317: A diverse crop assemblage in the RBA

Pit fill 317 was subdivided in the field into several subunits (317a-d) and these all showed the presence of miliacin. Unit 317 is the fill of a refuse pit from the transitional period RBA1-RBA2. At this time, the excavated portion of the settlement feeatures several clay-built open fireplaces, probably used for crop processing (Cupitò *et al.* 2015a). This pit, as well as the other ones (*e.g.* Unit 207; Fig. 2), was filled after a fire destroyed a possible small, raised wooden granary located in the area, and the charred cereals were removed from the surface (Cupitò *et al.* 2019). The highest miliacin content in this archaeological context comes from the uppermost portion of the fill. The macro-botanical record is mostly composed of grains of other cereals, all known from the Bronze Age elsewhere in Europe (Stika and Heiss 2013), such as emmer, einkorn, barley, 'new type' glume wheat and free-threshing wheat (Fig. 2). Among the other identified remains are some crop weeds, a few hazelnuts and berries collected from the wild vegetation near the site (Berto and Rottoli 2015). Although broomcorn millet and foxtail millet are not abundant here, they were documented in other features in the same excavation trench (*e.g.* 207; Fig. 2). This broad crop spectrum and the presence of wild fruit and nut suggest a diverse plant-based diet of the inhabitants of Fondo Paviani. Such varied plant use may have been a strategy to buffer poor crop yields, whilst it indicates solid knowledge of plant use and cultivation. Pulses are much less represented than cereals in the studied samples – bitter vetch (*Vicia ervilia*) and common pea (*Pisum sativum*) were recognised (Berto and Rottoli 2015; Berto *et al.* in press).

Miliacin in extensive anthropogenic layer 19b: Domestic waste?

The extensive anthropogenic layer 19b, the samples from which gave high yield of miliacin (5.73 $\mu g\ g^{-1}$), belongs to the occupation phase in which the excavated portion of the settlement received dumps of domestic materials, both delimited and scattered (Cupitò *et al.* 2015a; Dalla Longa 2020). Unit 19b can be chronologically ascribed to the RBA2 (Cupitò *et al.* 2015a; Dalla Longa 2020). This layer was excavated in open area and was also recognised in two stratigraphic profiles (although these were not sampled for miliacin), where the anthropogenic units were investigated by soil micromorphology, geochemistry (Nicosia *et al.* 2011) and palynology (Dal Corso *et al.* 2012). These deposits are composed of a series of surface horizons on dry soil, where fine sediment accumulated in the form of material from dug-out features, import from alluvial terraces outside the settlement area, disruption of earth-based construction material and occasional (probably seasonal) overflow from the local drainage (see Unit 4 and horizon 4Anth2; Nicosia *et al.* 2011). The miliacin in this unit probably derives from domestic waste. The earthen construction material in other *terramare* is usually composed of ovicaprid dung (Cardarelli *et al.* 1997; Cremaschi and Ottomano 1998; Cremaschi *et al.* 2004). More work is needed to determine if caprines were foddered with millet at Fondo Paviani. There is no direct evidence of this (Tafuri *et al.* 2018), apart from the association of herbivore dung and millet recovered from the ashes in the ditch (Dal Corso *et al.* 2017).

Miliacin in extensive layer 19a: Millet also in the first phases of the Final Bronze Age arable plots?

Unit 19a, overlying Unit 19b, is interpreted as an arable zone within a ridge-and-furrow field system. This is evidenced by the uneven distribution in the soil of finely fragmented, worn anthropogenic materials (ceramics, charcoal, bones, fired clay or daub) with rounded edges, corresponding to manure derived from domestic waste (4Anth1 in Nicosia *et al.* 2011). This unit was also excavated in open area and was recognised in the two stratigraphic profiles, as in the case of Unit 19b. The arable fields were established after a functional change detected in the excavated area, which, as we note above, previously hosted domestic deposits (Unit 19b) (Cupitò *et al.* 2015a; Dalla Longa 2020). Agricultural activities brought up material from the deposits below, and some pedo-relicts show the import of allochthonous soil, brought here on purpose from outside the settlement (Nicosia *et al.* 2011). This unit has a strong reworking of sediments and points to the arable use in the first phases of the FBA, but includes also RBA2 materials and sediments (Cupitò *et al.* 2015a). For this reason, the presence of miliacin here cannot be taken as clearly indicating local millet cultivation.

Conclusions

In the Late Bronze Age *terramara* of Fondo Paviani, in the Po valley, miliacin is present in many anthropogenic deposits. These early results support the validity of miliacin extraction and identification as a tool to track the presence of millet in different sediments from settlement sites. This cereal was previously documented at the site in the form of macro-remains and phytoliths. A multi-proxy approach applied to investigate the ditch fill revealed a concentration of grass and millet phytoliths in ashes, most likely derived from the practice of burning litter or dung from domestic animals fed with millet. Miliacin as well as charred millet caryopses and processing remains were registered in pit fills and in extensive cultural layers formed and trampled in the open. A stable isotope study of the three main domesticates attested at Fondo Paviani (sheep, pig and cattle) only showed evidence of millet consumption in pig, probably because this species thrived on remains of crop processing and other domestic waste. The MBA2-RBA human population living in the region also consumed millet, at least those individuals analysed isotopically, including an exceptional case of an EBA infant fed with millet (Tafuri *et al.* 2018). Broomcorn and foxtail millets were part of the diverse crop spectrum used by the inhabitants of Fondo Paviani, suggesting food economy aimed at preventing harvest failures and at the use of different environments for cultivation. More should be done to investigate winter fodder strategies and the possible use of millet for herbivores at the site.

Further research is required on the long-term behaviour of miliacin in sedimentary contexts (Jacob *et al.* 2008; Courel *et al.* 2017). Compound-specific radiocarbon dating of miliacin has considerable potential (Courel *et al.* 2017). The presence of miliacin in the RBA at Fondo Paviani is in accordance with other evidence signalling consumption of millet during this period (Berto and Rottoli 2015; Tafuri *et al.* 2018). It is not possible to comment on the last settlement phase, dated to the first phases of the FBA. The only layer that has chronological markers attributable to this phase (Unit 19a) also includes materials and sediment pulled up from the RBA2 layer below it (Unit 19b). The miliacin content detected in Unit 19a may then also derive from this reworked sediment. In order to find out if millet was used in the first phases of the FBA, and also to test the method for detection of miliacin within such a deposit, a multi-proxy approach should be applied in an FBA context, where layers specific to this chronological span are present. A suitable site to attempt this could be Frattesina, as it contains both settlement layers and inhumation burials dating to the first phase of the FBA.

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Exploring seed impressions within the fabric of pottery: Using a silicone cast method for reliable identification

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Abstract

This paper presents an improved method to analyse seed impressions in pottery and describes its effectiveness for distinguishing millets. It may be especially helpful to distinguish grains of millet cultivars, such as foxtail (*Setaria italica*) and broomcorn (*Panicum miliaceum*) millet. This method has rapidly become popular across the Japanese archipelago over the past decade and has strongly improved knowledge about plant utilisation in ancient times. For example, it has revealed the exact timing of the acceptance of crop cultivation during the Jōmon-Yayoi culture transitional period and the diversity in the development of Yayoi agriculture in various parts of the archipelago as a result of differences in social organisation and ecological environments. Based on these achievements, the method represents a valuable alternative to flotation-based studies in the field of archaeobotany. One of the important advantages of the study of seed impressions is that we can get information on plants even from archaeological sites where flotation was not performed. In addition, it can provide direct links between pottery culture and plant use, which are more complicated to explore based on charred seed assemblages. However, due to their complex formation processes, there has been no agreement about how to interpret plant impressions in pottery in relation to human subsistence economies. Therefore, this chapter discusses potential formation processes of plant impressions based on an extensive dataset from the Japanese archipelago.

Introduction

This paper introduces a method to analyse plant impressions (mostly seeds) in pottery and outlines its value for distinguishing grains of different millet species. There is a long history of research concerned with pottery impressions in the study of plant use by prehistoric and early historic cultures. However, nowadays, many archaeobotanists believe that the identification of impressions is often ambiguous and thus are sceptical about impression-based botanical datasets (Zohary and Hopf 2000, 5; Hunt *et al.* 2008; Stevens *et al.* 2016, 1545). In addition, due to plant impressions' complex formation processes, quantitative analysis of impressions is limited (Willcox and Fornite 1999; McClatchie and Fuller 2014). Some scholars have pointed out that it is possible to discuss activities such as crop processing (*e.g.* threshing) or pottery production by using the impressions of temper (Hovsepyan and Willcox 2008; McClatchie and Fuller 2014; Moskal-del Hoyo *et al.* 2017). However, this paper focuses on seed rather than temper impressions. Although it may be difficult to identify impressions by naked eye and to analyse the data in a quantitative way, impressions are informative in terms of plant use in everyday life, and they contribute to understanding the relationship between humans and plants.

Recently, several improvements in the analytical methodology of plant impression studies have been achieved (*e.g.* Takase 2011; Arobba *et al.* 2017). One innovation, which the present author has been applying successfully, is the analysis of casts made by means of silicone fillings. Another method, using materials other than silicone, is also practised; however, the author considers silicone to be an excellent material due to its transfer function. This method allows reliable identification of imprints to species level if they were formed under appropriate conditions. It may be especially helpful to distinguish different millet species, such as foxtail (*Setaria italica*) and broomcorn (*Panicum miliaceum*) millet, which is often difficult for charred, and thus sometimes deformed, millet grain assemblages due to overlaps in morphology and size (Spengler *et al.* 2013). By analysing the surface structure of the casts, more reliable plant taxonomic identifications are possible.

Refined silicone cast method

The silicone cast method adopted by the author was introduced by Ushino and Tagawa (1991) and improved by Hisa and Katada (2005) to reduce working time in order to facilitate analysis of a large amount of material. Positive casts are made from impressions by means of silicone and are then analysed using scanning electron microscopy (SEM). Thanks to the high-resolution transcription of clay, morphological details of the plant surface can be observed at 500× magnification or higher. Grikpedis (2019), who used this technique in Belarus, noted that the application of SEM to investigate silicone casts of plant impressions facilitates inspection and evaluation not only of the shape and size of imprints, but also their surface elements and, therefore, allows for secure identification of the impressed objects.

Procedure

The detailed procedure is as follows (see Fig. 1):

a. Search for impressions on the inner and outer surface and cross-section of pottery fragments by naked eye and with the use of a magnifying glass. Pay attention to those impressions that are not fully exposed, because most of their shape is located inside the pottery fabric and is accessible only through a small hole in the surface (Fig. 1A); thanks to the elasticity of silicone, it is possible to also take casts from such deep and overhanging impressions, without destroying the pottery.
b. Clean the impression to remove soil, using a soft brush.
c. Coat the impression and the surrounding part of the pottery with acetone containing 5% Paraloid B72 to protect the pottery surface (Fig. 1B).
d. Fill silicone into the impression (Fig. 1C).
e. Remove the cast from the impression after hardening (Fig. 1D).
f. Remove the coating liquid to clean the surface, using 100% acetone.
g. Analyse the cast using SEM (Fig. 1F).

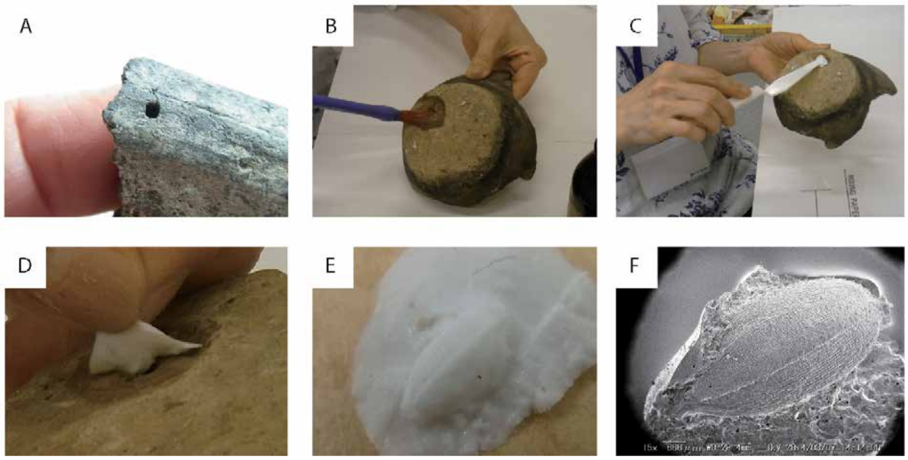

Figure 1. Main working steps of the seed impression casting method.

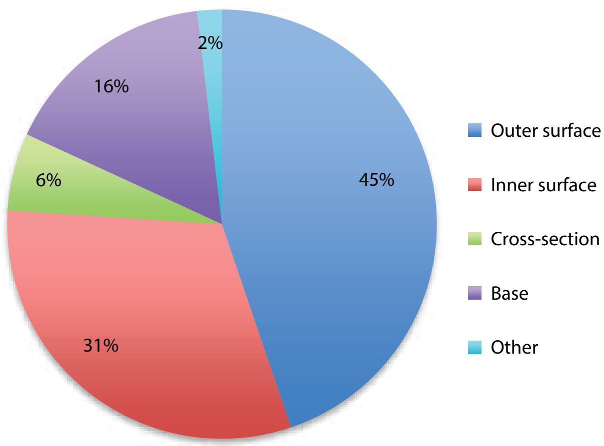

Figure 2. Location of impressions of 1451 rice, foxtail millet and broomcorn millet seeds in a combined assemblage of Jōmon-, Yayoi- and Kofun-type pottery.

Processes of formation of plant impressions

As mentioned above, quantitative analyses of plant impressions data have generally not been accepted due to the diverse formation processes that are potentially involved. In the following sections, the author discusses the potential processes of formation of plant impressions based on an extensive dataset from the Japanese archipelago covering the Jōmon (15,000-2500 cal BP) (Noshiro and Sasaki 2014), Yayoi (2500 cal BP-250 CE) and Kofun (250-710 CE) (Mizoguchi 2013) periods, represented by 2951 impressions from 166 archaeological sites.

What was the condition of the pottery when the seeds became impressed within the fabric?

Impressions of crops (*Oryza sativa*, n=737; *Setaria italica*, n=425; *Panicum miliaceum*, n=289) were identified on the inner and outer surfaces, flat base and cross-section of pottery (Fig. 2). They are distributed on various parts of pottery; therefore, crops were likely incorporated into the fabric in the clay state before the pottery obtained its final shape. That impressions were more often detected on the outer surface than the inner surface may be due to the difficulty of observing the inner surface on, for example, vessels with bottlenecks. However, regarding impressions on the flat base of the pottery, it is possible to infer that, here, the incorporation happened after the pot was formed and before the fabric dried (*i.e.* hardened). The impressions of such formation process may be described as impressions 'on' pottery.

Where did the seeds become incorporated into the pottery?

In the assemblages analysed, most of the impressions identified to species or genus level were cultivated cereals. The relatively few remaining specimens comprise other cultivated plants or wild plants (Table 1). Given the dominance of crop plants and the low abundance of wild plants, the author presumes that the preparation of the fabric was done inside dwellings, where the crops were stored and cooked. The predominance of crop plants in flotation samples from burnt dwellings from settlements of the Yayoi and succeeding cultures also suggests that crops were stored inside dwellings (*e.g.* Takase 2004; Takase and Endo 2010). In addition, impressions of household insect pests, such as the maize weevil (Obata *et al.* 2019), support the assumption that fabric for pottery was prepared indoors.

The conditions and preserved features of the identified crops

The dominant features of the crops that are preserved are the caryopsis with lemma and palea (Table 2). Therefore, the author suggests that most seeds were incorporated into fabric during the final stage of dehusking. Furthermore, given the presence of husks of *Oryza sativa*, it seems likely that threshing was done indoors.

Did the grains become incorporated into the fabric intentionally or accidentally?

Based on examples of large amounts of impressions in pottery, some researchers have argued that seeds were sometimes mixed into fabric intentionally. For example, Obata (2016) has identified a large fragment of Jōmon pottery with 526 impressions of perilla (*Perilla frutescens*) using soft X-ray instruments. He argues that this cannot occur without a strong intention to mix perilla with fabric. Such evidence has also occasionally been recorded by the author, raising questions about if/how seeds that were intentionally mixed into clay would have increased the risk of damage during firing of the pot or would have limited the pot's functionality (Fig. 3). The author believes it is debatable whether seeds were intentionally mixed into the fabric or were incorporated by chance. The origin of impressions of crop processing by-products is clearer. If they are detected in large numbers on the entire surface of pottery or daub, it is most likely that they were admixed with the fabric as a temper.

Current results from the study of plant impressions

Due to the lack of charred plant remains obtained through flotation. or the data on them, the replica method has become popular across the Japanese archipelago over the past decade. It has helped reconstruct and discuss plant use in prehistoric times since the impressions in pottery have revealed a diverse utilisation of plants and the advent of agriculture during the Jōmon-Yayoi transitional period. For instance, regarding the use of legumes during the Jōmon period, seed impression studies have demonstrated that continuous utilisation of these plants started in the first half of the Early Jōmon period and that an increase in the seed size started in the Middle Jōmon period (Nakayama 2020). Concerning the spread of agriculture, seed impressions studies have revealed that the crop package of *Oryza sativa, Setaria italica* and *Panicum miliaceum* arrived in western Japan at the end of the Final Jōmon

Taxon	Count
Oryza sativa	737
cf. *Oryza sativa*	122
Setaria italica	425
cf. *Setaria italica*	49
Panicum miliaceum	289
cf. *Panicum miliaceum*	75
Setaria viridis	14
Paniceae	12
Perilla	19
cf. *Perilla*	11
Cannabis	4
Lactuca raddeana var. *elata*	1
Carpinus tschonoskii	1
cf. *Echinochloa*	2
Sambucus	2
Fabaceae	2
millipede	1
maize weevil	1
insect	6
shell	3
Total	1776

Table 1. Total counts of identified impressions in Jōmon-, Yayoi- and Kofun-type pottery.

Taxon	Caryopsis	Floret (caryopsis with lemma and palea)	Spikelet	Husk (chaff)
Oryza sativa	64	664		8
Setaria italica	11	14		
Panicum miliaceum	4	282	3	

Table 2. Parts of cereal fruits recognised in the silicone casts of impressions.

Figure 3. A lid with impressions of Oryza sativa *(n=3),* Setaria italica *(n=21) and* Panicum miliaceum *(n=12) recovered from the Daizuda site (Late Yayoi period), in Nagano Prefecture, Japan.*

period and that, in the succeeding Yayoi period, a diverse agriculture developed in various parts of the archipelago as a result of differences in social organisation and ecological environments (Endo 2015). In the western part of the archipelago, *O. sativa* was dominant and accompanied by a small amount of millets. In the Central Highlands, one of the most developed areas of the Jōmon culture, only millet was selected in the first half of the Yayoi period.

Although it is difficult to examine plant impressions data quantitatively, the presence/absence data allow researchers to analyse the relationship between pottery types and cultivated plants. For example, impressions on the Ongagawa-type pottery, which was distributed across western Japan in the Early Yayoi period and has been in Japanese archaeology used as a chronological marker of the start of agriculture, are mainly *O. sativa* accompanied by only little millet. On the other hand, almost all of the impressions on Fusenmon-type pottery, which was distributed across the Central Highlands and is synchronous with Ongagawa-type pottery, are from millets. In addition, during the Middle Yayoi period in the Kanto region in eastern Japan, *O. sativa* dominates in the Miyanodai-type pottery used in the southern part of the Kanto region, while *O. sativa* and millets are mixed in the Kitajima-type pottery used in the northern part of the region (Table 3).

A combination of systematic flotation and use of the silicone-casting method at the Sunadadai site in southern Kanto revealed more than 2500 charred grains of *O. sativa*, but none of millet (Kanagawa Prefecture Buried Cultural Heritage Research Centre [KPBCHR] 1991). It also revealed impressions of eight *O. sativa* caryopses and one *S. italica* grain (Endo 2019). Similarly, the combination of impressions in pottery of rice and millets (Endo 2019) is consistent with the recent results of flotation at Maenakanishi, a site located in northern Kanto, at which mainly Kitajima-type pottery has been recorded (Leipe *et al.* 2020).

Recently, the presented method has been also successfully applied in regions outside Japan, such as the Russian Far East (Fukuda *et al.* 2019), South Korea (Son *et al.* 2010; Nakayama 2014), southern India (Nakayama and Uesugi 2015), Ukraine (Endo 2019) and Belarus (Grikpedis *et al.* 2018; Grikpedis 2019) (Fig. 4).

Differentiation between *Setaria italica* and *Panicum miliaceum*

One of the most important advantages of the method is the opportunity to obtain information on the spectrum of the plants used at archaeological sites where archaeobotanical recovery (*e.g.* flotation) is otherwise not performed or where the preservation of botanical materials is very poor. Even where plant remains have been preserved and recovered, the differentiation of small seeds, particularly those that are morphologically similar, such as grains of millets, can be difficult because charring/carbonisation causes deformations. Silicone casts of impressions are replicas of the fresh (uncarbonised) seed, exhibiting all morphological details. Furthermore, most cereal grains were still covered with lemma and palea when they became incorporated into the fabric, whereas most charred specimens are without lemma and palea. Thus, in silicone casts of impressions, more details of the original material are preserved, which allows a more reliable identification. For distinguishing *Setaria italica* and *Panicum miliaceum* caryopses, the papillae distribution on lemma and palea of *S. italica* is one of the basic criteria. Another criterion is the smooth surface, without papillae, of *S. italica* grains, which is observed only on the lemma and, more specifically, on the part that overlaps with the palea (Fig. 5A). The lemma and palea of *P. miliaceum* have no such papillae and the surface is overall smooth and glossy (Fig. 5B). In addition, it has been shown that *S. italica* is distinguishable from other *Setaria* species, such as its progenitor *S. viridis*, based on the non-ridged base of the papillae on the upper lemma of *S. italica* (Nasu *et al.* 2007). This feature can be also observed in high-quality SEM images of silicone casts (Fig. 5C).

Period	Pottery type	Region	site	Number of observed pottery shards	Number of shards with cereal impressions	*Oryza sativa*	*Setaria italica*	*Panicum miliaceum*
Early Yayoi	Ongagawa	Western Japan	Nishisiga	20,819	95	48		1
			Tamura	423	5	10		
	Fusenmon	Central Highland	Ishigyo	360	47	1	60	26
			Yazaki	132	22		41	2
			Gongendomae		15		5	
			Ohsyuku	182	8		13	2
			Kitakatakitanohara	133	5		4	19
			Fukayamada	42	2		5	9
Middle Yayoi	Miyanodai	Southern Kanto	Ikego	1249	36	30	2	5
			Asukayama	1536	9	9		
	Kitajima	Northern Kanto	Kitajima	1500	24	10	20	1
			Maenakanishi	2373	42	20	24	

Table 3. Identified crop impressions in pottery organised by cultural period, pottery typology and location.

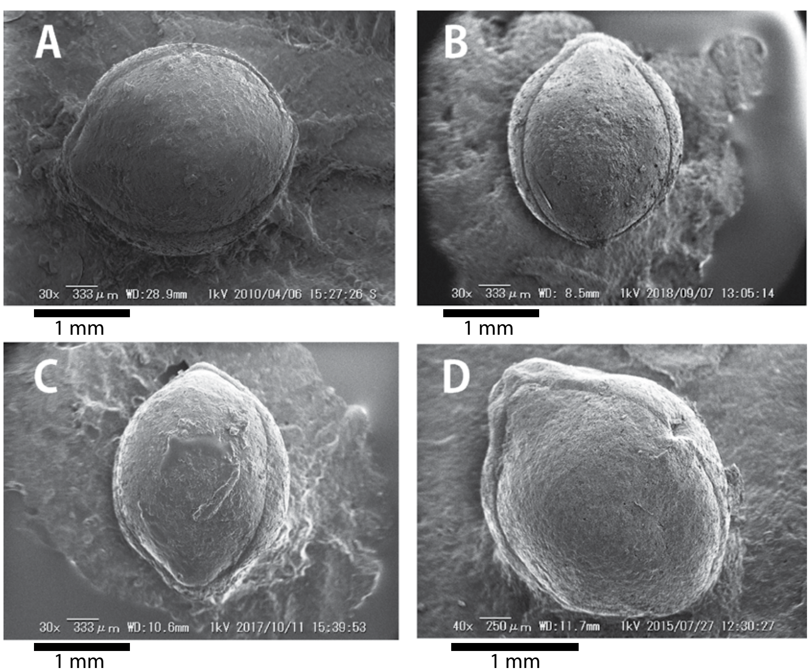

Figure 4. SEM images of Panicum miliaceum *grain impressions from selected sites in Eurasia: (A) Ishigyou (Nagano Prefecture, Japan); the pottery fragments with impressions are typologically dated to the first quarter of the 1st millennium BCE; (B) Novokyivka (Ukraine), typologically dated to 1600-1300/1200 BCE; (C) Kamen 6 (Belarus), typologically dated to the 3rd and 2nd millennium BCE; (D) Zhertyj Yar (Russian Far East), typologically dated to the 3rd century BCE-4th century CE.*

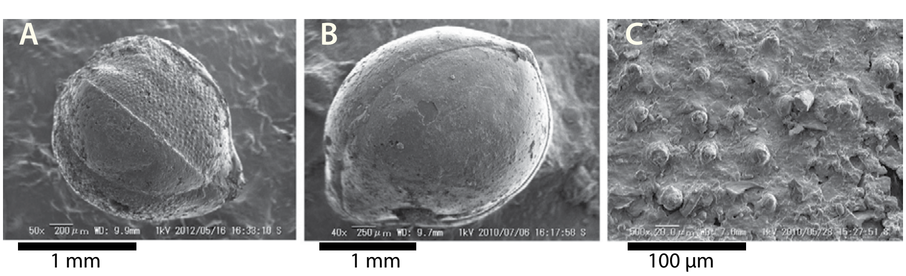

Figure 5. SEM images of Setaria italica *and* Panicum miliaceum *grains: (A)* S. italica *with papillae on the lemma and palea; (B) the smooth and glossy surface on the lemma and palea of* P. miliaceum*; (C) the non-ridged base of the papillae on the upper lemma of* S. italica.

Conclusions

This paper summarises an improved method to study seed impressions in pottery and describes its advantages for identifying small seeds. Seed impressions studies can substantially contribute to our understanding of the relationship between humans and plants in prehistoric times, thus representing a valuable alternative or a complement to flotation-based studies in the archaeobotany. Especially, such studies can provide direct links between pottery making and plant use, which are more complicated to explore based on charred seed assemblages. Further experimental and ethnoarchaeological research is needed to improve our understanding of the formation processes and taphonomy of seed impressions and to allow a more quantitative interpretation of the obtained datasets.

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Traditional millet cultivation in the Iberian Peninsula: Ethnoarchaeological reflections through the lens of social relations and economic concerns

Andrés Teira-Brión

Abstract

In this paper, I propose a reassessment of some widespread archaeological claims about millet agrarian practices – double rotation and an increase in cereal production – based on conclusions derived from ethnographic analogy. The reflections presented here arose from experiences during fieldwork, which has transformed my perception of the material record of and historical sources on millet farming. The results of the ethnoarchaeological investigation, carried out within the project 'New cultivars, new landscapes: Agriculture and anthropisation of the first farming societies in northern Iberia (2012-2014)', have made it possible to recognise the different stages of the *chaîne opératoire* of millet production and processing, as well as millets' uses in human food and animal feed.

Introduction

In a broad sense, ethnoarchaeology is

> '*…the study of how material culture is produced, used and deposited by contemporary societies in relation to the wider social, ideological, economic, environmental and/or technical aspects of the society concerned, and with specific reference to the problems of interpreting archaeological material*' (Sillar 2000, 6).

Over the past two decades, researchers have explored the relevance and meaning of the material past within distinctive disciplinary traditions (Hamilakis and Anagnostopoulos 2009), including approaches to the materiality of 'primitive' societies within contemporary modernity (González-Ruibal 2014). Essentially, however, it is still necessary to distinguish between ethnographic analogy and ethnoarchaeology. According to A. Hernando (1995), analogy is descriptive, establishing specific similarities between two cultures – present and past – under their respective cultural contexts; whereas ethnoarchaeology makes generalisations that aim to be laws, reviewing the ethnographic record in relation to a specific behaviour, process of change, *etc.*, in order to understand in which socio-economic, ideological or environmental conditions a particular model of conduct may appear.

Ethnoarchaeological studies have made important contributions to our knowledge about millet agriculture and processing, based on observation of traditional farmers (*e.g.* Hörander 1995; Lundström-Baudais *et al.* 2002; Hamon and Le Gall 2013; Song *et al.* 2013). These studies have the capacity to connect the pieces of the puzzle we recover from the past with current materials, but not in a direct analogy. The materiality we study at present is not static, immutable or timeless. It is a snapshot of a specific moment in a continuously changing process. The conducts we observe may have been established after the moment we aim to study or at different timescales; therefore, translating these practices into the archaeological record cannot be done uncritically. Indeed, conjectures about current agricultural practices may even transcend into the scientific literature as theories. To avoid this, ethnoarchaeology provides valuable information to reflect on the limitations of archaeological approaches.

A key question in the study of millet farming is what social changes it may have led to. In line with the results of ethnographic studies, two claims have been disseminated among archaeologists: a) short growth cycle of millets involve the production of two cereal harvest per year and, associated with this, b) millet cultivation means an increase in cereal surplus. But, at present, we hardly know how they were cultivated in western Europe by prehistoric communities. These ideas remain as a kind of research artefact towards arguing for a higher complexity and intensification of agricultural practices since the Bronze Age.

Although both proposals are feasible, their generalisation to any past society is problematic. Far from helping to establish the role of millets, they make it difficult to understand their multiple relationships within different agricultural systems. Even though these proposals may be attractive in terms of highlighting millets' potential, they remain speculative and often become stereotypes. In order to acquire agricultural knowledge, the information generated from a single archaeological discipline is often insufficient. Therefore, ethnoarchaeology exists not only to provide similarities or laws of conduct, but also to warn about the problem of transferring practices from the present without evaluating other aspects of the system in which they are enmeshed. An interdisciplinary and multiscale conception and definition of the social and economic contexts of agriculture can allow us to test the appropriateness of the above statements.

Farming millets in the Iberian Peninsula: A case study

Several studies on millets in the Iberian Peninsula have used an ethnographic or ethnoarchaeological approach (Vázquez Varela 1994; Barboff 1995). All these works are focused on the northwestern region, where traditional millet cultivation was carried out until recently. Between 2012 and 2014, I participated in a project led by Lydia Zapata, which made it possible to encounter farmers who were still growing millets or who had only recently abandoned this practice (Moreno-Larrazabal *et al.* 2015). The scope of the study integrated interviews in Spain – in the regions of Asturias and Galicia – and northern Portugal, mainly among elderly people, which allowed us to document farming practices going back to the 1920s. The aim

Figure 1. a) Aitor and Lydia during ethnographic fieldwork in Manuel's foxtail millet plot (Asturias, Spain); b) milling broomcorn millet using an electric mill (Galicia, Spain); c) Delia dehusking P. miliaceum *with the pilão (Paredes de Coura, Portugal); d) mortar and pisón (pestle) from A Capela (A Coruña, Galicia) (photograph by Fernán López); e) mortar with different type of pestle from A Coruña province (Galicia). The author has the consent of the people depicted in this figure for the dissemination of their images.*

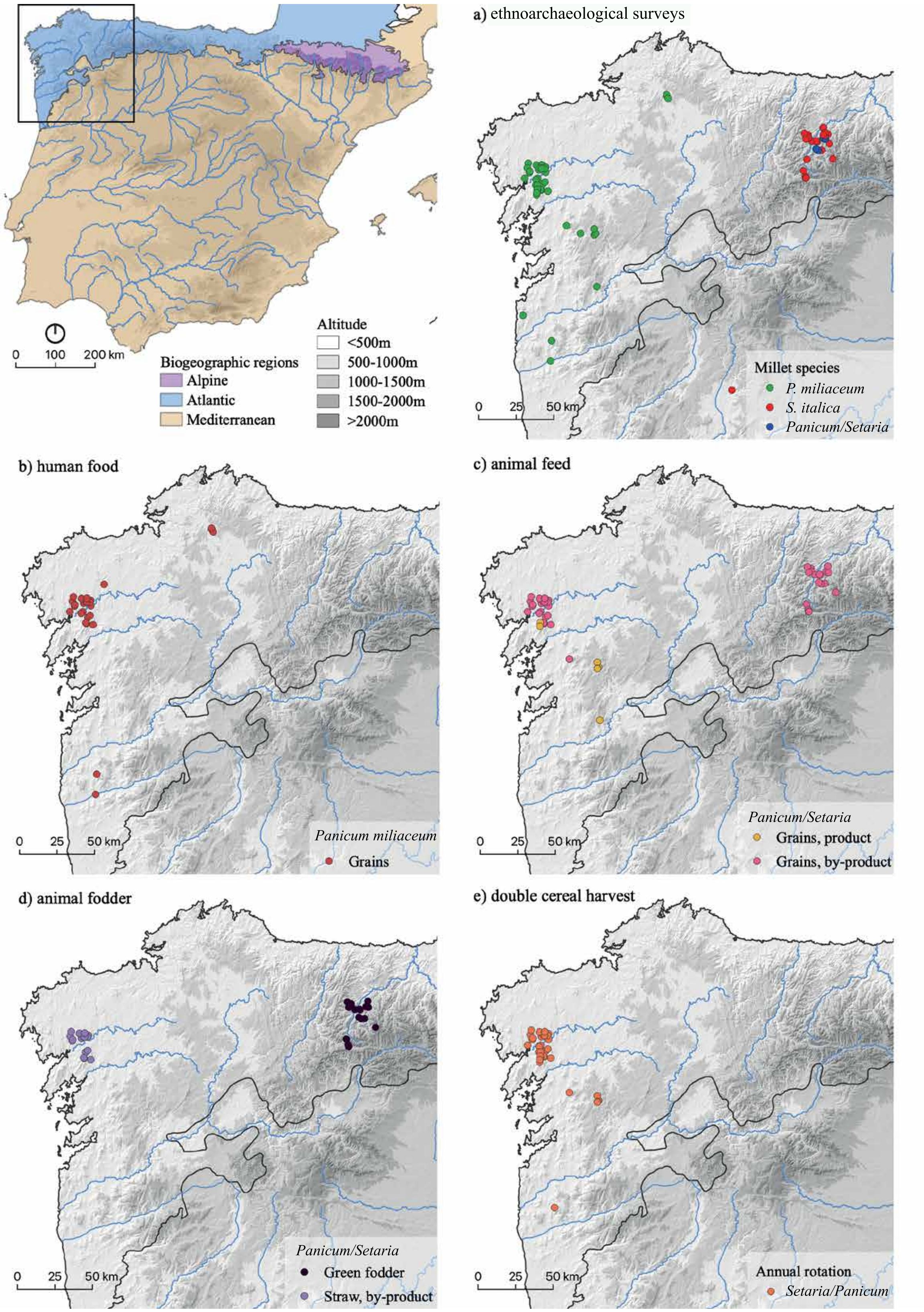


Figure 2. a) distribution of P. miliaceum *and* S. italica *in peasant traditional farming based on ethnobotanical fieldwork; b-d) different plant end uses, as products and by-products; e) double cereal harvest per year with a rotation of rye and broomcorn millet.*

of the project was to recognise the *chaîne opératoire* and to determine criteria for interpreting the archaeobotanical evidence from millet products and by-products in relation to actions and tools. In establishing this analogy, the remains were identified for each stage of the processing according to the remains preserved in archaeobotanical assemblages. But at the same time, we reflected on whether contemporaneous millet-related practices have any connection to past ones, when changes in millet use or distribution occurred, and for what reason.

During the ethnographic study, we observed differences in agricultural practices (Fig. 1), primarily related to the species grown and their uses. In Galicia, Spain, and the Minho region of Portugal, broomcorn millet (*Panicum miliaceum*) is grown exclusively. The farmers interviewed did not recognise the foxtail millet (*Setaria italica*) plant. In all cases the grains were the main product, which were destined for two uses: for human food (porridge, pudding or bread) or for animal feed (chickens and hens were fed the whole grains, and cows were fed the flour after calving). The stems of the plants were used as fodder for cattle as a secondary use. Cultivation practices were fairly homogeneous. Sowing was done in June on the land where rye (*Secale cereale*) had been gathered and harvested the previous September or October. A double winter (rye) and spring (broomcorn millet) cereal harvest was therefore carried out in the same plot. Only farmers in the westernmost area of Lugo province documented a single annual rotation with other crops. The way the millet was processed showed one of the most significant differences. Milling of the grains without removing the husks was documented in western areas of the province of A Coruña. The resulting flour had a sort of sandy texture due to the inclusion of some husk fragments that had not been separated out during sieving. Here, although mortars were known, they were not associated with millet processing. Elsewhere in Galicia and Portugal, the grains were not ground, so the use of stone mortars was the usual way for dehusking. For dehusking, two different types of mortars and pestles were used, one in the most northern area (Fig. 1d-e) and another in the southern area (Fig. 1c).

Asturias is the region where we documented the cultivation of foxtail millet (Fig. 2), closely associated with the use of the plant as green fodder for livestock. This plant was very appreciated as fodder to fatten animals in the summer months, when pasture was scarce in the valleys. The grains had a secondary use for feeding the chickens. In no case was human consumption documented. It was common to buy seed grains for sowing at local markets, mainly the one held in the village of Cangas de Narcea. Only two populations of *P. miliaceum* were documented, in maslin plots with *S. italica*. However, farmers did not consider broomcorn millet as a crop, but as a companion plant of foxtail millet. It did not even have a different name.

Reconstructing past cultivation practices using historical records

All crops studied in 2012-2014 (Moreno-Larrazabal *et al.* 2015) were marginal products at the time of the fieldwork. They had survived within a traditional agrarian society that had kept them as a complement for human and animal alimentation. The practices documented can be understood as an example of the resilience of a rural society in the process of transformation towards a market economy. This is visible in the adaptation of processing to current tools. Some of them are easily identifiable, such as the use of the tractor for trampling *P. milaceum* as a substitute for using cattle or flails. On other occasions, it is complex to identify the exact moment when a practice is being transformed, or even if there is a territorially differentiated behaviour. Grinding in electric mills is clearly a 20th century replacement for grinding in hydraulic mills. However, in certain areas, we do not know when the change to using the flour instead of the whole grains for the same recipes took place. Sometimes, within a homogeneous system of practices, such as the cultivation of *S.*

italica in Cangas de Narcea and Degaña, in Asturias, we find individual specificities. Wetting the grain before sowing was documented in only a few families. We found only one farmer who did not level the ground before sowing. These behaviours can be considered as personal choices but are also a notable source of information. Identifying all these variables is useful for observing the diversity of the practices carried out. They break the strict and uniform picture of crop cultivation. However, it is difficult to know at what point each of these adaptations took place.

The boundaries established by an ethnographic study area can give us a biased notion of the spatial distribution of cultivation. It is therefore important to trace for each behaviour whether it is a modern adaptation or has its roots in remote times. For this purpose, written and archaeological sources provide a multitemporal overview of the distribution of millets and their relationship with other crops within agricultural systems. The need to establish the wealth of countries in modern and contemporary times lay at the origin of national inventories made throughout Europe. One of these sources in the Spanish territory is the *Diccionario Geográfico-Estadístico-Histórico de España y sus posesiones de ultramar,* published by Pascual Madoz (1846-1850). He coordinated a survey to find out about the goods, products and economic activities of each village. The survey was sent to the entire country, with the exception of territories with a specific tax system, such as Navarra, Guipuzkoa or Bizkaia. Although the quality of the information is uneven, as it depended on each local administration, the inventory provides valuable information on the most important crops in each place and the produce supplied to the markets (Fig. 3). In the Madoz inventory, the words *mijo,* commonly used in Spanish for *Panicum miliaceum,* and *panizo*, used for *Setaria italica,* are recorded a total of 478 times (Fig. 3a). However, we cannot associate these words with millet cultivation since *mijo* and *panizo* may also refer to corn (*Zea mays*), as regional substitutes for the more usual name *maíz*. Separating out the populations where maize cultivation is not mentioned provides a more precise distribution of those cases where *maíz* was accompanied by the cultivation of *mijo* (215 times) and/or *panizo* (53 villages) (Fig. 3b). Incorporating this source of information significantly changes the distribution which had been observed in the ethnographic interviews and outlines new social settings. In fact, three or four generations earlier, broomcorn and foxtail millet were widely grown in the Iberian Peninsula. In many of these regions, these crops did not endure in the memory of the farmers. The key reasons for this neglect may be the replacement of millets by other crops and the loss of traditional knowledge orally transmitted from generation to generation.

We must question the extent to which the results of the study of the materiality of these contemporary traditional societies can be transferred to the past. Traditional societies are not the guardians of ancestral practices, but the result of a process of technological, economic, social or environmental adaptation and change. The transformation of traditional agricultural societies in this part of Iberia is not recent, because agriculturalists have adopted many technical and social changes since the 19th century (see Fernández Prieto 1992). Furthermore, traditional agriculture presents social, economic and cultural conducts that cannot necessarily be extrapolated to the recent past. If we focus on the search for archaeological analogy, it may be more interesting to recognise these social settings. In this way, we can consider all available parameters. When it comes to characterising the origin of a behaviour, all behaviours have the same initial value. In other words, farming practices are a portrayal of the objects and the people at the exact moment when they took place, in each specific social and cultural setting.

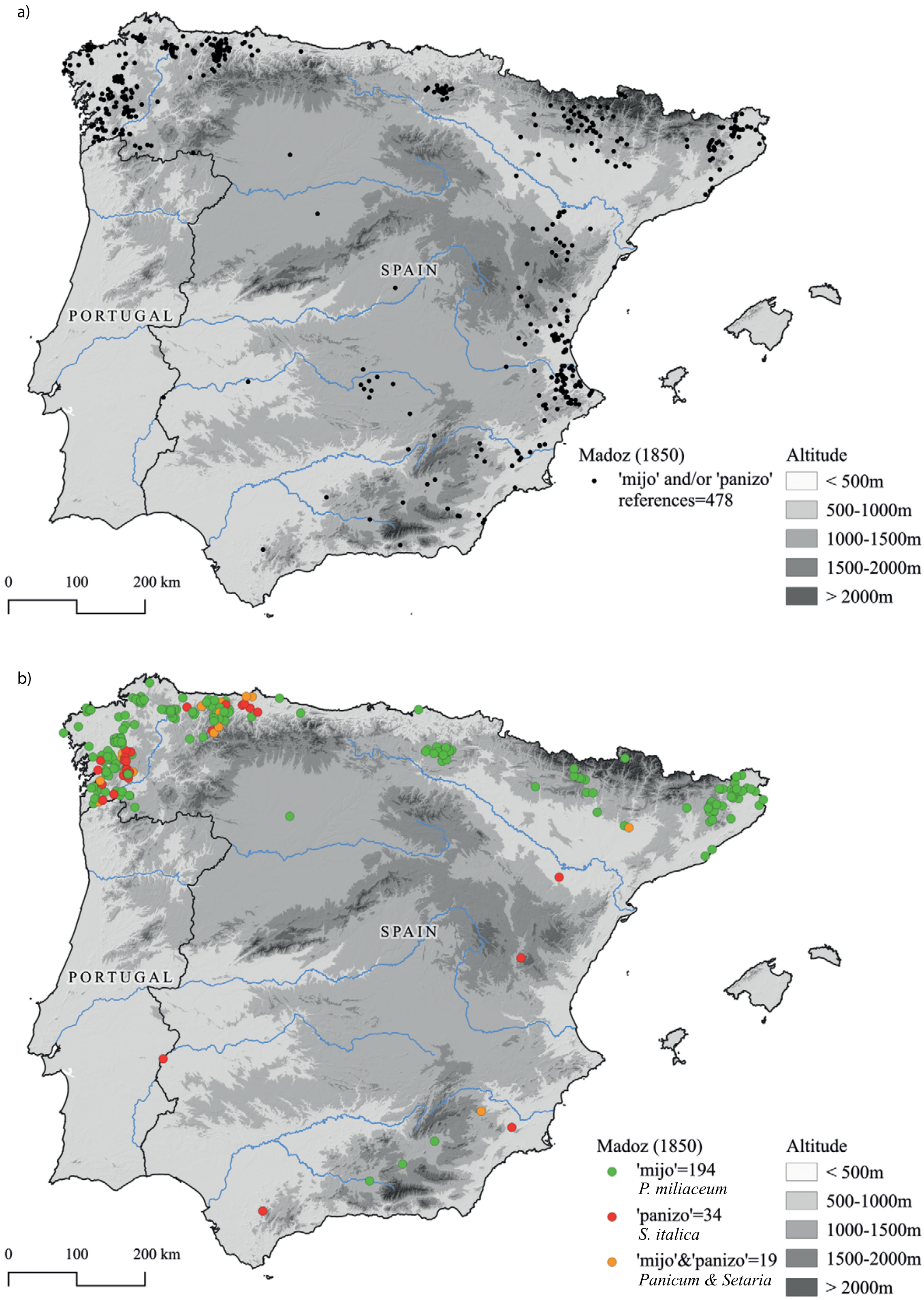


Figure 3. Millet cultivation in Spain according to the survey conducted by Pascual Madoz (1846-1850). a) references to 'mijo' and 'panizo'; b) filtered nomenclatures to separate out references to millets from probable references to maize.

Diversity of social networks and climatic determinants

Millets are resilient to a variety of agroclimatic challenges, require minimal energy input to yield grain, have a short growth cycle (of 50-90 days) and are well adapted to limited rainfall and poor soils. These characteristics allow their cultivation both in rainy seasons in semi-arid areas and in dry seasons in wet climates. The Iberian Peninsula has high contrasts in rainfall patterns. The southeast collects less than 300 mm per year, while several territories in the northwest and the north reach more than 2500 mm per year. The places studied in the ethnographic research are located within the area of the Atlantic oceanic climate, which has high rainfall. The information extracted from Madoz's survey also indicates that the humid regions of Spain are where cultivation of millets was the most well established until recently (Fig. 4). These are areas with high rainfall (1000-2500 mm per year). Millets are extremely rare in the Mediterranean climate region, except in the northeastern area which receives considerable summer rainfall. In central and southern Iberia, they are cultivated in rainy mountainous areas or in valley bottoms close to river courses. Accordingly, *Panicum miliaceum* and *Setaria italica* found their best agricultural niche in the dry seasons of wet areas, as summer crops. This is corroborated by the sowing seasons. In Asturias, traditional sowing of *S. italica* took place between the end of May and mid-June (Moreno-Larrazabal *et al.* 2015). In Galicia and northwestern Portugal, sowing of *P. miliaceum* took place later, from the first to the last week of June (Vázquez Varela 1994; Moreno-Larrazabal *et al.* 2015).

Although climate is a factor that determines agricultural decisions, a purely climate-based explanation is insufficient to interpret the complexity of the distribution of millet crops. This requires understanding their roles and their interaction with each element of each agricultural system. Communities have sought their own ways of exploiting the land. In Iberia, millet was more related to intensive farming systems than to extensive systems. Broadly speaking, traditional intensive agriculture occupied the northern area, that is, the area with the highest rainfall. Agricultural intensification, with higher inputs of labour, increased fertilisation, frequent rotation and crop diversification allowed high profits on small plots. The land was generally farmed by smallholders, usually from the same family group. Here, thanks to their adaptability, millets found a suitable niche for their cultivation. In the Mediterranean bioclimatic area, rainfall is concentrated in the winter months. Agriculture was focused on an extensive system geared towards the production of winter cereals, but with areas of intensive irrigated production (orchards) and forestry (fruit trees).

Family models, inheritance systems and land ownership or usufruct also exert strong influence on agricultural systems. Although investigating these aspects of archaeology is a difficult task, it is worth doing so ethnographically, because they play a crucial role in the choice of crops. The different systems of inheritance between the coastal and inland areas of Galicia during the Modern Age (16th-18th centuries CE) are a good example. In many areas of inland Galicia, inheritance to a single descendant predominates. Here, an extensive system based on winter cereals, such as rye and wheat, was maintained, together with the exploitation of silviculture species, such as vine and chestnut, which provided economic profitability. The widespread use of fallowing led to the need to preserve the patrimonial goods belonging to the household and to encourage a complex type of family organisation in the domestic group, necessary for extensive agricultural production (Sobrado Correa 2001). A double cereal harvest would mean overexploitation of the land, which was not in the group's best interest in the mid-term. Therefore, in these interior areas of Lugo, millet cultivation involved a single harvest per year.

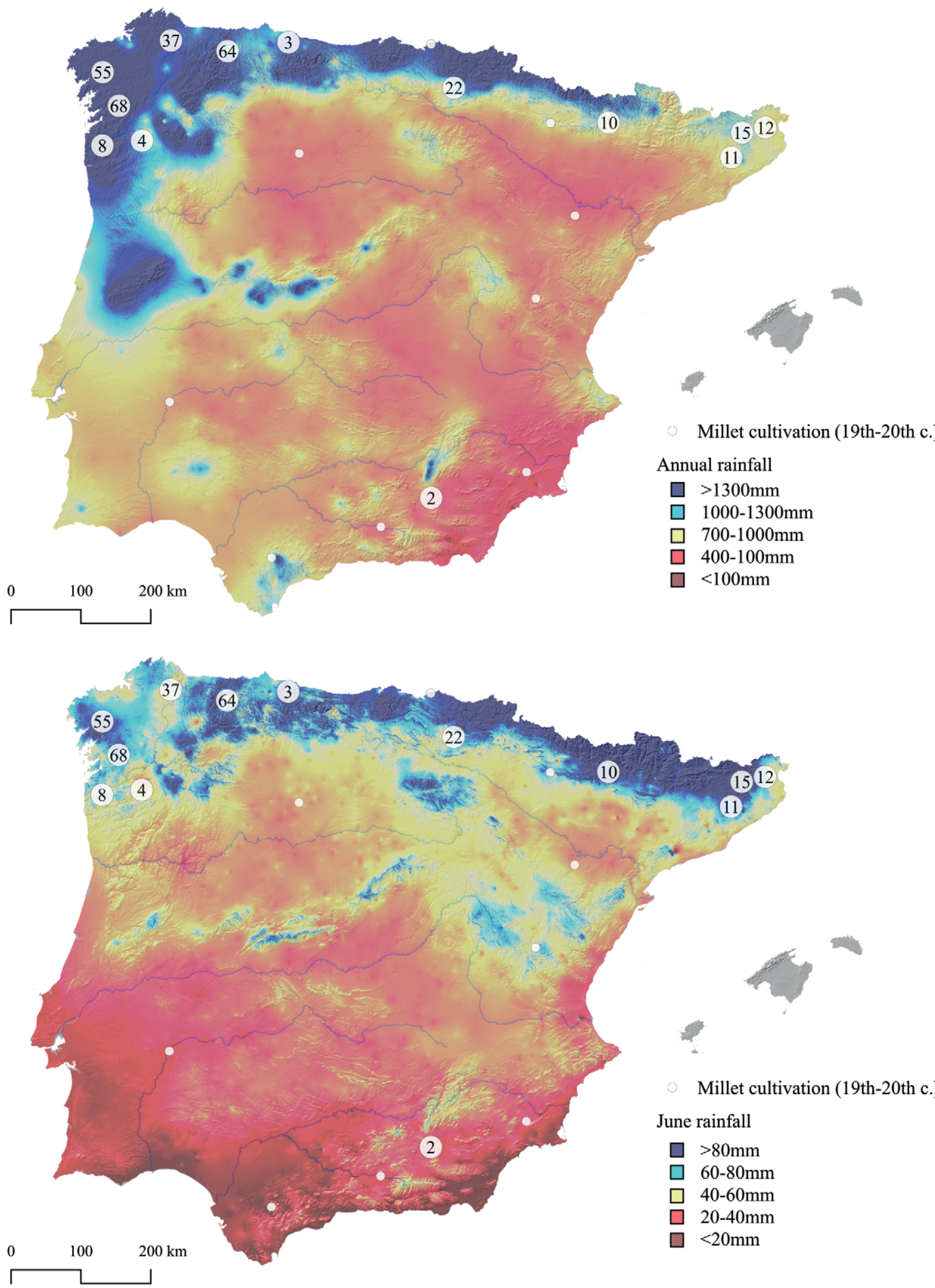


Figure 4. Rainfall in Spanish millet-growing areas since the 19th century, according to Ninyerola et al. (2005): a) annual rainfall; b) June rainfall.

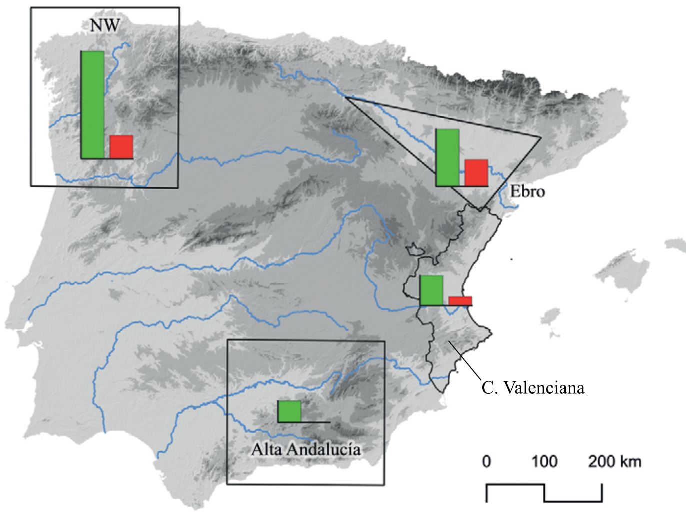
In the western area of Galicia, influenced by the coast and its surroundings, the inheritance system was more equitable. Generally, all the descendants received a portion of the land, although one of them received twice the amount of the others. Smallholder farming with reduced plot size is a characteristic element of agricultural production, which was balanced by intensive farming, rotation and diversification. In this system, the cultivation of millets would potentially be of greater interest thanks to their flexibility in crop rotation. The straw is of little interest as fodder, as the preferred method of livestock feeding was the production of pasture grass, alternated with the cultivation of oats, maize, vegetables or tubers, among others. This is where annual rye-broomcorn millet rotation was documented ethnographically (Fig. 1e). The written sources also mentioned this association and other rotations, at least since ca. 1600: winter cereal-broomcorn millet-fallow, winter cereal-turnips-broomcorn millet (Saavedra 2018). During the Modern Age, millets represented up to one third of the income received by the ecclesiastical institutions in many Galician coastal regions, until the arrival of maize, which displaced millets in importance starting with the economic crisis of 1627-1632 (Fernández Cortizo 1991).

Early millets in the Iberian Peninsula: Uneven adoption

In the previous chapters, different examples have been given of factors that may have influenced millet agriculture in the past and which point to situations different from an ideal picture of a uniform transmission of farming. In fact, it is common to find different spatial distributions and intensities of millet when analysing archaeobotanical assemblages. Some of the patterns mentioned can be traced back to protohistory (Fig. 5), but others seem to reflect a different trajectory.

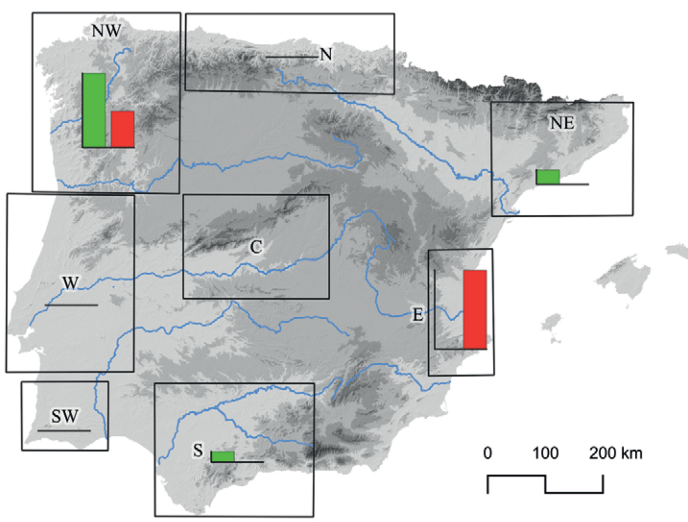
Archaeobotanical research indicates the possible early introduction of millets into the Iberian Peninsula around 1650-1300 BCE (cf. Alonso Martínez 2000b; Peña-Chocarro 2000; Tereso *et al.* 2016; Tarongi Chavarri 2017; Jesus *et al.* 2020), although the timing still needs to be tested by direct dating of the grains. Despite finds of some significant archaeobotanical assemblages (Alonso Martínez 2000b), their distribution does not yet provide us information about their differential acceptance by the communities of the Middle Bronze Age and Late Bronze Age.

For the 1st millennium BCE, regional overviews corroborate the great expansion and intensity of millet cultivation (Alonso Martínez 2000a; Pérez Jordá 2013; Tarongi Chavarri 2017; Teira Brión 2019). Territories in the northwest have the highest frequency per sample; here, *Panicum miliaceum* is the second-most ubiquitous crop (24.90%), right after *Triticum* spp. (Teira Brión 2019). Millets were fundamental crops within a balanced system incorporating winter cereals and spring cereals; a poorly diversified leguminous group centred on two species, broad bean (*Vicia faba*) and pea (*Pisum sativum*); and the management of wild forest resources, such as acorns. In other territories, it was also a common cereal. For example, in the Ebro River valley, the ubiquity of *P. miliaceum* is 13.3% and that of *Setaria italica* is 6.24% in the samples from the 1st millennium BCE (Tarongi Chavarri 2017). In the region of València, the ubiquity of broomcorn millet is 11.85% and that of foxtail millet is 5.67% (cf. Pérez Jordà 2013). In contrast, in Upper Andalusia, the frequency of both cereals is low (cf. Montes Moya 2014). Although they are generally well documented in the parts of Iberia with a Mediterranean climate, millets were secondary cereals here, coming after wheat, barley and fruits, such as the vine (*Vitis vinifera*) (Alonso Martínez 2000a; Tarongi Chavarri 2017). In these areas (the Mediterranean and southern regions), occupied by Iron Age communities known as the Iberians, agriculture was based on winter cereals, forestry practices that had been introduced by the Phoenicians (Pérez-Jordà *et al.* 2021), and a greater variability of legumes that can withstand dry



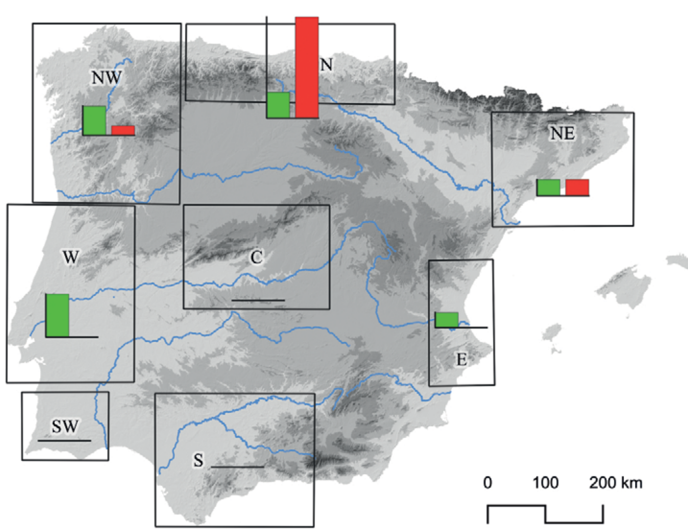
1st millennium BCE

Name	Sites	Samples	Ub. *P. mil*	Ub. *S. ita*
NW	36	554	24.9	5.41
Ebro	20	434	13.3	6.24
A. Andalucía	2	20	5	0
C. Valènciana	21	328	7.01	2.13



Roman Period (2nd/1st *c.*BCE-5th *c.*CE)

Name	Sites	Samples	Ub. *P. mil*	Ub. *S. ita*
NW	15	331	17.22	8.46
N	1	47	0	0
NE	11	132	3.33	0
W	2	2	0	0
E	5	82	0	18.29
SW	1	6	0	0
S	3	82	2.44	0



Middle Ages (5th-13th *c.*CE)

Name	Sites	Samples	Ub. *P. mil*	Ub. *S. ita*
NW	6	44	6.82	2.27
N	5	149	6.04	23.49
NE	20	290	3.79	3.79
W	8	50	10	0
C	6	53	0	0
E	10	85	3.53	0
SW	2	25	0	0
S	3	63	0	0

Figure 5. Ubiquity (Ub.) of Panicum miliaceum *(*P. mil*) and* Setaria italica *(*S. ita*) in Iberian archaeobotanical samples from the Iron Age (data from the databases by Pérez Jordá 2013; Montes Moya 2014; Tarongi Chavarri 2017; Teira Brión 2019), Roman period and Middle Ages (data from the database by Peña-Chocarro* et al. *2019).*

conditions, such as lentil or chickpea and bitter vetch (Buxó 1997; Alonso Martínez 2000a; Tarongi Chavarri 2017). In the Iberian south, one of the areas yielding the first documented *P. miliaceum* during the Bronze Age, the cultivation of millets seems to have been rare and had already declined during the Iron Age.

For the Roman period and the Middle Ages, we have information from 1353 archaeobotanical samples compiled in a recent synthesis of the entire Iberian Peninsula (Peña-Chocarro *et al.* 2019). Although there are areas that are poorly investigated, the data provide us with an excellent overview for understanding the distribution of millet cultivation. In both periods, millets played a more important role in the northern regions than in the central and southern areas of the peninsula. The high frequency of *Setaria italica* in the eastern region in Roman times and in the northern area in the Middle Ages can be interpreted as being the result of sampling bias, caused by the low number of samples taken and the consequent overrepresentation of some contexts. However, there seems to be no doubt that they were widespread cereals. Archaeological evidence indicates that northern Iberia would have been the area with the highest incidence of millets, and where they would have been more resilient to the changes introduced in agricultural systems over time. Also, it is important to note their significantly lesser importance and near-absence in many settlements in the south.

Despite the unequal evolution observed throughout these periods, we still cannot interpret the relative importance of each crop. Differences in specific practices may have been mediated by the decisions of each society regarding agricultural production, diet and the formation of each social or economic network and cultural tradition. In fact, carpological analyses hardly distinguish between uses, between fallow or crop rotation systems, and they do not tell us whether a double annual harvest is feasible, or even whether uses are similar throughout the Iberian Peninsula or are regionally differentiated. To investigate these questions, we still need the help of interdisciplinary approaches and regional case studies to allow the information obtained to be deciphered in the relevant social context. In this sense, millet research has been revitalised to address the questions of when and how it was consumed, based on the isotopic analysis of human bones. This research brings some interesting results, some of which were also observed using the ethnographic approach and some of which have revealed important dietary novelties. For example, isotopic evidence from the Iron Age village of La Hoya suggests that C4 cereals may have played a role in infant and child feeding, being consumed during the weaning period, probably as porridge (Fernández-Crespo *et al.* 2019). Isotope studies show significant disparities in millet consumption, which reflect: 1) regional and local differences (Lubritto *et al.* 2017; López-Costas and Alexander 2019); 2) preferential ingestion by middle- to lower-class (López-Costas and Müldner 2019) or high-status members (Toso *et al.* 2019); 3) distinct intakes between childhood and adulthood (Dury *et al.* 2019); 4) gender differences in adult diet, with higher C4 values among women (Alaica *et al.* 2019) or men (Toso *et al.* 2019); and 5) food preparation based on a combination of C3 and C4 crops in the diet of dogs (Albizuri *et al.* 2021).

Conclusions

In this text, I have aimed to draw attention to the problems that result from uncritically transferring some ethnography-based statements made in the present to the past. The evolution of millets in the Iberian Peninsula shows different developments based on each agricultural system and the aspects such as the land use, rotation, crops, property and type of family that condition the importance of their incorporation. All these practices involve societies in different ways and require diverse social and productive organisations – aspects that also influence the present that we study through ethnoarchaeology.

Not everything we observe necessarily has ancient roots; some things may be linked to practice transformations that are closer in time. Adaptive changes happen within a short or long period. It is a complex and laborious task to untangle at what point many practices we observe could have taken place in the past. It is the human being who decides on the agricultural system and the obtaining of resources, and who ultimately chooses, harmonises and selects some uses and some crops over others. The examples in the previous chapters indicate behaviours inherent to extensive or intensive farming systems, which cannot be understood in isolation from possible soil and climate conditions (optimal growing period) or independently from the uses given by each community.

Carpological results by themselves do not support certain views which are held in research about the introduction of millets into European agriculture: the hypothesis of double annual cereal production simply because of the coexistence of millets with other cereals, and the hypothesis about the increase in agricultural production. These two statements can only be evaluated by assessing all the elements which make up each agricultural system.

During the past four millennia, since the introduction of millets in the Iberian Peninsula, some trends have endured over the long term, despite the social and technological changes that continue until the present day. We can attribute this to the adaptability of millets, which has allowed them to be resilient to changes in socio-economic models. We should not forget the role of the transmission of traditional knowledge in peasant societies, which implies mechanisms, adaptations and the transmission of know-how that regulate the practices of each community both socially and culturally, and which are used to respond to the environment and guide the management of resources (Berkes *et al.* 2000). The knowledge of millet cultivation would have survived until the arrival of changes leading to a quick or progressive transformation of the agricultural system, until the substitution of their role as essential cereals or as secondary crops. Therefore, one of the aspects we can consider as important is to establish the chronological depth of the practices we are studying.

When studying millet farming, we must apply a multidisciplinary and multiscale approach in order to accommodate different settings. It is in this context that the contribution of ethnoarchaeology can be crucial, giving us guidelines on which social aspects we need to heed and which particular material elements to analyse. Ethnographic results should not be taken only as the standardisation of ideas that highlight those elements that are most interesting from our point of view. The picture created through ethnography is a construct that must contemplate a diversity of practices in a constant process of construction. In conclusion, if millets have a transformative power in agriculture and diet, we must understand how they are embedded in each agricultural system and society.

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Versatile usage of millet: Brooms and animal fodder from *Sorghum technicum*

Wiebke Kirleis and Marta Dal Corso

Abstract

On a field survey in northwestern Moldova in August 2019, when searching for archives for palynological investigations, we passed by fields of *Sorghum technicum* and had the good fortune of meeting local farmers on the fields, who introduced us into a very special local tradition. The growing of *Sorghum technicum* is directly linked with the production of sorghum brooms in the nearby village of Cărăcuşenii Vechi. Tying sorghum brooms is a highly specialised craft that in modern times is rarely encountered. Therefore, we decided to share our observations and take the opportunity to document small-scale, traditional broom production in Moldova.

Introduction

Sorghum and millets are commonly used for human consumption or as animal fodder. Here we focus on the special breed *Sorghum technicum* and document its cultivation, harvesting and processing in the vicinity of the village of Caracușenii Vechi (Briceni district), in northwestern Moldova, in 2019. The crop's name is already indicative of its main purpose, that is, a technical use. *Sorghum technicum* is the basic resource for organic broom production. The by-products, in this case the leaves and the grains, serve as animal fodder. In Caracușenii Vechi, the tradition of manufacturing sorghum brooms is kept alive in small, family-owned workshops. In addition to Moldova, there are other places in eastern Europe, Thailand and China where organic sorghum broom production takes place, one further example being EcoBrooms, in the Vojvodina, in Serbia (Taylor *et al.* 2019, 414). In Bulgaria, *Sorghum bicolor* is referred to as the crop for broom making (Nedelcheva *et al.* 2007).

Sorghum technicum is a C4 plant, and its growth habitus is reminiscent of maize (*Zea mays*), which is taxonomically and genetically a close relative of all *Sorghum* species. It grows up to 3 m high, and its pendant panicle reaches lengths of 60 cm

Figure 1. Sorghum technicum, *exhibiting the growth habitus of a typical C4 plant, such as maize (photo: Wiebke Kirleis).*

Figure 2. Sorghum technicum *panicle (photo: Marta Dal Corso).*

(Figs. 1 and 2). It is a macro-thermal crop (or summer crop), which at Caracușenii Vechi was seeded in April and harvested at the end of August.

Different from maize, which originates in the Americas, sorghum originates in Africa and was domesticated ca. 3000 BCE (Fuller and Stevens 2018; Winchel *et al.* 2018). From there it spread to India and China (Liu *et al.* 2019), and in a later stage of history it reached the Americas by means of ships transporting enslaved people (Taylor 2019). Botanically, it belongs to the Panicoideae subfamily of the Andropogoneaea tribe, which is in the Poaceae family. The classification within the genus *Sorghum* is very complex. According to De Wet and Harlan (1971; USDA Germplasm Resources Information Network), all cultivated sorghum species belong

Figure 3. Single plants of Sorghum technicum *towering above the arable field (photo: Marta Dal Corso).*

to *Sorghum bicolor* ssp. *bicolor.* However, a huge genetic diversity is observed within the genus *Sorghum,* as gene flow occurs freely between cultivars as well as between the genus *Sorghum* and its wild and weedy relatives (Taylor 2019). In Caracușenii Vechi, such diversity is expressed by single plants, towering above the field (Fig. 3).

In the Mansfeld World Database of Agricultural and Horticultural Crops (Schultze-Motel 1986; IPK Gatersleben 2020), *Sorghum technicum* is listed as *Sorghum saccharatum* convar. *technicum* (Koern.) Tzvelev in Novosti sist. vyss. rast. vol. 5, 15. 1968, with several synonyms:

1. *Holcus sorghum* var. *technicus* L.H. Bailey, Gentes Herb. vol. 1, 132. 1923.
2. *Andropogon sorghum* var. *technicus* Hack. ex A. DC. & C. DC., Monogr. phan. vol. 6, 508. 1889.
3. *Sorghum vulgare* var. *technicum* Fiori & Paol., Fl. Italia vol. 1, 46. 1896.
4. *Sorghum technicum* Battand. & Trab., Fl. Algerie Monocot., 128. 1895.
5. *Andropogon sorghum* var. *technicus* Koern., Handb. Getreideb. vol. 1, 308. 1885.
6. *Sorghum dochna* var. *technicum* Snowden in Kew Bull., 235. 1935.

From millet to broom: *Chaîne opératoire* of broom making in northwestern Moldova

In the vicinity of Caracușenii Vechi, sorghum is grown in monoculture on small, family-owned or leased fields some hectares in extent. In 2019, harvesting took place in late August, before the rainy season started. The long stalks were harvested either by hand, using a sickle or a scythe (Fig. 4), or with the aid of large machines. The stalks cut by the harvesting machine are left for 3-4 days to dry on the field, before being manually picked from the ground (Fig. 5) and transferred to small heaps in a shady location along the edge of the field.

In 2019, the harvesting was organised with several family members gathering in the village and collectively working on the field. Other people from the community joined in for further on-field processing of the plants. Tasks did not appear to be gendered: adult men and women of diverse age classes worked together. The next

Figure 4. Harvesting sorghum with a scythe (photo: Wiebke Kirleis).

Figure 5. Post-mechanical cutting: a family collecting the plants on the arable field (photo: Wiebke Kirleis).

Figure 6a. Collective labour: defoliating the plants on the arable field (photo: Wiebke Kirleis).

Figure 6b. Defoliating the plants on the arable field (photo: Wiebke Kirleis).

step, after collection of the dry stalks and piling them up into small heaps, is to defoliate the stalks. Individuals were responsible for defoliating the stalks of each sorghum heap (Fig. 6a-b).

After the stalks have been defoliated, they are bundled and stacked (Figs. 7-8). The leaves, being a by-product, are piled into heaps beneath the stacked sorghum bundles. The bundled sorghum is then taken to the village (Fig. 8).

The next stages of processing of the sorghum bundles take place in the village. Bundle after bundle of sorghum is treated with a mechanical threshing machine. The panicles are fed into the machine and the grains are released and caught in small containers. The grains serve as animal fodder, and the threshed bundles are

Figure 7. Defoliated bundles, and leaves representing a by-product (photo: Wiebke Kirleis).

Figure 8. Defoliated bundles, detail (photo: Marta Dal Corso).

Figure 9. Transport of the bundles to the village (photo: Wiebke Kirleis).

Figure 10a. Bundles after mechanical threshing, ready for broom production (photo: Wiebke Kirleis).

Figure 10b. Detail: threshed panicles with some remaining fruits (photo: Wiebke Kirleis).

positioned alongside fences along the streets to for further drying before they are distributed to the workshops for tying into brooms (Figs. 10a-b and 11).

The tying of brooms takes place as mass production in small, specialist workshops or is individually organised as a hobby during long winter evenings spent tying nicely decorated prestige brooms (Fig. 12a-b).

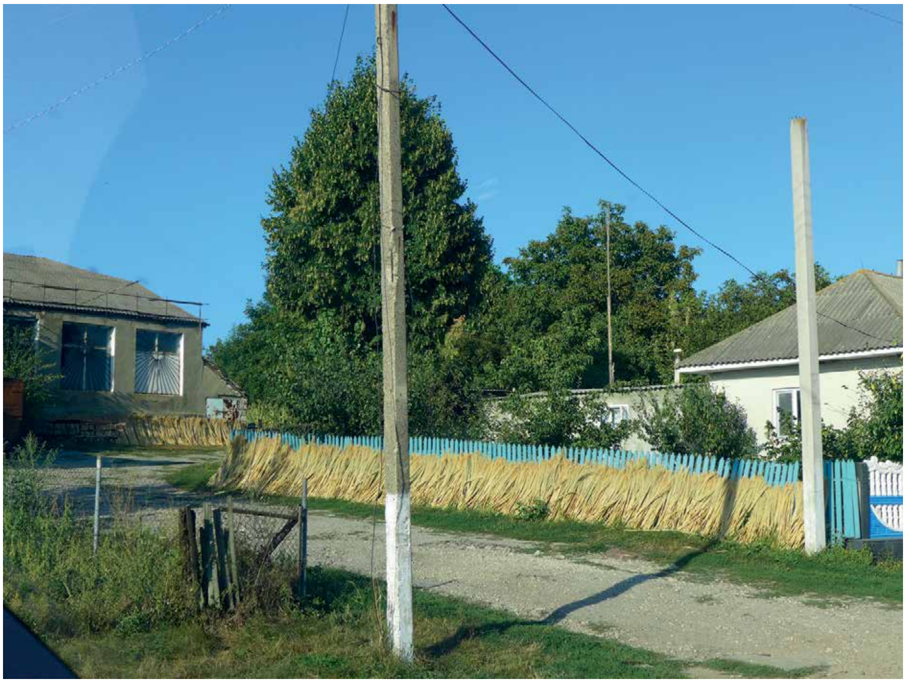

Figure 11. Drying of threshed bundles of Sorghum technicum *in the village of Caracușenii Vechi, Moldova (photo: Marta Dal Corso).*

Figure 12a. Broommakers' workshop (photo: Wiebke Kirleis).

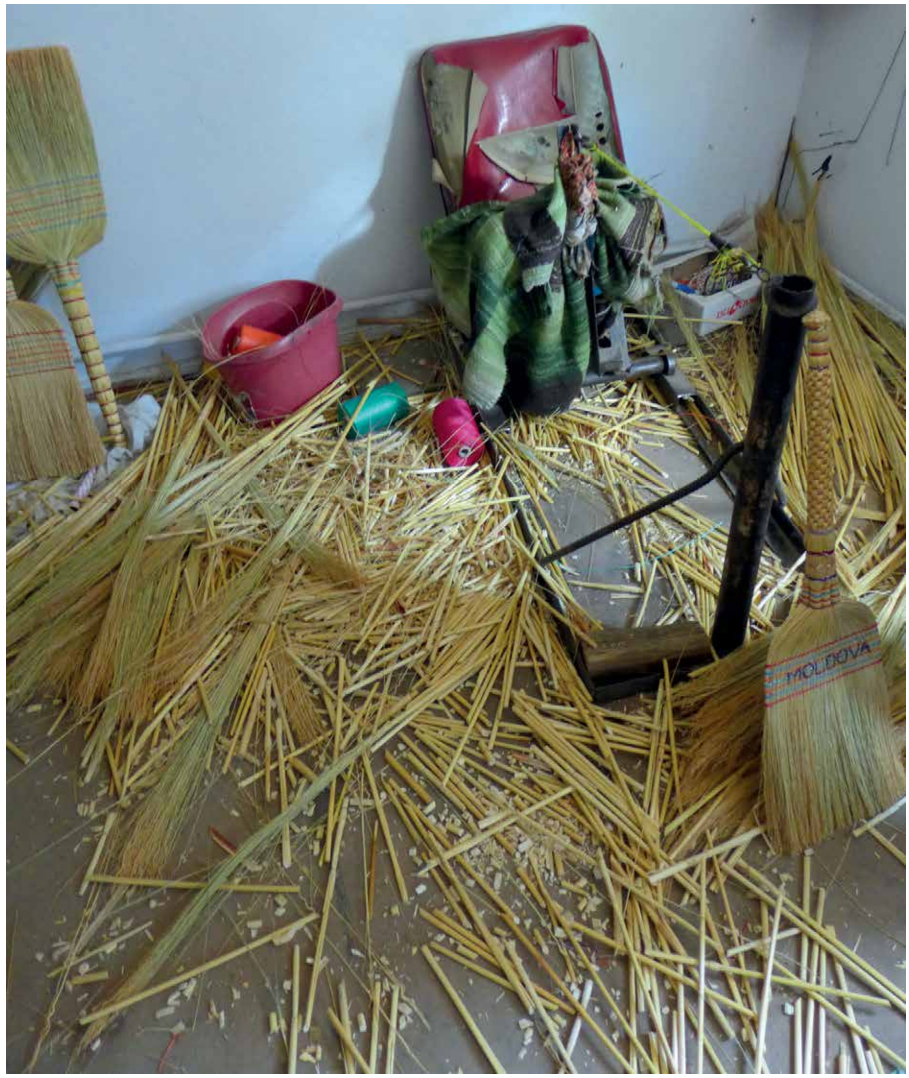

Figure 12b. Special chair with construction for clamping the broom while cording it (photo: Marta Dal Corso).

Tying of the brooms in Caracușenii Vechi starts with combining some bundles and clamping them in a specific chair construction to achieve compact brooms (Fig. 12a-b). In this construction, the bundles are corded to fix the broom's handle. Afterwards, the handle's rough end is cut off. Then the loose ends of the threshed panicles still have to be fashioned into the shape of a broom. Afterwards, they are cut off straight. This is the final stage of the mass production of simple sorghum brooms (Figs. 13-14).

Figure 13. Storage of simple sorghum brooms in the workshop (photo: Marta Dal Corso).

Figure 14. Sale of custom sorghum brooms (photo: Marta Dal Corso).

Figure 15. Prestige sorghum broom with embroidered text, which translates as 'My village with people, hardworking, beautiful, good, Caracuşenii Vechi' (photo: Wiebke Kirleis).

To obtain more sophisticated brooms, the handles are sometimes plaited. Further, stitching is done to keep the broom flat. Some brooms even represent prestige items, with embroidery, being one expression of cultural identity. Nowadays these are used to decorate the walls of homes, serve as talisman to bring luck, are given as a souvenir to family members moving away to the cities or abroad, or are sold at traditional handicraft markets (Fig. 15).

Concluding remarks

The aim of this contribution on the uses of *Sorghum technicum* is twofold. First, it documents the cultivation of a specific crop directly linked to traditional handicrafts, in particular the *chaîne opératoire* from sorghum harvesting to the tying of brooms. The technical processing of sorghum reflects different sociocultural and economic aspects of life. It gives insight into plant use and related techniques, related social organisation, and related cultural value. Second, viewed from an archaeological perspective, organic brooms belong to the perishable material culture. They rarely survive in archaeological deposits (Nedelcheva *et al.* 2007; Hurcombe 2014). The documentation presented here is a reminder for the archaeological community when reconstructing former routine activities to consider multiple human-plant relationships that extend beyond dietary aspects. Lateral thinking is required to reconstruct the missing parts.

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CONCLUSION: Early cultivation of millet in Europe: What else and where next? Concluding the workshop proceedings

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Millet and what else?

In much of Europe, broomcorn/common/proso millet (*Panicum miliaceum*; Fig. 1) is nowadays still primarily considered as animal feed (*e.g.* bird feed) and is rarely grown. With the modern-day climate change requiring new agrarian solutions, this and other millets are regaining importance because of their adaptability to sub-optimal to poor growing conditions. There have, for instance, been calls to start cultivation of pearl millet (*Pennisetum glaucum*) or sorghum (*Sorghum*) in the Po valley[1], in northern Serbia, in the Czech Republic (Hermuth *et al.* 2016) and elsewhere in Europe, and also in Asia and Africa[2], to counter crop failure caused by drought.

Both previous and most recent multidisciplinary research has shown that millet has been cultivated in Europe since the middle of the 2nd millennium BCE, that is, the Middle or the Late/Recent Bronze Age (depending on the part of Europe). It has since then been consumed by both humans and animals. What do we know about the history of this crop on the continent? The workshop that took place in Kiel in November 2019 aimed to start the conversation on the circumstances and consequences of early broomcorn millet cultivation in Europe. The focus was mainly on the Bronze Age subsistence economy in different regions, and on changes in this economy potentially linked with the integration of this new crop into the pre-existing spectrum of cultivars. But participants also shared knowledge on aspects of the recent and modern-day growing of millet in Europe and on other continents; on traditional millet-based cuisine; on conventional and state-of-the-art

1 https://www.plantagbiosciences.org/people/matteo-petitti/2017/08/27/drought-proof-crops-in-italy-is-millet-the-grain-of-the-future/

2 One of the workshop participants, Dr Stefania Grando of the International Crops Research Institute for the Semi-arid Tropics (ICRISAT) presented initiatives and projects aimed at promoting the cultivation of resilient crops and educating the farmers. See more at https://www.icrisat.org/

Figure 1. Broomcorn millet experimentally grown at the Archäologisch-Ökologisches Zentrum Albersdorf, Schleswig-Holstein, Germany (photo: Wiebke Kirleis).

(*i.e.* biogeochemical) methods of detecting millet in archaeological layers; and on the biology and physiology of millet. Even animals were brought into the picture, since millet was, and still is, used in animal husbandry.

This book brings together many of the workshop papers, reflecting the array of topics and research areas that the workshop covered. The contributions inform us on the range of cultivated and collected plants from the time before and after the start of millet cultivation in Europe; present the cultural setting in which millet arrived; discuss possible reasons driving the acceptance of this innovation; and reconstruct possible uses of millet and the methods of its cultivation, processing and storage. Not just the plant, but also the animal economy is represented, offering an integrated view of the Bronze Age food economy. Techniques used to trace millet archaeologically continue to be developed or improved, and this book describes the application of a few of them. This broad-based collection of papers demonstrates the complexity of the theme of the workshop, and of the research on the diffusion of agricultural innovations in general. As such, and together with the older and recent, ever-growing literature discussing millets in Eurasia, this book adds another layer to the dynamic picture of the interconnected continents.

The spread of millet is a spectacular display of the power of human interaction. The adaptability and resilience of the plant may have been the main reasons for its successful integration into pre-existing farming systems. This innovation was a cog in the wheel of the economic, political and social transformation in Bronze Age Europe.

Millet in Europe: Where from?

The history of the spread of millet is as complex as the physical features of the land it was carried over and through after its domestication in northeastern China (Fig. 2). Possible roads that millet took across the continents have been proposed based on the isotopic, radiocarbon or archaeobotanical evidence, or a combination thereof (*e.g.* Spengler *et al.* 2014; Stevens *et al.* 2016; Wang *et al.* 2017), but the location of its last stop in Asia before entering Europe is still unclear.

There is now substantial evidence that the earliest cultivation and domestication of broomcorn millet happened in northeast China, in the lower reaches of the Yellow River, at the latest by around 6000 BCE (Motuzaitė Matuzevičiūtė and Liu 2021). This coincided with and may have led to the formation of Neolithic cultures in northern China. According to the radiocarbon dates on millet grains from the sites in this and

Figure 2. Map of Eurasia indicating locations and regions (marked in brown) with early records of broomcorn millet mentioned in the text (base map © OpenStreetMap contributors; map: Dragana Filipović): 1. Begash, 2. Tasbas, 3. Dali, 4. Pethpuran Teng, 5. Adji Kui 1, 6. Ojakly, 7. Namcheduri, 8. Kabardinka-2, 9. Chishkho (Чишхо), 10. Guamsky Grot (Гуамский грот), 11. Safyanovo, 12. Sos Höyük, 13. Haftavan, 14. Malyan, 15. Kaneš in Kültepe, 16. Kinet Höyük, 17. Kilise Tepe, 18. Ḫattuša, 19. Troy, 20. Vinogradnyi Sad (Виноградний Сад), 21. Assiros Toumba, 22. Măgura-Buduiasca, 23. Kastanas.

adjacent regions, recently compiled by Leipe *et al.* (2019), it appears that, for a couple of millennia, millet cultivation was restricted to the region of origin. The practice was transferred to north-central China (the upper courses of the Yellow River) by the end of the 4th millennium BCE. The network through which broomcorn millet was transmitted westward extended from the Yellow River via the Gansu Corridor between the Tibetan and the Loess (Huangtu) Plateau, on to the 'Inner Asian Mountain Corridor' (IAMC), stretching between the southwestern slopes of the Altai Mountains and the middle course of the Amu Darya River (present-day Uzbekistan), and bordered by the central Eurasian steppes in the northwest and the Tarim River basin in the southeast (Frachetti 2012; Spengler *et al.* 2014; Jones *et al.* 2016; Stevens *et al.* 2016; Wang *et al.* 2017; Hermes *et al.* 2019; Liu *et al.* 2019).

It appears that it took several centuries for millet to reach the western parts of central Asia, at least based on the dates obtained on millet grains from sites in Kazakhstan, the Kashmir valley and Turkmenistan. About halfway along the IAMC, the AMS-date on charred grains from a burial cist at the pastoralist campsite of Begash in southeastern Kazakhstan (Dzhungar Mountains) demonstrates the presence of broomcorn millet here in the mid- to late 3rd millennium BCE. Millet grains from the neighbouring site of Tasbas are probably of a similar age (Frachetti *et al.* 2010; Spengler *et al.* 2014). The stable isotope evidence from the livestock herded at the nearby settlement of Dali in the early-mid 3rd millennium BCE was interpreted as reflecting the consumption of millet (Hermes *et al.* 2019), implying that millet was already being used (as fodder) in this location at this time. It is suggested that the mobile pastoralists roaming these regions acted as a medium for the spread of the crop (Frachetti *et al.* 2010; Spengler *et al.* 2014). Southeast of this region, similarly early millet dates (from the mid-3rd millennium BCE) were reported from the site of Pethpuran Teng in the Kashmir valley (Yatoo *et al.* 2020).

According to the stable isotope values in humans and livestock from pastoralist sites located in north-central Kazakhstan, to the north and northwest of the IAMC, there was no to very little millet consumption (by animals) in the late 2nd millennium BCE and slightly more (by humans) at the turn of the millennium. Farther to the northwest, in the Trans-Urals, millet is not recorded in the diet of pastoralist groups from the 2nd and first half of the 1st millennium BCE (Motuzaite-Matuzeviciute *et al.* 2015; Wang *et al.* 2017; Ventresca Miller and Makarewicz 2019; Ananyevskaya *et al.* 2020). It is absent in the archaeobotanical record before the very end of the 2nd millennium BCE, and perhaps it is absent until even later (Ryabogina and Ivanov 2011; Rühl *et al.* 2015).

In southern central Asia (present-day Turkmenistan), archaeobotanical studies and direct radiocarbon dates document the presence of broomcorn millet starting from the end of the 3rd millennium BCE at the earliest and with certainty by the second quarter of the 2nd millennium BCE (*e.g.* at the sites of Adji Kui 1 and Ojakly in the Murghab alluvial fan; Spengler *et al.* 2016, 2018). For much of the 2nd millennium BCE, large parts of southwestern central Asia were home to agricultural communities living in urban centres and to mobile pastoralists occupying small campsites, constituting and interacting within what is known as the Oxus civilisation (Rouse 2020). It is understood that the mobile pastoralists, who engaged in farming as part of their lifestyle, introduced millet to the sedentary populations. The latter incorporated it into their cultivation system, utilising the crop as both human food and animal fodder (Spengler *et al.* 2014; cf. Anthony 2007; Frachetti 2008).

From central Asia, the millet route may have forked to run to the north and south of the Caspian Sea (Jones *et al.* 2016; Wang *et al.* 2017) but perhaps at very different times, since the stable isotopic evidence from northern and central Kazakhstan does not show C4 signals in humans or animals before the late 2nd millennium BCE (Motuzaite-Matuzeviciute *et al.* 2015; Ananyevskaya *et al.* 2020). To the south, towards the Iranian Plateau, broomcorn millet transmission could have followed long-known north-south trade routes. These are marked by fortified settlements along the northern foothills of the Kopet Dag mountain chain, and they connected the steppe communities with the proto-urban centres in Mesopotamia (*e.g.* Weeks 2003; Lecomte 2012). Absolute dates are not yet available for archaeobotanical finds of millet from sites along the southwestern coast of the Caspian Sea. Nonetheless, according to the associated archaeological finds, they derived earliest from about 1550 BCE (the site of Haftavan – Nesbitt and Summers 1988; see also Miller 2015; Stevens *et al.* 2016). A few grains recorded as '*Panicum* sp.' from the multi-period site of Malyan in the southern Zagros mountains (roughly end of the 3rd/first half of the 2nd millennium BCE based on the pottery [Miller 1982 cited in Nesbitt and Summers 1988, Table 2]) are likely of uncertain identification, as they were not reported in recent publications (*e.g.* Miller 2015; Miller *et al.* 2016).

West of the Caspian Sea, in the southern Caucasus region, the earliest recorded archaeobotanical finds of broomcorn millet come from the Late Bronze Age (1500-1100 BCE; Hovsepyan 2015). Recently, a project has been completed that combined archaeobotanical and stable isotopic analyses and radiocarbon dating of grains of broomcorn and foxtail (*Setaria italica*) millet from prehistoric (Neolithic through Iron Age) sites in the Caucasus (Herrscher *et al.* 2018a-b; Martin *et al.* 2021). The results point to the middle of the 2nd millennium BCE (Middle-Late Bronze Age) as the earliest possible time when broomcorn millet could have come into cultivation/use; the earliest obtained date is that on *P. miliaceum* from the site of Namcheduri in Georgia (Poz-66777, 3150±35 BP, 2σ 1501-1305 cal BCE; Martin *et al.* 2021, SI Appendix Table S2). Stable carbon isotope analysis of humans and animals from the Caucasus confirms this finding, particularly in the case of humans, in which a significant increase in $\delta^{13}C$ values is seen from the Late Bronze Age onwards (Martin *et al.* 2021).

A cross-Caucasian diffusion of millet into Europe is plausible given the continuous communication and cultural connection between the areas south and north of the Caucasus mountains, which intensified from the mid-2nd millennium BCE onwards (Sagona 2018, 378-379, 422). However, just before this time, only mountain plateaus seem to have been occupied in the northern Caucasus, whereas the foothills and the steppe areas immediately to the north were apparently uninhabited, perhaps due to the adverse living conditions that developed here following the 4.2k BP event (Knipper *et al.* 2020, 5). The site of Kabardinka-2 in the Kislovodsk region of the Northern Caucasus yielded millet grains dated to the last quarter of the 2nd millennium BCE (Poz-82838, 2950±30 BP, 2σ 1260-1051 cal BCE; Martin *et al.* 2021).

Farther north, in the lower Don River valley, numerous settlement sites and graves of the Late Bronze Age Srubnaya culture (1900-1500/1400 BCE) are recorded, indicating dense occupation and use of the river valleys and the surrounding dry steppe (Chernykh 1992; Anthony *et al.* 2005; Van Hoof *et al.* 2012). Limited archaeobotanical recovery at Srubnaya culture sites shows the presence of cereals including broomcorn millet, but the remains have not been dated (Лебедева 2005). West of this culture, between the Azov Sea and the lower Dnieper River, lived the partly contemporaneous Late Bronze Age Sabatinovka culture (1600-1300/1200 BCE). Sabatinovka culture sites also yielded millet, and the grains from one of them (Vinogradniy Sad, Ukraine) gave mid-2nd millennium BCE dates, which are currently the earliest in Europe (Filipović *et al.* 2020; Dal Corso *et al.* 2022).

By around 1400 BCE, in the broader region of the Don Delta, the Srubnaya cultural tradition was replaced by the Kobyakovo culture (1400/1300-1000 BCE), which is thought to have developed in the northwestern Caucasus, in the Kuban River valley. The Kobyakovo culture may have facilitated the diffusion of millet to the north. Occasional millet grains have been discovered at a few sites in the Kuban River area (Лебедева 2011, Table 2; Trifonov *et al.* 2017); one from the site of Chishkho was dated earliest to the 14th century BCE (Poz-82836, 3000±30 BP, 2σ 1377-1126 cal BCE; Martin *et al.* 2021). A little to the south, at the Guamsky Grot rock shelter, a concentration of millet grains was radiocarbon dated to 12th-10th century BCE (Trifonov *et al.* 2017).

North of the northwestern Caucasus, millet grains were discovered at the Kobyakovo culture settlement in Safyanovo on the Don River (Van Hoof *et al.* 2012, 73). According to the results of the stable isotope analysis so far, it was at the very end of the 2nd millennium BCE (start of the Early Iron Age) that millet consumption began on the northern slopes of the Caucasus (Hollund *et al.* 2010; Fuchs 2020; Knipper *et al.* 2020). This was almost half a millennium after millet arrived both in the southern Caucasus and in southwestern Ukraine. It thus remains unclear whether the northern/northwestern Caucasus was an early millet transition zone or whether it received the new crop later than the neighbouring regions. In addition, given the near-synchronous finds of millet in the southern Caucasus and southern Ukraine, it cannot yet be concluded whether the crop translocation proceeded south-north or north-south or whether instead or in addition to the cross-Caucasus route(s), this traffic was expedited via the Black Sea and the Crimean peninsula. That the so far earliest dated find of millet in the southern Caucasus comes from a site on the Black Sea coast (Namcheduri in Georgia; Martin *et al.* 2021) may point to the seaborne crop transfer.

The apparent absence of early (*e.g.* early to mid-2nd millennium BCE) millet south and southwest of the southern Caucasus and the Armenian highlands is, perhaps, illuminating and may suggest that millet cultivation and consumption were initially confined to only some regions. There are several sites in Anatolia with early broomcorn millet finds and their archaeological context indicates that they are unlikely to be older than the mid-2nd millennium BCE (Nesbitt and Summers 1988; Riehl 1999; Miller *et al.* 2016; Stevens *et al.* 2016). The recently obtained radiocarbon dates on millet grains from Sos Höyük, located in the highlands of northeastern Turkey, comply with this impression, as they fall in the last quarter of the 2nd millennium BCE (Poz-66780, 2945±35 BP, 2σ 1261-1039 cal BCE and Poz-66781, 2960±35 BP, 2σ 1276-1051 cal BCE; Martin *et al.* 2021). Stable isotopic measurements on human and animal samples from several 3rd millennium BCE sites (regional Early Bronze Age) in Anatolia do not point to regular consumption of C4 plants; the slightly more positive $\delta^{13}C$ values in some of the analysed faunal remains probably result from wild C4 forage (Irvine *et al.* 2019), which is abundant in this region and known to have contributed to animal diet from the Early Neolithic (*e.g.* Richards and Pearson 2005; Filipović 2014). It appears that broomcorn millet did not enter the Assyrian trade network operating in the first half of the 2nd millennium BCE (regional Middle Bronze Age) in Anatolia, judging by its absence from the major administrative and trade centre, the ancient city of Kaneš in Kültepe, central Turkey (Fairbairn *et al.* 2013; Fairbairn 2014). There were several millet grains in the Middle Bronze Age layer at Kinet Höyük in northern Levant (http://www.ademnes.de), but, without a radiocarbon date and with the later (Iron Age, early 1st millennium BCE) occupation of the site also yielding millet, the age of these finds is uncertain. At the neighbouring Bronze and Iron Age site of Kilise Tepe, millet grains (identified as *Panicum/Setaria* spp.) occur from the 12th century BCE onwards (Bending and Colledge 2007, 588).

For the Hittite kingdom (1650-1190 BCE, regional Late Bronze Age; Bryce 2005), the historical texts describe wheat and barley as staple foods, but do not mention millets (Hoffner 2003; Bryce 2005). This is in line with the absence of broomcorn millet from the immense grain storage facility in the capital of Hattuša, which burnt in the early 16th century BCE (Neef 2001; Diffey *et al.* 2017), as well as from the archaeobotanical record from much of the second half of the 2nd millennium BCE in Anatolia (Nesbitt and Summers 1988; Fairbairn and Bradley 2008; Dörfler *et al.* 2011; Fairbairn *et al.* 2018). At the northwestern tip of Anatolia, at Troy, small quantities of broomcorn millet grain were discovered in several occupation layers, but no earlier than phase Troy VI (1700-1250 BCE; Riehl 1999, 9, 46) and mainly in phase VII (starting at *ca.* 1250 BCE; Riehl 1999, 9; http://www.ademnes.de). Nesbitt and Summers (1988, 94-95) consider the possibility that broomcorn millet entered Anatolia from the north, via Transcaucasia, as more likely than that it entered from the west (or east), although they acknowledge the scarcity of the archaeobotanical record and the chronological gaps. The gaps still exist, and one should allow for the possibility that the new crop, once in the region, could have circulated within the Aegean Basin both in north-south (Valamoti 2016) and in west-east direction.

The nearest directly dated millet to Troy/Anatolia comes from the Late Bronze Age site of Assiros Toumba, in Greece, 300 km to the northwest, where large grain stores were discovered in dedicated store-rooms (Jones *et al.* 1986); the millet date falls in the 14th century BCE (Wardle *et al.* 2014). Akin to the situation Anatolia, the stable isotope values for animals and humans in mainland and northern Greece do not suggest consumption of millet during the 3rd and most of the first half of the 2nd millennium BCE (*e.g.* Petroutsa and Manolis 2010; Triantafyllou 2015; Nitsch *et al.* 2017). However, Neolithic and Early Bronze Age cattle consumption of C4 plants was noted and, as in Anatolia, explained by grazing on the local C4 vegetation, such as C4-rich coastal salt marshes (Papathanasiou 2015, 40; Nitsch *et al.* 2017). Animal consumption of wild C4 plants probably explains the $\delta^{13}C$ value of -18‰ in an Early Bronze Age human in the Peloponnese (Richards and Vika 2008). The data for the period 1600-1100 BCE in Greece (the Late Bronze Age in the Aegean Basin) indicate sporadic intake of C4 plant protein (by both animals and humans), but not necessarily or not invariably coming from millet (Petroutsa and Manolis 2010; Triantafyllou 2015).

Similarly, there are isolated cases of a C4 signal in animals (and occasionally in humans) in the coastal areas of Romania and Bulgaria since the Neolithic, and these early occurrences have also been attributed to grazing on the wild C4 vegetation (*e.g.* Honch *et al.* 2006; Balasse *et al.* 2014, 2017; but see Privat *et al.* 2018). For now, the earliest radiocarbon-dated finds of millet from Romania are the grains from Măgura-Buduiasca from the 15th-13th century BCE (Motuzaite Matuzeviciute *et al.* 2013). In Romania and Moldova, the sites of the Late Bronze Age Coslogeni and Noua cultures (second half of the 2nd millennium BCE), both closely linked with the Sabatinovka culture in the North Pontic, yielded archaeobotanical evidence of millet cultivation (Sava 2005; Sava and Kaiser 2011; Dal Corso *et al.* 2022).

On human interaction in Bronze Age Europe

Human interaction, mobility and openness to, or search for, innovations took millet from the places of its domestication and early cultivation to new, distant locales. The recently created spatiotemporal frame for the arrival and spread of broomcorn millet in Europe dates this innovation to the mid-2nd millennium BCE and demonstrates its swift adoption across the continent (Filipović *et al.* 2020). This was in the middle of the Bronze Age, a highly dynamic period in Europe teeming with new developments in nearly every sphere of life and with extensive changes in material production – the time of a wholesale societal transformation. A great deal of this dynamic stemmed from intra- and extra-regional interaction that facilitated the distribution of goods and influences in Europe and beyond. Accordingly, Bronze Age interaction and interconnectedness have been traced archaeologically based on the distribution of raw materials (most prominently metals), artefacts (*e.g.* weapons, utilitarian objects and pieces of jewellery), ornamental styles and mortuary rituals (*e.g.* Gimbutas 1965; Sherratt 1993; Harding 2000, 2013; Kristiansen 2016). Trade in goods, movement of people and spread and exchange of influence acted as the mechanisms enabling the distribution, which was underpinned by new technological inventions in the domain of maritime and land-based transport, for instance, in shipbuilding and wagon construction (Anthony 1995; Harding 2000; Pare 2004; Kristiansen 2016).

Cultural contact and commercial relations were maintained between both neighbouring and more distant regions (Gimbutas 1965; Bouzek 1985; Jockenhövel 1991; Alberti and Sabatini 2013). Some regions had a more prominent role, such as the Mediterranean, which represented an '*unusually favourable theatre for interaction and transmission*' (Broodbank 2016, 19). Inland, the significance of the Carpathian Basin has been emphasised as a junction of cross-continental communication corridors, an epitome of cultural diversity and a cradle of increasing social hierarchy (Fisch *et al.* 2013). Farther to the north, in the regions assigned to the Nordic Bronze Age, one finds the start- and end-points of long-distance routes of trade of amber and metals respectively (Bergerbrant 2013; Vandkilde 2014; Kristiansen and Suchowska-Ducke 2015). Because rivers and river valleys connected regions, they also served as home to centres emerging along these routes and at crossroads, which initiated or boosted communication and exchange of goods. Excellent examples are the Middle-Late Bronze Age Terramare sites, in the Po Plain in northern Italy (*e.g.* Cardarelli 2009; Jones *et al.* 2014; Dalla Longa *et al.* 2019; Cardarelli *et al.* 2020), and the Late Bronze Age sites in the North Pontic region (*e.g.* Gorbenko and Grebennikov 2009); these were key west and east nodes in the network, and the Carpathian Basin was a central redistribution point.

In the archaeological scholarship on Bronze Age interaction in Europe, the main focus has been on the socio-political and economic connectivity in the context of the development of complex societies and regional hierarchies, and the concentration of power in the emergent political centres (*e.g.* Sherratt and Sherratt 1998; Harding 2000; Kristiansen and Larsson 2005; Knapp and Van Dommelen 2014; Suchowska-Ducke *et al.* 2015). In the political sphere, economic activity is a highly influential factor. Of the various economic domains in the Bronze Age, such as trade/exchange, craft production and flow of information/ideas, the subsistence economy appears to have received comparatively less research attention. There are, however, many studies documenting and discussing the incorporation of new plant or animal species into farming systems in Europe in the Bronze Age and the (resulting) changes in subsistence strategies (*e.g.* Bökönyi 1974; Sherratt 1981; Halstead 1987, 1996; Harding 1989, 2000; Behre 1998; Benecke 1998; de Hingh 2000; Greenfield 2005; Halstead and Isaakidou 2011, 2017; Bartosiewicz 2013; Stika and Heiss 2013; Kneisel *et al.* 2015; Effenberger 2018; Dal Corso *et al.* 2019; papers in this volume). Here too, inter-cultural contacts are seen as the means by which the innovations spread. Whereas identifying the 'source' and the 'recipient' of new materials, technologies or foodstuffs is of great importance for tracing the spread of materials and influences, scholars agree that a uni-directional flow between the origin and the destination is unlikely. Rather, the interacting sides actively shaped the nature, scale and content of the interactions (*e.g.* Sherratt 1993; Sherratt and Sherratt 1998; Harding 2000; Kristiansen and Larsson 2005; Galaty *et al.* 2014; Kristiansen 2016).

There have also been studies exploring spatiotemporal correlations between new developments in food economy and those in material culture, demography, ritual and environment (*e.g.* Valamoti 2016; Kneisel *et al.* 2019; Filipović *et al.* 2020; papers in this volume). This is challenging, not least because of the multiple, asynchronous chronologies, different classification and description systems, and varied terminology used for the same cultural period in different regions and vice versa. All the more challenging is understanding the nature of the relationships (if any) between changes and trends seen in different aspects of the Bronze Age archaeological record, including archaeobotanical. As the old adage goes, 'correlation does not imply causation' and so how does one determine economic, ecological or social reasons for, and ramifications of, the uptake of a new resource, such as a foreign cereal crop?

Millet as the theme of the workshop and the proceedings

The workshop in Kiel was an excellent occasion for a scientific exchange on ‘all things millet’ during direct interaction among a relatively small group of specialists, who are diverse in their expertise or in their regional research focus. Knowing what the interactions were like among the many different cultural entities living in Europe in the later part of the Bronze Age (cf. Fokkens and Harding 2013), and what their interactions with their natural environment were like (*e.g.* Capuzzo *et al.* 2018; Feeser *et al.* 2019), provides a necessary background to the knowledge of *when* millet arrived. The proceedings are an attempt to address social relations, food and materials economy and associated technologies, and the natural environment as reasons behind, or consequences of, the beginnings of millet cultivation in Europe. One of the major conclusions was that studies focusing on local or regional practices are needed to come closer to a general understanding of the *why* and *how* of the early millet cultivation.

This book offers several such studies, some looking at local, *e.g.* settlement-level evidence of millet production and use, and others taking a broader, regional or supra-regional perspective and looking at the entire plant or animal component of food economies. They emphasise the necessity for and demonstrate the potential to push further and refine the broad, continental-level picture of millet cultivation. It is with this smaller-scale, but more focused type of research that we can identify people’s needs, choices and perceptions with respect to food production strategies, and to begin to understand how individual, environmental and social dynamics may have influenced decisions such as acceptance or rejection of an innovation.

Another set of contributions in this volume outlines additional methodologies and perspectives used in the millet-centred research that, as illustrated by the findings described in these papers, can provide information not only on the cultivation and consumption of different millet species as food, but also on their uses as fodder and raw material. Just like was the case with crops known from the Neolithic, the multi-functionality of broomcorn and other millets could have been at the core of their widespread incorporation into plant economies.

Knowledge on the early history of millet in Europe: Where are we now and where do we go next?

Bioarchaeology in general has been almost saturated with millet studies or related studies, and almost every month there is a new publication dealing with this crop in one way or another.

Major archaeological interest in millet started with a focus on Asia (and China in particular) within the ERC-funded Food Globalisation in Prehistory (FOGLIP project), directed by Martin Jones and conducted at Cambridge University, UK (from a much longer list, Jones *et al.* 2011, 2016; see http://www.foglip.mcdonald.cam.ac.uk/). This project offered valuable guidance for the millet-centred research that has been and can be carried out in Europe. There had previously been some interest in the appearance of millet in Europe as well as in its archaeobotanical and archaeological context (*e.g.* Harding 1989; Marinval 1992; Hörander 1995; Hunt *et al.* 2008). With the refining of traditional methods, such as radiocarbon dating, and the development and application of new ones, such as stable isotopic, biochemical and genetic approaches, the scope has been enlarged and the detail improved. Thanks to this, even though it still lags behind that in China for example, the knowledge of early millet cultivation and consumption in Europe has grown substantially in recent years. The Millet Dating Programme (Filipović *et al.* 2020), carried out in the Collaborative Research Centre 1266, at Kiel, brought together the expertise of 40 archaeobotanists and archaeologists from multiple countries; it was a key milestone, and it laid the groundwork for future work on the history of millet in Europe.

Through AMS radiocarbon dating of a large number of millet grains, this programme established that the crop first appeared in Europe around the mid-2nd millennium BCE – no earlier than the late 17th century BCE in the southeastern Europe (Ukraine) and no earlier than the late 13th century BCE in north-central Europe (northern Germany). There are now more than 100 archaeological sites with radiometrically dated millet grains (Motuzaite-Matuzeviciute *et al.* 2013; Dreslerová *et al.* 2020; Filipović *et al.* 2020; Dal Corso *et al.* 2022; Toulemonde *et al.*, this volume). Figure 3 shows the sites that have yielded 2nd millennium BCE AMS-dates on millet. In a number of other AMS-dated cases, the 'early' millet finds turned out to be (significantly) younger than the archaeological layers in which they were found. The intrusive finds are, as a rule, small in number (one to several grains in a deposit or a feature) and they almost always come from multi-period sites or those disturbed in recent times (by, for instance, modern agricultural activity). Large, high-density millet finds (termed 'concentrations') are much more likely to correspond to the age of the archaeological layer or context they came from. Several papers in this volume present the cases where millet finds fit the expected date (based on archaeological periodisation), and several present cases where there is a mismatch (Reed *et al.*; Hellmund; Toulemonde *et al.*). Thus, the caution raised in some previous studies is reiterated here:

1. Before suggesting the age of broomcorn millet finds based on the dating of other materials from the site, researchers should assess the possibility of contamination/intrusiveness, by considering the density of the finds, as well as the nature of the site (whether single-phase or multi-phases occupation), its proximity to later sites, and modern-day disturbance of the find location.

Combined, the radiocarbon dates and archaeobotanical finds of millet document the start of *cultivation* of this crop in Europe. The stable isotope analyses of human and animal tissues and the biomarker (miliacin) records from Europe also point to the mid-2nd millennium BCE as also the onset of the *consumption* of millet (*e.g.* Tafuri *et al.* 2009; Gerling 2015; Heron *et al.* 2016; Gamarra *et al.* 2018; Cavazzuti *et al.* 2019; Pospieszny *et al.* 2021; Standall *et al.* this volume). Taken together, these strands of evidence suggest that:

2. Millet arrived in Europe as a crop and was recognised as such; it seems unlikely that it was first a tolerated weed or accidental inclusion, as previously thought based on the low presence of 'early' millet at pre-Bronze Age sites. The status of crop, perhaps in some places similarly or more important than other staples, may in part explain the faster diffusion and adoption of the new cultivar compared with the spread of Neolithic crops several millennia earlier.

It has been stated before and emphasised in the papers here (Reed *et al.*; Hellmund; Pashkevych; Toulemonde *et al.*) that taking up millet and other new Bronze Age plant resources may have been a risk-buffering measure, a strategy that guaranteed sufficient food. This has been seen as particularly relevant in areas considered agriculturally marginal (*e.g.* with poor or shallow soils and/or low rainfall) or where millet may have enabled colonisation of parts of the landscape unsuitable for winter crops or more demanding crops (*e.g.* areas in wetlands accessible only during the dry/summer season). The contribution by Toulemonde *et al.* underscores how the areas uninhabited during the Early Bronze Age were colonised in the Middle-Late Bronze Age and how the incoming groups cultivated significant amounts of millet. This may have been the case in northern Germany too (Feeser *et al.* this volume). We can, therefore, propose that:

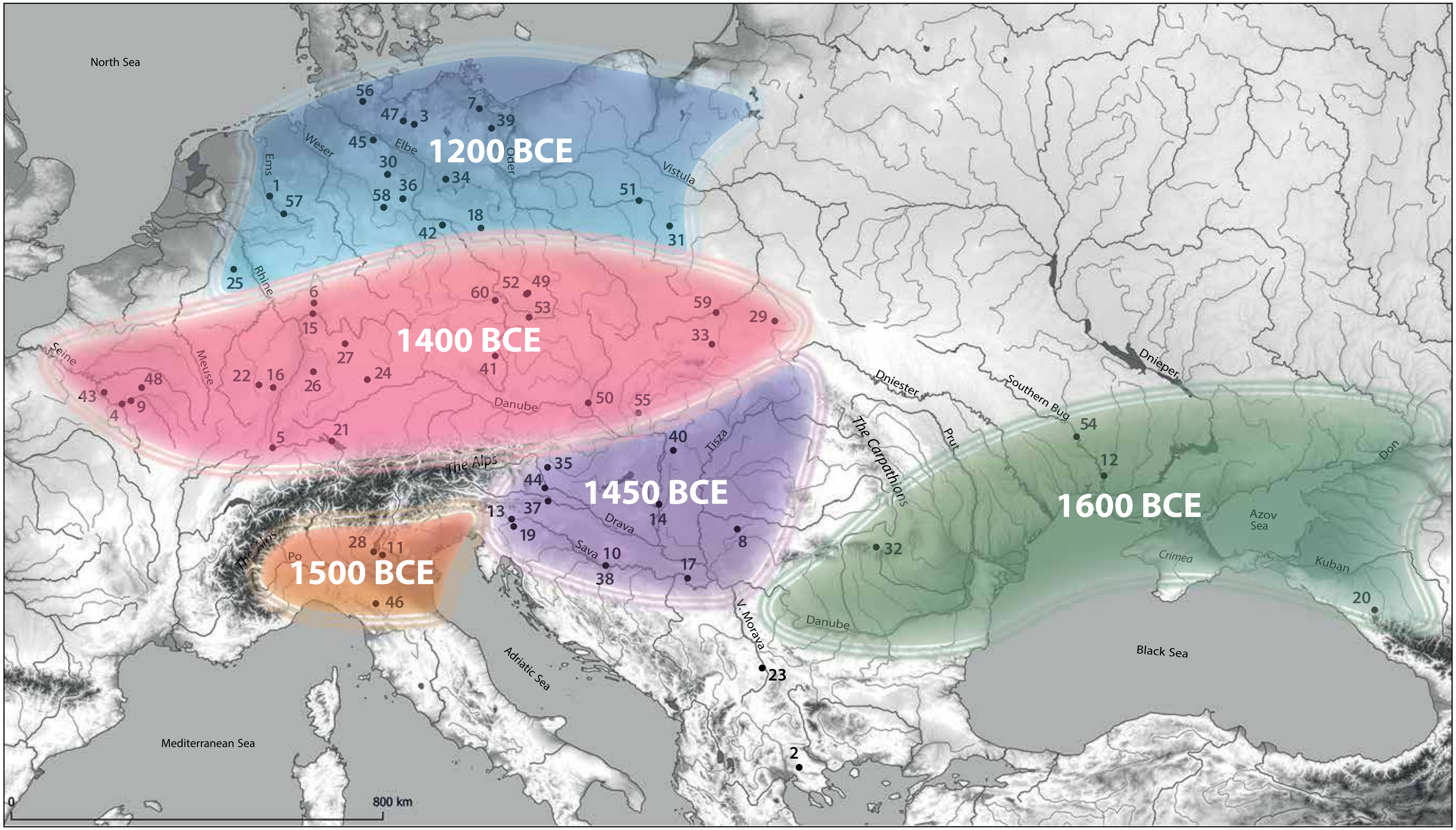

Figure 3. Sites in Europe from which broomcorn millet grains probably or possibly derive from the 2nd millennium BCE. The selection is based on the upper bound of 2σ cal BCE range of the [14]*C AMS-dates published in Filipović* et al. *(2020 [Supplementary Data]) and papers in this volume (Tolar and Pavlin; Toulemonde* et al.*); calibration using OxCal v4.4.2 and IntCal20 (Bronk Ramsey 2009; Reimer* et al. *2020). Shaded areas indicate the geographical division used in Filipović* et al. *(2020) and the years BCE-labels note the modelled start of millet cultivation (base map © OpenStreetMap contributors; map: Dragana Filipović, Anna Carina Lange): 1. (Rhine-) Altenrheine, 2. Assiros Toumba, 3. Badegow 19, 4. Balloy, 5. Binningen, 6. (Friedberg-)Bruchenbrücken, 7. Butzow 10, 8. Cornești-Iarcuri, 9. Courceroy, 10. Mačkovac- Crišnjevi, 11. Custoza, 12. Dikiy Sad (Дикий Сад), 13. Dragomelj, 14. Fajsz 18, 15. Fechenheim (Frankfurt am Main), 16. Gingsheim, 17. Gomolava, 18. Großbahren 4, 19. Grosuplje, 20. Guamsky Grot (Гуамский грот), 21. Hagnau(-Burg), 22. Hérange, 23. Hisar (Leskovac), 24. Ipf, 25. Jülich-Güsten, 26. Knittlingen 5, 27. (Lauda-)Königshofen, 28. Lavagnone, 29. Lipnik 5, 30. Lüdelsen 6, 31. Lutomiersk, 32. Măgura-Buduiasca, 33. Maszkowice, 34. Möthlow 5, 35. Neudorf, 36. (Hundisburg-) Olbetal, 37. Orehova vas, 38. Mačkovac-Oštrovi, 39. Pasewalk 109, 40. Pécel 02, 41. Pisek-Sever, 42. Radis 1, 43. Réau, 44. Reznei, 45. Rullstorf 5, 46. Santa Giulia, 47. Schwerin 81, 48. Sézannes, 49. Soví převis, 50. Stillfried an der March, 51. Szczepidło 17, 52. Valečov 1, 53. Velim, 54. Vinogradnyi Sad (Виноградний Сад), 55. Vráble(-Vel'ké Lehemby), 56. Wahlstedt, 57. Warendorf(-Einen), 58. (Hünenburg bei) Watenstedt, 59. Witów 1, 60. Zahájí.*

3. Millet may have encouraged or facilitated (re-)colonisation of uninhabited or less inhabited areas and unused or underused parts of the landscape, such as those we tend to label as agriculturally marginal. Perhaps we can infer that the colonising groups indeed relied on millet to a great degree because of its good response to a range of growing conditions. This premise could lead to a conclusion that early millet growers in Europe were aware and took advantage of the potential of the new crop. Millet may have gone from being a choice to being a necessity, or it may have been both, depending on the context.

A general decrease in humidity in the course of the Bronze Age and increasing openness of the landscape have been mentioned as having stimulated or accelerated the adoption of millet (*e.g.* papers in this volume by Bartosiewicz; Filatova; Feeser *et al.*; see also Cremaschi *et al.* 2006, 2016; Tafuri *et al.* 2009; Dal Corso 2018; Feeser *et al.* 2019; Gumnior and Stobbe 2021). Perhaps the regions which gave the earliest radiocarbon dates in Europe were affected by these environmental trends and millet cultivation 'saved' parts of them from becoming decolonised. Approaching millet as an 'enabler crop' foregrounds its possible contribution to maintaining or increasing population numbers in some places. The middle and late 2nd millennium BCE indeed witnessed apparently growing numbers of settlements or cemeteries in, for instance, the North Pontic region, the Po River valley, the Carpathian Basin, northeastern France, and north-central Europe (Cardarelli 2009; Capuzzo *et al.* 2018; Kneisel *et al.* 2019; Pospieszny *et al.* 2021; Dal Corso *et al.* 2022; Toulemonde *et al.* this volume). With this in mind, and also that millet was effectively diversifying farming and cooking niches, we can hypothesise that:

4. The 'millet effect', embedded in the overall diversification in the Bronze Age of farming and culinary niches, as well as economic and social relations, extended beyond food production and consumption, into symbolism and ritual. There are in Europe quite a few examples of the early finds of millet in contexts that may suggest its potentially ritual use or symbolic role, such as within or in association with burials or 'ritual pits' (*e.g.* Bartík and Hajnalová 2004; Palmer 2007; Filipović *et al.* 2020, Supplementary Data; in this volume: Hellmund; Reed *et al.*; Toulemonde *et al.*).

Millet, so what: Why adopt millet into food production systems already relying on a range of crops?

The Middle and Late Bronze Age archaeobotanical records from different parts of Europe contain remains of a wide range of cultivated and wild plants found in settlements and cemeteries. Besides crops used from the Neolithic onwards, such as several types of wheat (*Triticum*) and different variants of barley (*Hordeum*), lentil (*Lens culinars*), pea (*Pisum sativum*) and flax (*Linum usitatissimum*), several new species, in addition to broomcorn millet, were taken into cultivation in the later part of the period or towards its end, including gold-of-pleasure (*Camelina sativa*) and broad bean (*Vicia faba*), and perhaps *Lallemantia,* foxtail millet (*Setaria italica*) and safflower (*Carthamus*). The Middle Bronze Age was in some places characterised by a greater range of pulse crops, which, besides the earlier lentil and barley, also included bitter vetch (*Vicia ervilia*) and grass pea (*Lathyrus sativus*). Spelt wheat (*Triticum spelta*) seems to have been (more) regularly cultivated too. For wild resources, many Late Bronze Age sites show evidence of the collection of oak (acorns; *Quercus*), chenopods (*Chenopodium*) and perhaps wild crucifers (*Brassicaceae*) and large-seeded grasses (Poaceae) (*e.g.* Harding 1989; Jones and Valamoti 2005; Gyulai 2010; Pashkevych 2012; Stika and Heiss 2013; Kroll 2016; Perego 2017; Effenberger 2018; Šálková *et al.* 2019; papers in this volume). The fact that such a wide spectrum of edible plants was in use suggests that these were the times of plenty.

Food can become more abundant when environmental conditions are favourable. On the other hand, diversification of the subsistence base can be seen as a strategy for countering scarcity, which can, among other things, result from unfavourable growing conditions of plants due to extreme weather or harsh climate. The late Holocene is characterised by an overall decline in temperature, with warm or cold anomalies in some regions (*e.g.* Bradley and Bakke 2019). The Bronze Age overlaps with the Subboreal period, which is known for its unstable climate and at least two significant and adverse oscillations in the (Eastern) Mediterranean – the 4.2 ka BP and the 3.2 ka BP 'events' (documented as 'megadroughts'; Kaniewski and van Campo 2017; Weiss 2017). It is unclear what consequences, if any, these and other climatic anomalies would have had in terms of plant food availability and acquisition in other parts of Europe.

Because the internal climate systems vary among regions, and the general (*e.g.* sub-continental) oscillations affect these regions in dissimilar ways, regional or micro-regional perspectives are necessary for the identification of possible correlations among climate, environment and plant consumption. The growing number of well-dated palaeoclimatic, palaeo-environmental and archaeological proxies create a platform for collaboration among these disciplines (Capuzzo *et al.* 2018; Kneisel *et al.* 2019; Weiberg *et al.* 2019; Schirrmacher *et al.* 2020). It is, therefore, to be expected that the recognition of any possible links between the developments in these different spheres will ensue (*e.g.* Gumnior and Stobbe 2021).

As highlighted in the introduction to this volume and in some of the contributions, the biology and ecology of broomcorn millet could have made it a highly attractive member of the Bronze Age crop-suite. Whether or not the first millet cultivators in Europe became instantly aware of the advantageous properties of millet – in other words, whether the knowledge of these properties arrived in Europe along with the crop or was acquired – cannot be inferred without more details on the growing conditions, both those imposed by the climate and weather and those created by people. Was millet a sought-after buffer crop from the start (as a fast-growing, drought-resistant, low-demanding supplement or alternative to the 'traditional' cultigens, wheat and barley) or had there been a phase of 'learning' its potential, an initial episode in the 'cultural history of millet use' (Weber and Fuller 2008)? Marijke Van der Veen contends that

'*… the introduction of a new crop may be started by allocating just a small part of the available land to it, allowing an assessment over one or more years before making the decision whether to switch wholesale to the new crop.*' (Van der Veen 2010, 3)

A much more populated 'early millet map' of Europe could shed some light on this issue, and would likely emphasise how varied the picture is depending on the local ecological and cultural factors, which likely differed within and between macro- and micro-regions. There have already been some indications of the uneven adoption or consumption of millet in the early days of its presence in Europe. For instance, stable isotopic data from the Bronze Age in the Po Basin, in northern Italy, show that the same community included both individuals who consumed millet and those who did not (Tafuri *et al.* 2009, 2018), and that among those who did, different individuals ate different amounts of millet (Cavazzuti *et al.* 2019). A similar situation is observed in southern Poland, where the stable isotope analysis of a series of Bronze Age burials revealed that individuals buried in the upland zone (the northern fringes of the Carpathian Basin) consumed millet at the time when members of the same community buried in the lowlands to the north did not. Both cultural and natural factors (elevation, latitude) may have dictated these differences (Pospieszny *et al.* 2021).

Curiously, according to the radiocarbon dates on millet (Filipović *et al.* 2020), latitudes north of ca. 50 parallel North in north-central Europe received or accepted millet later than those south of it. This apparent delay could be due to the natural constraints (*i.e.* cold climate, low availability of daylight) or different cultural perceptions of millet, or both. With respect to the former, it would be worth taking a plant perspective and consider what kinds of adaptations (*e.g.* genetic mutations) were necessary for the millet plant to develop landraces able to succeed in conditions that differed from one area to another within its region of dispersal.

Instead of or in addition to natural factors necessitating broadening of the subsistence base, a long list of social and cultural factors and relations tend to shape the spread and adoption of introduced foods (Palmer and Van der Veen 2002; Van der Veen 2003, 2010; Hastorf 2017; Twiss 2019). They depend on, and at the same determine, the role of the innovations, which leads us to the next question.

Millet for what: Food, drink, fodder, symbol, currency, or all of the above?

Both millet and other contemporary crops have been used for multiple biological and technical purposes, *i.e.* human food or drink, animal graze or fodder, construction and craft material. Therefore, millet can archaeologically or historically be found in any of these roles (*e.g.* Moreno-Larrazabal *et al.* 2015; Teira-Brión this volume). Site- or region-specific studies explore the share of millet in food production and consumption, and we can expect further exciting discoveries in this area.

Culturally determined cooking methods and tastes influence the way millets are processed and prepared for consumption as food or drink – for instance dehusking, (par)boiling, malting, milling, mixing with other foods (*e.g.* de Garine 2001; Kohler-Schneider 2001, 153; Lundström-Baudais *et al.* 2002; Weber and Fuller 2008; Pashkevych this volume). Some archaeological evidence of millet processing and millet-containing food or drink has already been discovered (see Standall *et al.* this volume; Popov *et al.* 2018; Heiss *et al.* 2019). If not millet eating, certainly millet drinking would have in some instances been symbolically charged, such as at rituals, festivals and similar occasions of conspicuous consumption (cf. Palmer and Van der Veen 2002; Twiss 2019), although in some modern-day traditional communities, millet beer is perceived as food and consumed both day to day and on special occasions (de Garine 2001).

Stable carbon and nitrogen isotope measurements from Europe demonstrate that both humans and animals consumed millet from the very first days of its presence on the continent (*e.g.* Tafuri *et al.* 2009; Cavazzuti *et al.* 2019), humans doing so both directly and via animals. This suggests that millet had a similar dietary standing as other crops, and, as the biomolecular and anatomical analysis of food residues document, that it was apparently combined in meals with other ingredients, both of animal and of plant origin (Heron *et al.* 2016; Popov *et al.* 2018). Given its mild, indistinct taste, it could have been used to bulk up foods and drinks and give them a sticky texture, as in the Ukrainian/Russian dish *kulish* (Pashkevych this volume); or the 'barley-millet-brome grass risotto' in Early Iron Age Stillfried (Kohler-Schneider 2001, 153). It may also have been combined with animal foodstuffs as in Late Bronze Age Bruszczewo (Heron *et al.* 2016). And it may also have been used as a weaning food, such as at Iron Age La Hoya (Fernández-Crespo *et al.* 2019). The surviving tradition of millet cooking among the Cossack groups in Ukraine and of millet farming in northwestern Iberia (Moreno-Larrazabal *et al.* 2015; Teira-Brión this volume) exemplifies how the role(s) and importance of millet in diet construct its cultural meaning and significance and give it a place in cultural identity.

Approaching millet as a cultural category creates a possibility to examine the cultural affinity and status of millet farmers and/or consumers (cf. Palmer and Van der Veen 2002). As the modern-day examples described by Kirleis *et al.* (this volume) aptly illustrate, millet production and consumption can reflect individual or group social status, or a desire for social distinction; they can define and delineate economic, social and dietary identity.

Cropping system		Definition
Monoculture	*Increased following mechanisation*	One crop grown on the same plot for successive years.
Monocropping		One crop grown on one plot in a single year.
Multiple (‚mixed') cropping		Two or more crops grown on the same plot in one year, simultaneously or sequentially.
	Sequential	More than one crop grown per plot per year, in sequence. Single or two/three crops grown per stage in the sequence.
	Intercropping	Two or more crops grown simultaneously on one plot (usually a combination of cereals and pulses).
	Mixed	Simultaneous cropping with random distribution.
	Row	Two or more crops per plot sown singly in separate rows.
	Strip	Two or more crops per plot sown singly in separate strips.
Relay intercropping		Simultaneous cropping for only part of crop life-cycles.
Ratoon cropping		Cultivation of crop regrowth after harvest.

Table 1. Summary of types of cropping system, modified after Buttler 1999, Table 24.1.

An interesting case described by Roland Hardenberg is that of the Dongria Kondh indigenous tribe now living in Odisha state, eastern India, whose members use pearl, finger and other locally grown millets as a currency – to pay for labour (Hardenberg 2021). This reminds us that early millet production need not necessarily have been geared (only) towards local consumption and that in some contexts millet could have been purely a cash crop (*sensu* Sherrat 1999). That its grain is lightweight and has a profitable ratio of grain sown to grain harvested would have been advantageous from the perspective of exchange. This aspect of millet re-opens an area of research on the value of staple crops as exchangeable items, as currencies. Further, it has implications for the understanding of the modes and mechanisms via which millet (and other organic commodities) were distributed, and how the networks circulating the products were formed and shaped by internal and external socio-economic and environmental factors. Coming from afar, broomcorn millet could have initially been perceived as an exotic food in parts of Europe (cf. Sherratt 1999; Van der Veen 2003; Boivin *et al*. 2012) and could have represented a valuable tradeable good.

We are inclined to believe that the new crop increased food security and, by extension, eased life for the agriculture-reliant prehistoric communities; that its adoption brought about a good thing and may have saved lives in times or places of food shortage. We should, however, not forget that the opportunity to produce more food would have increased the level of exploitation of the land and the workload of those working the land. Apart from thorough weeding early in the growing cycle, millet crops require little field management compared with most of the cereals, but their processing is similarly laborious to that of hulled wheats (Lundström-Baudais *et al.* 2002; Harvey and Fuller 2005; Weber and Fuller 2008). Where millet was sown regularly, and after winter or early spring crops, it would have added another set of agricultural tasks at sowing and harvesting time and required re-scheduling of the annual cycle revolving around winter crops. This would have placed pressure on the food producers.

We should be examining the archaeological and land-use records for signs of reorganisation of agricultural production at the time of and after the start of cultivation of millet and other new crops of the Bronze Age. Ann Buttler has conveniently summarised historical and ethnographic evidence of systems producing multiple crops, and described their advantages (Table 1; Buttler 1999). Her work offers an extremely useful framework for inspecting the archaeological and related evidence and inferring agricultural solutions. Some directions already transpire in the contributions to this volume. The archaeological (spatial and temporal) co-occurrence of millet and broad bean emphasised by Hellmund (this volume) and also to some extent by Reed *et al.* (this volume) is a peculiar one and brings to mind intercropping of pearl millet and cowpea (*Vigna unguiculata*) in West Africa (Herrmann 2017; Styring *et al.* 2019). Intensification of arable production could have been done in this and other ways, including varied (*i.e.* more strategic) use of field manure, expansion into previously less-used or unused parts of the landscape, flexible fallowing and crop rotation regimes, use of more efficient tools and technologies. Thus, *ecological opportunism*, when viewed as a reason behind the adoption of millet in Eurasia, likely extended beyond the widening choice of crops and included pragmatic approaches to securing food and maximising returns (Jones *et al.* 2011; Liu *et al.* 2019).

In addition to the diversification, seen both in the range of plants cultivated or gathered and in the range of production techniques, we should expect to see indications of specialisation, probably aligned with agricultural tasks. Burhan Ulaş (2021) informs us that, until recently, there were specialised harvesters in southeastern Anatolia, hired in season throughout the region. Further back in the past, there also were specialised agricultural workers for sowing, threshing and grain-mill operating. They were paid in agricultural products (wheat, bulgur, flour). While moving around, they transmitted their knowledge and grains of different wheat varieties. In other words, specialised seasonal workforce served as vectors for the diffusion of agricultural techniques and resources in eastern Anatolia. This observation becomes even more interesting when we consider that this region is home to different Christian and Muslim ethnic groups (Ulaş 2021). This and other similar examples are particularly inspiring in the context of the traditional association of early millet (cultivation and/or consumption) with various mobile human groups that are a hallmark of the prehistory of central Asia and parts of eastern Europe (Frachetti *et al.* 2010; Spengler *et al.* 2014; Hermes *et al.* 2019; Dal Corso *et al.* 2022; Pashkevych this volume).

Conclusions and outlook

On its arrival, the new crop was incorporated into the economic, socio-environmental and ritual spheres. The papers in this book address different aspects of the introduction of millet in Europe. They also ask and spark a host of new questions about the cultural and environmental history of the integration of millet into food production systems, its economic, dietary, symbolic and ritual roles. Building on the already existing knowledge, possibilities open up for more in-depth investigations on broomcorn millet and other agricultural innovations in prehistoric Europe.

Despite the growing research on the arrival of millet and its early cultivation and consumption in Europe, the question *Where (exactly) from* is still open, and we have outlined several different possibilities here and in other papers (Filipović *et al.* 2020; Dal Corso *et al.* 2022). Answering this question requires further archaeobotanical finds and direct dating of broomcorn millet from regions situated at the interface of Asian and European cultural interaction.

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