Chapter 6
Cereal Agriculture in Prehistoric North-Central Europe and South-East Iberia: Changes and Continuities as Potential Adaptations to Climate

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6.1 Introduction

Climate change today is determining the success of agriculture on a global scale and is exerting a visible influence on agricultural decisions, from choice of cultivars to seasonality of various tasks to product price for end-consumers. Historical and modern examples point to reactions in the form of innovations in, and diversification of, the crop repertoire, including re-introductions of abandoned crops, greater emphasis on resilient crops, diversification of production strategies (e.g. inter- and multi-cropping, crop rotation, heavy manuring), cropping in areas less suitable for farming, moving agricultural tasks between the seasons, shifting to other/additional sources (greater emphasis on animal husbandry, hunting, wild plant-gathering: Duarte et al., 2017; Halstead, 2014; Hardenberg, 2021; Olesen et al., 2011; Swagemakers et al., 2012). Modern research demonstrates that manifestations of recent global warming do and will vary among regions and affect them in different ways (IPCC, 2019). Particularly, cereal agriculture is projected to struggle in many regions with increasing temperatures and decreases in precipitation (Ray et al.,

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J. Müller et al. (eds.), *Perspectives on Socio-environmental Transformations in Ancient Europe*, Quantitative Archaeology and Archaeological Modelling,
https://doi.org/10.1007/978-3-031-53314-3_6

2015). Regional heterogeneity in long-term climate developments as well as short-term events has also been noticed during prehistory (e.g. Bini et al., 2019; Davis et al., 2003; Schirrmacher et al., 2020). Therefore, it can be assumed that during prehistoric times climate change demanded modifications of agricultural methods and practices.

Previous studies have revealed some major transformations within prehistoric societies or even collapses of these (Blanco-González et al., 2018; Hinz et al., 2019; Lillios et al., 2016; Müller, 2015) – part of which might have been related to abrupt climate change (Weiss, 2017). On the other hand, climatic 'improvements' may have fostered societal innovations and population growth (Warden et al., 2017). However, the identification of possible correlations between climate and social developments is challenging from a methodological point of view. While palaeoclimatic reconstructions usually have a rather high temporal resolution and provide continuous records, archaeological data is chronologically restricted to cultural periods of several centuries. On the other hand, palaeoclimatic archives eventually record a highly local signal and occasionally are affected by past human influence as well.

In an attempt to overcome some of these limitations, we designed a detailed methodology for comparing palaeoclimatic and archaeobotanical data, which allows us to investigate common patterns in prehistoric cereal agriculture due to past climate change. In order to minimise local climatic effects and human influence in the chosen palaeoclimatic archives, we analyse regional coherent climatic developments by combining multiple archives from a certain area. We do the same with archaeobotanical records, using the aoristic approach (Mischka, 2004), which has already been applied in archaeological research (Brozio et al., 2019; Kneisel et al., 2019; Chap. 5). The aoristic approach weakens the influence of broad cultural periods on a regional scale. To further improve the chronology of the studied archaeobotanical records, we also consider radiocarbon date ranges.

Applying this methodology, we study two regions with very different climatic conditions – north-central Europe (NC Europe) and south-east Iberia (SE Iberia) (Fig. 6.1). The comparison of both study regions enables the evaluation of how prehistoric societies between 4000 BCE and 500 BCE have been adapted to climatic variability in the highly seasonal Mediterranean and the more moderate Atlantic climate zones. Still, we are aware that the cereal spectrum was not solely influenced by climate variability. Other potential factors for changes in the cereal spectrum are considered to be local or regional environmental conditions (e.g. soils, soil depletion), technical innovations of agricultural practices (e.g. ploughing), cultural preferences, and social networks influencing the availability of certain cereal taxa. A detailed discussion of these factors is, however, beyond the scope of this study. Here, we focus on the recognition of coinciding patterns in palaeoclimatic and archaeobotanic data in order to identify potential phases of agricultural adaptation to climate change.

6.1.1 Study Areas

For our archaeobotanical and palaeoclimatological assessment, we have chosen two study areas – NC Europe and SE Iberia (Fig. 6.1). The NC Europe region includes archaeobotanical data from modern-day Germany north of the German Lower Mountain Range and modern-day Denmark. In order to acquire a sufficiently large database for palaeoclimatic reconstructions, we included records from southern Scandinavia (up to 61 °N). The SE Iberian region is bordered by the Mediterranean Sea in the south and east. In the north the region extends up to 40.5 °N. The westernmost border is 5 °W.

The study areas have been chosen due to their very different climatic conditions. The following precipitation amounts and temperatures have been gathered from the WorldClim 2.1 dataset (Fick & Hijmans, 2017). SE Iberia is, since recent times, the driest region of Europe with less than 400 mm of annual precipitation. Furthermore,

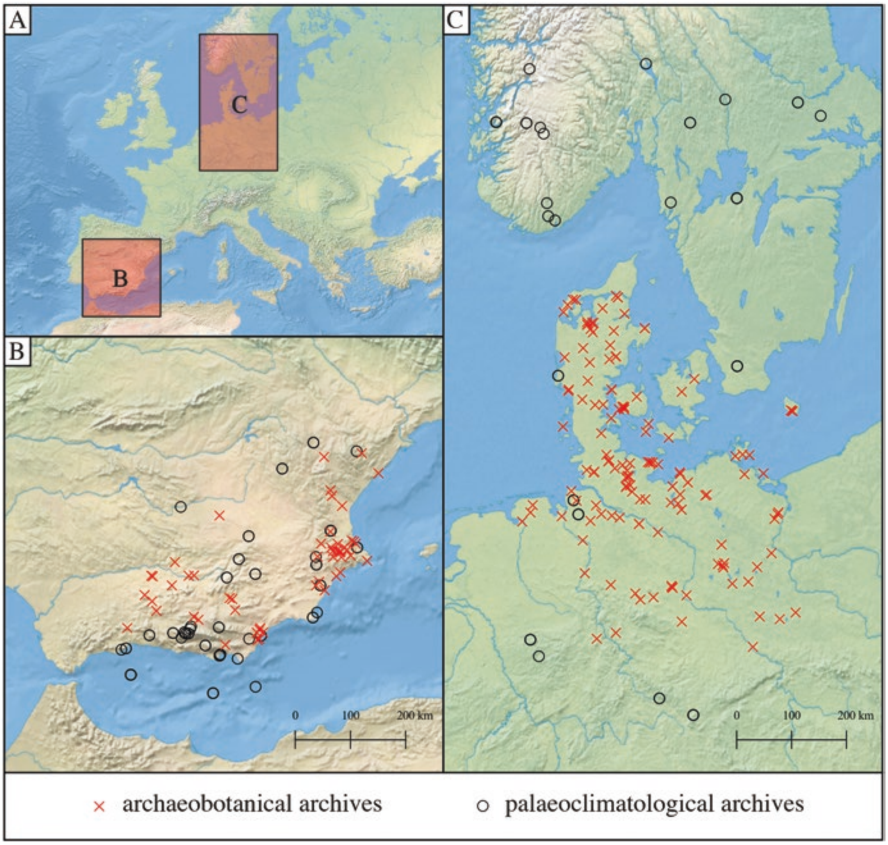

Fig. 6.1 Overview map showing the two study areas – south-east Iberia (B) and north-central Europe (C). The distribution of archaeobotanical archives is indicated by red crosses, while the location of palaeoclimatic archives is denoted by black circles. Figure by the authors

precipitation in the area reveals a marked seasonal bias, with the majority of precipitation occurring from October to March. Air temperatures in SE Iberia vary a lot with altitude. Leaving out high altitude regions of the Sierra Nevada, the average annual temperature is approximately 15 °C with a minimum of c. 7 °C in January and a maximum of c. 25 °C from July to August. In NC Europe the annual precipitation gradually increases from a minimum of 500 mm per year in the east to 900 mm per year in the west. In contrast to SE Iberia, precipitation is spread more evenly throughout the annual cycle. The average annual temperature in NC Europe is about 9 °C with a minimum of around 1 °C in January and a maximum of c. 17 °C from July to August.

In both study areas, climate has been shown to affect vegetation and cereal growth in particular. However, both regions differ in the most important climatic parameter. For SE Iberia it has been shown that precipitation events primarily affect crop yields (Cammarano et al., 2019; Frieler et al., 2017; Ray et al., 2015). In particular, reduced winter precipitation has been shown to limit plant growth (Gouveia et al., 2008). However, increasing spring temperatures may also have a negative effect on crop yields in the area (Bento et al., 2021). On the other hand, low winter temperatures impede vegetation growth in NC Europe, as the growing season tends to be reduced (Gouveia et al., 2008; Olesen et al., 2011).

6.2 Materials and Methods

Except for the data compilation and standardisation, all analytical methods described from Sect. 6.2.3 onwards have been carried out using R version 4.2.1 (R Core Team, 2022). The standardised datafiles and the R code are available at ZENODO (https://zenodo.org/doi/10.5281/zenodo.10082301).

6.2.1 Data Compilation

Archaeobotanical information for NC Europe comes from the in-house archaeobotanical database 'ArboDat-in-Kiel'. The data derived either from the research projects conducted by Kiel University, in which case they are as detailed as possible, or have been extracted from publications and grey literature and entered into the database, in which case the level of detail and accuracy is that provided in the reports. Altogether, 1723 archaeological features containing cereal remains from 158 sites have been compiled for this chapter (Table 6.1). Archaeobotanical data from SE Iberia has been extracted from published literature. Overall, 2057 features from 52 sites have been compiled for SE Iberia (Table 6.1). Unfortunately, not all publications provided their archaeobotanical data at the feature level. Accordingly, in some cases already aggregated archaeobotanical data has been included, which during the subsequent analysis is treated as single feature. The total number of archaeobotanical records regarded as 'feature' is listed in Table 6.1.

Table 6.1 Summary of compiled data. Feature counts refer to features classified as such for this analysis (see Sect. 6.2.1)

	NC Europe	SE Iberia	Total
Archaeobotany			
Features	1630 (1723)	1099 (2057)	2729 (3780)
Sites	158	52	210
Radiocarbon dates			
Total	460	897	1357
Improved chronologies	437	167	604
Palaeoclimate			
Precipitation	14	65	79
Air temperature	35	4	39

Feature counts in brackets indicate the true number of features with archaeobotanical remains studied here. 'Improved chronologies' shows the number of features for which chronology has been improved by the use of radiocarbon dates

Radiocarbon dates on botanical or other materials from the selected contexts were compiled from the online databases RADON (Hinz et al., 2012), XRONOS (https://xronos.ch/), IDEArq (http://www.idearqueologia.org/), in-house repositories, and published reports. For all 210 sites in both study areas, we compiled 1357 radiocarbon dates (Table 6.1).

For both study areas, palaeoclimatic datasets reflecting either precipitation or air temperature variability have been compiled from the literature, public databases (NOAA Paleo Data Search, https://www.ncei.noaa.gov/access/paleo-search/; European Pollen Database, http://epd.imbe.fr/index.php; PANGAEA®, https://www.pangaea.de/; Comas-Bru et al., 2020), and our own data (Schirrmacher et al., 2019). Altogether, 118 datasets have been compiled for the period between 4500 and 0 BCE. From these, 69 datasets are located in SE Iberia and 49 datasets are located in NC Europe (Fig. 6.1 and Table 6.1). The datasets are based on various proxies, with the majority being pollen (n = 96) followed by geochemical measurements on speleothems (n = 8). The distribution of the datasets among the studied climatic parameters differs for the study areas, with the majority reflecting precipitation in south-eastern Iberia and air temperature in north-central Europe (Table 6.1).

6.2.2 Standardisation of Archaeobotanical Data

Altogether up to seven key cereal taxa occur in each region and their absolute grain counts have been considered. These are: emmer (*Triticum dicoccum*), einkorn (*T. monococcum*), spelt (*T. spelta*), free-threshing wheat (*T. aestivum/durum/turgidum/compactum*), naked barley (*Hordeum vulgare nudum*), hulled barley (*H. vulgare vulgare*), and broomcorn millet (*Panicum miliaceum*). In SE Iberia, no spelt has been found in any of the features considered. Regarding millet in SE Iberia, we combined the counts of broomcorn millet and foxtail millet (*Setaria italica*). A separate assessment of both millet taxa has not been considered due to their low counts. Given the findings of the radiocarbon dating of millet grains from NC Europe (and other parts of Europe), the records of millet grains from contexts attributed to the Neolithic (c. 4000–1700 BCE) were removed from the respective datasets used in this study (Filipović et al., 2020).

All tentative identifications (denoted as 'cf.') were added to the respective precise identifications. Counts of rachis and glume bases have been converted to grain counts. To do so, rachis counts have been multiplied by 2 to account for the minimum of two grains per rachis segment (in case of barley and free-threshing wheat). The counts of glume bases have not been divided, because the majority of them belong to emmer, where one glume base holds one grain. We have not done the conversion for einkorn either (where normally two glume bases enclose one grain), in order to account for the possible occurrence of two-grained einkorn. These chaff-converted-to-grain counts have only been considered if the sample or feature contained no grains of the respective species, or if the converted count was higher than the count of grain present in the sample/feature. In such cases, the converted grain counts replaced the 'real' grain counts. There were no records for millet chaff in either of the study areas. In the case of spelt, only the counts of chaff (glume bases) have been considered since the identification of grains is ambiguous. Indeterminate cereal grains such as *Hordeum* sp., *Triticum* sp., or other ambiguous identifications (e.g. *T. dicoccum/monococcum*) have been proportionally re-assigned to the respective precisely identified species. In cases where the total grain count consists only of indeterminate remains, it was re-assigned to all of the possible/relevant species.

6.2.3 Archaeobotanical Analyses

6.2.3.1 Chronological Refinement

Along with the archaeobotanical data, the archaeological chronology of the respective contexts has also been standardised. In order to improve the chronological resolution of the archaeological chronologies, the available radiocarbon (^{14}C) dates have been considered. If possible, the radiocarbon dates were assigned to a 'structure' (e.g. a certain house, pit, or site-phase) and/or even to an individual 'feature' (i.e. an archaeobotanical entry). Radiocarbon dates have been calibrated with the 'clam' package (Blaauw, 2022) using either the intcal20 (Reimer et al., 2020) or the marine20 calibration curve (Heaton et al., 2020).

Based on the calibrated two sigma (2σ) ranges of each radiocarbon date, outliers have been identified as those dates that do not overlap with the archaeological chronology of the respective feature, structure and site allowing for a tolerance of ±100 years. They have been omitted from further analysis. From the remaining radiocarbon data, ^{14}C age ranges were calculated on a feature, structure and site level. In the case of multiple radiocarbon dates per site, structure, or feature, the minimum and maximum limits of all 2σ ranges were used. In cases where the age range of the radiocarbon dates is narrower than the respective archaeological dating range, the radiocarbon age range replaced the archaeological chronology for further analyses. Otherwise the original archaeological chronology has been used. The number of features with refined chronology is listed in Table 6.1.

6.2.3.2 Application of the Aoristic Approach to Archaeobotanical Data

In a second stage of the data standardisation, the aoristic approach (Mischka, 2004) was applied. First, cereal taxa counts from all features were distributed into temporal bins of 100 years according to their chronological ranges. Afterwards, the distributed counts from all features belonging to a particular site were summed in order to receive site-based counts for each 100-year bin within the studied period (4000–500 BCE). Finally, we derived cereal counts of each taxa for 100-year bins for each site, which built the basis for further analyses.

The further examination of the archaeobotanical data was aimed at identifying changes in the relative proportions of the different cereal taxa in the two study regions. Therefore, three different approaches to data representation and calculation were applied. The first approach is the summing up of all counts per 100-year bin in each region for the selected cereal taxa. The results of this are shown in Figs. 6.2 and 6.3.

Secondly, site-based relative proportions of the cereal taxa were calculated for each 100-year bin and, subsequently, averaged for the respective region. For this, the average percentage of each cereal taxon was calculated per site and temporal bin. Afterwards, the mean of all site-based relative proportions within a 100-year bin was calculated for each region (shown in Figs. 6.2 and 6.3). In this approach, sites with very low cereal counts are likely overrepresented. This, however, can be partially overcome by omitting sites with low counts. We tested the effect of such sites on our results using various thresholds for minimum counts. Ultimately, we decided that the threshold of a minimum 20 cereal counts per site in each 100-year bin is satisfactory because it removes very small assemblages and rare or insecure occurrences, whilst maintaining reasonably high number of sites represented in each 100-year bin. Results of alternative settings using no threshold (a minimum count of 0) and a stricter threshold of 100 counts are available in the Appendix (Figs. 6.A1, 6.A2, 6.A3, and 6.A4).

Another bias might be introduced by mass finds (i.e. storage finds with very high counts of a single cereal taxon), which tend to have strong effect on both previously described approaches. The third approach, which has been shown to neutralise a possible effect of mass finds, is the calculation of a so-called representativity index (RI). It factors in the different archaeobotanical processing and sampling strategies as well as depositional processes at archaeological sites. It conducts a semi-quantitative evaluation of the importance of crops in cultivation, taking into account the underlying number of samples (Stika & Heiss, 2013a). For the calculation of the RI, we adopted the refined approach developed by Effenberger (2018a, b) for the Bronze Age of northern Germany (Table 6.2). As in the original approach by Stika and Heiss (2013a), every taxon is attributed a RI score according to its quantity and proportion. Whereas Stika and Heiss (2013a) originally used a 4-point

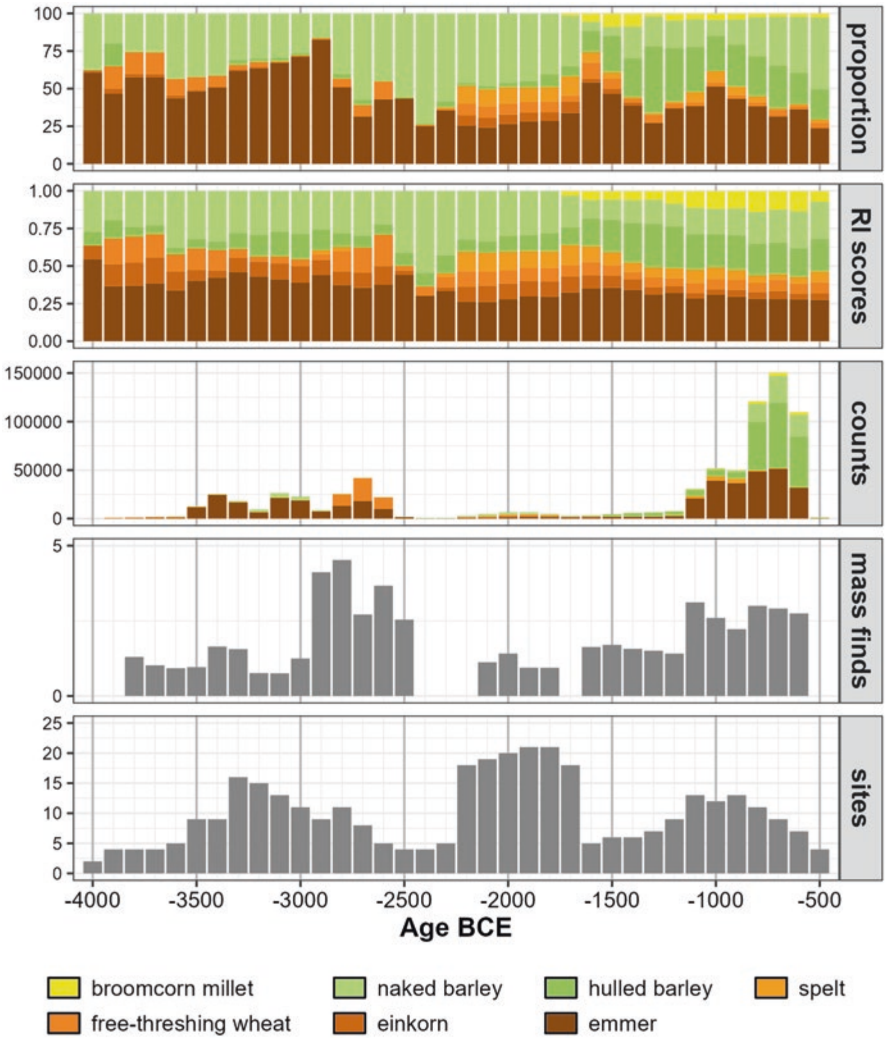

Fig. 6.2 Archaeobotanical results from north-central Europe applying a threshold of 20 minimum counts. From top to bottom the relative proportion of each cereal taxon per 100-year bin is shown, followed by the representativity index (RI), the total number of counts per 100-year bin, the proportion of features characterised as mass finds (more than 1000 grains per bin and site), the total number of sites providing archaeobotanical data for each temporal bin

scoring scale, Effenberger (2018a) used a refined 7-point scoring scale to avoid overrepresentation of rare taxa. The RI scores are subsequently multiplied by a factor, which depends on the number of features and the quantity of finds. Unlike the previous applications of the method, where the RI scores were calculated for rather long periods (i.e. archaeological periods spanning several centuries), we reduced the limits for the scoring system with respect to our 100-year temporal bins.

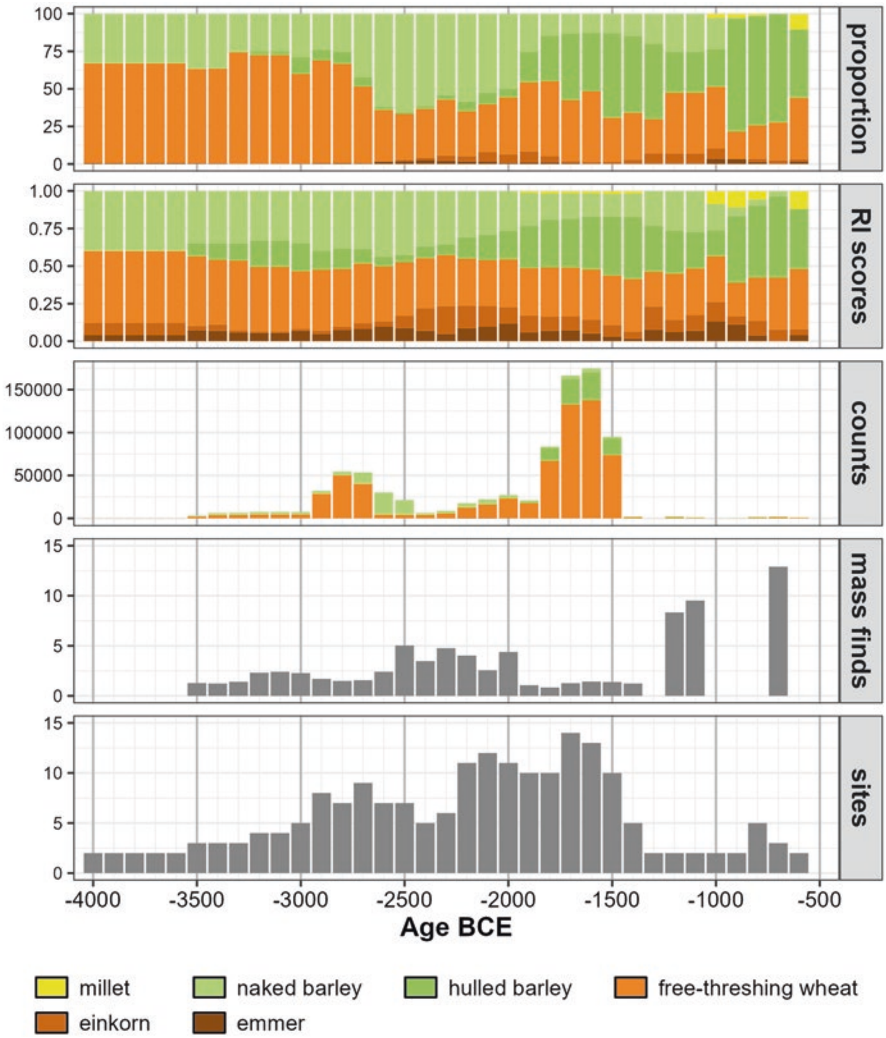

Fig. 6.3 Archaeobotanical results from south-east Iberia applying a threshold of 20 minimum counts. From top to bottom the relative proportion of each cereal taxon per 100-year bin is shown, followed by the representativity index (RI), the total number of counts per 100-year bin, the proportion of features characterised as mass finds (more than 1000 grains per bin and site), the total number of sites providing archaeobotanical data for each temporal bin

As in the analyses of Effenberger (2018a) the investigated time periods span generally about 500 years, we reduced the limits by a factor of five (Table 6.2). Due to the lack of data on the archaeobotanical sample volumes for many of the features, the representativity factor is in this study solely based on the number of features and the cereal counts. Accordingly, we calculated the RI scores for every cereal taxon per 100-year bin and site. Subsequently, the RI scores have been averaged per 100-year bin for each region. The RI scores for each region are shown in Figs. 6.2 and 6.3.

Table 6.2 Comparison of scoring and factor systems used in the calculation of the representativity index (RI) in previous studies and in this study. S: number of seeds/fruits

	Stika and Heiss (2013a)		Effenberger (2018a, b)		This study	
Score	ΣS < 1000	ΣS > 1000	ΣS < 1000	ΣS > 1000	ΣS < 1000/5	ΣS > 1000/5
1	<100 S	<100 S	<10 S	<10 S	<10/5 S	<10/5 S
2	>100 S	>100 S	10–49 S	10–49 S	10/5–49/5 S	10/5–49/5 S
3	–	–	50–99 S	50–99 S	50/5–99/5 S	50/5–99/5 S
4	–	25–49%	>100 S	100–499 S	>100/5 S	100/5–499/5 S
5	–	>50%	–	>500 S	–	>500/5 S
6	–	–	–	25–49%	–	25–49%
7	–	–	–	>50%	–	>50%
Factor	Requirement per site					
x2	>20 samples or > 1000 litre sample volume				>20 features	
x3	–		>40 samples or > 5000 litre sample volume		>40 features	
x4	>40 samples or > 5000 litre sample volume		>100 samples		>100 features	
x5	>100 samples		–		–	
x2	<20 samples or < 1000 litre sample volume, but >10,000 S				<20 features, but >10,000/5 S	

6.2.4 Palaeoclimatological Analyses

The methodology for reconstructing the palaeoclimatic variables has been adopted from Schirrmacher and Weinelt (n.d.). Here, we give a short description of the most important steps. Where possible, we calculated updated age-depth models for the compiled archives (n = 110) using the 'Bacon' package (Blaauw & Christen, 2011). Some datasets have a very high temporal resolution. To account for the overrepresentation of such archives in the subsequent analysis, archives with a temporal resolution of less than 25 years have been downscaled to a resolution of 25 years. Datasets with a very low temporal resolution (more than 900 years on average) have been removed from analysis. In order to achieve a uniform data structure, datasets have been normalised if necessary. For this, the respective datasets have been multiplied by a factor of −1 to ensure that drier or cooler conditions are always associated with negative values. Subsequently, the datasets have been transformed into z-scores to allow a direct comparison of all the different proxies. The z-score has been calculated after Clark-Carter (2014). Afterwards, a mean as well as the 95% probability distribution has been determined based on a bootstrapped local gaussian regression using the 'locfit' package (Loader, 2020).

6.2.5 Pearson Correlation

Spearman correlation tests have been conducted among the archaeobotanical and palaeoclimatic datasets using the 'Hmisc' package (Harrell Jr., 2022). Before determining possible correlations, the palaeoclimatic data has been binned to 100-year time slices in order to match the archaeobotanical data. Subsequently, correlation tests have been carried out for undetrended as well as linear detrended datasets.

6.3 Results

6.3.1 North-Central Europe

The results of the archaeobotanical assessment for NC Europe are shown in Fig. 6.2. The relative proportions of the cereal taxa show emmer and barley as the dominant taxa throughout the studied interval. There is an overall decreasing trend of emmer in favour of barley. Similar long-term trends are visible in the RI-based reconstruction. Regarding the trajectories of barley and emmer (or wheat in general) some periods of change can be noted. Particularly, since 3600 BCE there is a gradual increase of emmer culminating at 2900 BCE, which is followed by its decrease and an associated increase in (naked) barley at 2800 BCE. A similarly high increase in naked barley is observable at around 2400 BCE. This particular change is the only one captured within the RI data. Some contraction of barley (and rise in emmer) proportions can be seen around 1600 BCE and again at 1000 BCE. Notably, at around 2000 BCE, hulled barley starts to increase steadily and becomes the dominant barley species between c. 1600 and 800 BCE. After 1000 BCE there is an increase in the naked barley proportions again. Prior to 1600 BCE, naked barley is by far the dominant barley species. At 1700 BCE our results indicate the first grains of broomcorn millet in NC Europe, which are present until the end of the studied period in low quantities. However, the pre-1300 BCE millet 'presence' in our overview is a result of imprecise chronologies (Filipović et al., 2020). Apart from emmer, other wheat species are also present in variable proportions. Particularly, the RI data indicates that free-threshing wheat and einkorn are present throughout the studied interval, while spelt appears around 2200 BCE for the first time. The relative proportions of these minor wheat species exhibit higher values between 3900 and 3400 BCE for free-threshing wheat and between 2200 and 1500 BCE for all three minor wheat species.

Both palaeoclimatic parameters reveal no long-term trends but overall variable conditions for NC Europe (Fig. 6.4). Overall, no correlation of precipitation and air temperatures is obvious. However, between 3000 and 1400 BCE it appears that higher air temperatures are associated with reductions in precipitation. Regarding precipitation, four major reductions can be noted from c. 3800–3700 BCE, 2600–2400 BCE, 2000–1800 BCE, and 1100–1000 BCE. Inbetween these periods, the precipitation levels are elevated. With respect to the air temperature

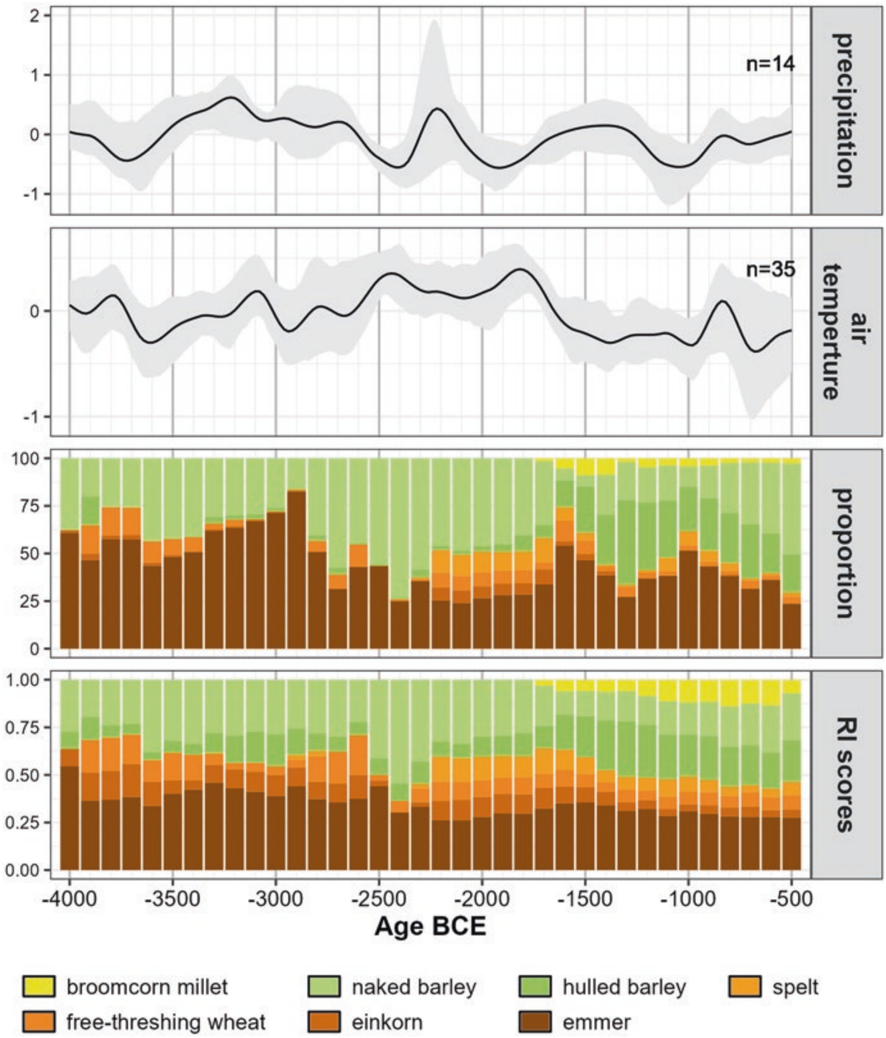

Fig. 6.4 Comparison of archaeobotanical and palaeoclimatic data for north-central Europe. From top to bottom the reconstructed precipitation, the reconstructed air temperature, the relative proportion of cereal taxa, and the RI scores of the archaeobotanical data are shown. The grey shading of the palaeoclimatic reconstructions denote their 95% probability interval

development, the period between 4000 and 2500 BCE is highly variable. Two abrupt cooling events are apparent at 3600 BCE and 2900 BCE. From 2500 to 1800 BCE, the highest and stable air temperatures are recorded. After 1800 BCE, a remarkable cooling is suggested, which remains stable until 500 BCE. The only exception is a brief warming episode at 800 BCE.

6.3.2 South-East Iberia

The results of the archaeobotanical examinations for SE Iberia are shown in Fig. 6.3. Both the relative proportions and the RI data show an overall increasing (decreasing) trend of barley (wheat) throughout the studied period. While free-threshing wheat is the dominant wheat taxon during the entire period, naked barley is the dominant barley taxon until 1900 BCE when it was almost entirely replaced by hulled barley. Based on the relative proportions of cereal taxa, some major short-term changes can be noticed. The most prominent change around 2700 BCE is the decrease of free-threshing wheat in favour of naked barley. After this time, free-threshing wheat (and wheat in general) does not reach pre-2700 BCE proportions again and barley remains dominant. Nevertheless, some periods of increased free-threshing wheat proportions are evident from 1900 to 1600 BCE and between 1200 and 1000 BCE. Other species, such as einkorn, emmer, and millet, are present in very small amounts. While millet appears in noticeable proportions only after 1000 BCE, RI scores indicate that emmer and einkorn are present throughout the studied period. Within this general pattern, two periods of increased emmer and, particularly, einkorn proportions are evident between 2600 and 1800 BCE and from 1400 to 900 BCE.

The palaeoclimatological parameters show dynamic and diverging developments (Fig. 6.5). The reconstructed regional precipitation reveals a long-term decreasing trend, which is punctuated by several short-term fluctuations. The highest precipitation levels are reached at 3500 BCE and are followed by a decrease to relatively low precipitation levels at 3200 BCE. Another decrease is visible around 2250 BCE, followed by a long period of reduced precipitation from 2000 to 1500 BCE. Another prominent reduction in precipitation occurred around 900 BCE. The air temperature reconstruction reveals no long-term trends, but highly variable conditions. Air temperatures are relatively warm and even slightly increasing between 4000 and 3000 BCE. After 3000 BCE a sudden reduction in air temperatures can be noticed, which remained cool until 1300 BCE. During this period an additional cooling event around 2100 BCE is suggested. Notably, the uncertainty in the air temperature reconstruction is large between 2300 and 1600 BCE. From 1300 to 900 BCE, air temperatures suggest a return to warmer conditions. After 900 BCE, air temperatures decrease until 500 BCE. Again, uncertainty of the reconstruction for this period is large.

6.4 Discussion

6.4.1 Prehistoric Cereal Agriculture in North-Central Europe

The overall dominance of emmer and barley in NC Europe agrees with the findings of previous related studies (Effenberger, 2018a, b; Kirleis, 2019; Kirleis & Fischer, 2014; Kirleis et al., 2012). The same is true for the overall, but minor, presence of free-threshing wheat and einkorn throughout the studied period (Kirleis & Fischer, 2014; Kirleis et al., 2012). Our results also indicate that, until 2900 BCE, emmer

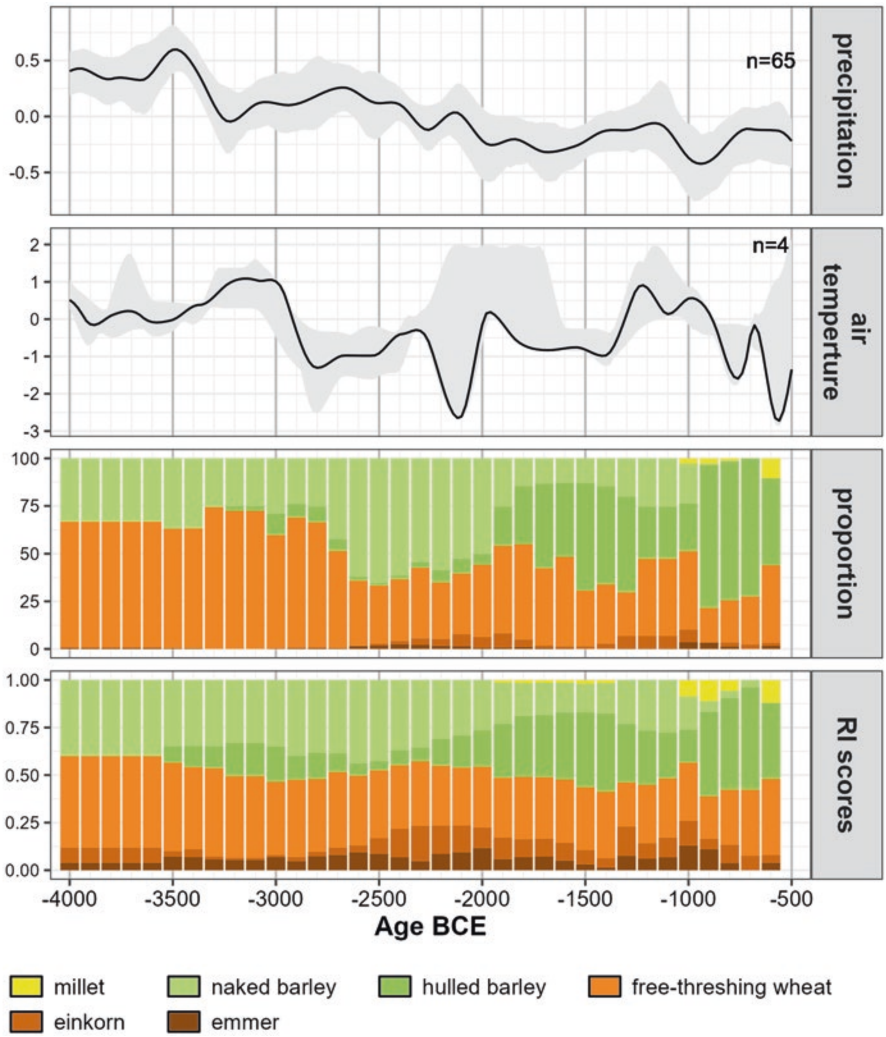

Fig. 6.5 Comparison of archaeobotanical and palaeoclimatic data for south-east Iberia. From top to bottom the reconstructed precipitation, the reconstructed air temperature, the relative proportion of cereal taxa, and the RI scores of the archaeobotanical data are shown. The grey shading of the palaeoclimatic reconstructions denote their 95% probability interval

prevails over barley. There may have existed intra-regional variation in the extent of use of emmer and barley. For instance, Kirleis et al. (2012) conclude that barley was the dominant cereal in the central part of our study region (the state of Schleswig-Holstein). On a regional scale, the emmer dominance changed at 2800 BCE, when barley became to be the dominant taxon throughout the studied period (with potential short-term interruptions at 1600 BCE and 1000 BCE). An overall increasing trend of barley cultivation during the studied period is known (Zohary et al., 2012). The increase in hulled barley proportions after c. 2000 BCE in NC Europe was observed by Zohary et al. (2012). Around that time our archaeobotanical results point towards a diversification of the cereal spectrum along with the introduction of spelt and increased proportions of free-threshing wheat and einkorn (Fig. 6.2). This trend has been observed in earlier studies (Effenberger, 2018b; Feeser et al., 2022; Filipović, 2023). Here, we note that the sites containing significant counts of spelt have a rather broad chronology of more than 500 years. Accordingly, it should be considered that spelt was introduced in the region sometime between 2200 BCE and 1700 BCE. Short-term increases in emmer proportions at 1600/1500 BCE and 1000 BCE are indicated by our results. So far it has only been noted that emmer proportions were higher during the Early Bronze Age (1800–1100 BCE) than during the Late Bronze Age (1100–600 BCE) (Effenberger, 2018b). While our results corroborate the overall higher emmer proportions during the Early Bronze Age, they add some more detail to this picture by pointing to the two short-term increases. For example, the apparently increasing trend in naked barley proportions after 1000 BCE; although naked barley indeed represented an important taxon during this period in NC Europe, such a marked increase was not detected by previous studies (Effenberger, 2018b). Notably, the increase in naked barley proportions agrees strongly with a decrease in sites with archaeobotanical remains (Fig. 6.2). Also, the total counts clearly point towards hulled barley being the dominant barley taxon on a regional-scale. Accordingly, the increase in naked barley after 1000 BCE is most likely an artefact introduced by some sites with exceptionally large finds of naked barley.

6.4.2 *Prehistoric Cereal Agriculture in South-East Iberia*

The total summed counts of cereal remains in SE Iberia (Fig. 6.3), as well as the temporal distribution of sites with cereal remains (Fig. 6.3), indicate a high research focus during the Chalcolithic and the Bronze Age – particularly between 3000 and 1500 BCE. This is in line with the overall archaeological research intensity in the area (e.g. Blanco-González et al., 2018). Nonetheless, no associated changes in cereal proportions or RI-scores are obvious. Consequently, we assume that research intensity had no major influence on the long-term trajectories and short-term changes of our archaeobotanical results.

The overall developments in the archaeobotanical record of SE Iberia have already been recognised in previous studies. The general predominance of free-threshing wheat and barley, along with the minor, but steady, importance of einkorn and emmer, has been suggested by numerous studies (Montes Moya, 2014; Peña-Chocarro, 1999; Peña-Chocarro & Pérez-Jordà, 2018; Pérez-Jordà, 2013; Rovira Buendía, 2007; Stika & Heiss, 2013a, b). Similarly, the increase in barley has been intensely described. However, regional differences are proposed within the study area. It appears that barley and free-threshing wheat reach rather equal proportions in western Andalusia and the Valencian region during the Bronze Age (after c. 2200 BCE; Montes Moya, 2014; Pérez-Jordà, 2013). This might be the reason for the elevated free-threshing wheat proportions between 1900 and 1600 BCE (Fig. 6.3). In eastern Andalusia, on the other hand, barley becomes the dominant cereal taxon – probably already during the

Chalcolithic (Castro et al., 1999; Peña-Chocarro, 1999; Rovira Buendía, 2007; Stika, 2003; Stika & Heiss, in press). This would be in line with the rapidly increasing barley proportions after 2700 BCE (Fig. 6.3). The replacement of naked with hulled barley has also been proposed for the Late Chalcolithic/Early Bronze Age before (Montes Moya, 2014; Pérez-Jordà, 2013; Peña-Chocarro & Pérez-Jordà, 2018; Rovira Buendía, 2007; Stika & Heiss, in press). Our results based on the relative proportions of both barley varieties suggest that the replacement started on the regional scale at around 1900 BCE. Although einkorn and emmer have only been present in very small quantities, the minor increases suggested by our results in the periods c. 2600–1800 BCE and 1400–900 BCE have also been identified in earlier studies (Montes Moya, 2014; Pérez-Jordà, 2013; Rovira Buendía, 2007; Stika et al., 2017). On the other hand, the sudden increase in free-threshing wheat proportions at 1200 BCE has not been noted before. Noteworthy is that this increase diminishes when applying a stricter threshold of 100 minimum counts (see Appendix). Thus, the increased free-threshing wheat proportions between 1200 BCE and 1000 BCE are likely an artefact due to sites with only a few cereal remains. Our results suggest that millet was introduced after 1000 BCE, which agrees with previous studies (Pérez-Jordà, 2013; Rovira Buendía, 2007). Consequently, millet seems to have been introduced later in SE Iberia than in the northern part of the Peninsula (Peña-Chocarro & Pérez-Jordà, 2018). After 800 BCE, cereal cultivation in SE Iberia becomes more diverse (Pérez-Jordà, 2013), which is captured within our data by increasing proportions of free-threshing wheat and millet.

6.4.3 Potential Adaptations to Climate Change in both Regions

In general, our results for both study regions agree with the observations available in the literature. Furthermore, they improve the chronological framework of some developments discernible in archaeobotanical datasets. They thus allow for a comparison to the regional palaeoclimatic developments.

A fundamental difference between the regions is that free-threshing wheat and barley are the dominant taxa in SE Iberia, while in NC Europe emmer and barley are the dominant taxa. The reason for this could potentially be the prevailing climatic conditions. Apart from the general variability in air temperature and precipitation in each of the regions, it is clear that, similar to today, SE Iberia was confronted with generally warmer and drier conditions than NC Europe. Barley is known for its tolerance of a wide range of climatic and environmental conditions, including aridity, salinity and cool temperatures (Riehl, 2019; Zohary et al., 2012). Cool temperatures, and possibly salinity in the coastal lowlands, were certainly factors contributing to the apparent success and long duration of barley cultivation in NC Europe. In SE Iberia, on the other hand, aridity and salinity probably determined the high importance of barley. In this regard, it is also noteworthy that the long-term increase of barley proportions (considering naked and hulled barley together) in SE Iberia is in accordance with the long-term decrease in precipitation (Fig. 6.5). Based on the significant positive correlation of increased barley cultivation and aridity in SE Iberia (rho = 0.50; $p > 0.05$) a causal relationship seems likely. This is in line with previous assumptions that barley possibly outperformed free-threshing wheat in SE Iberia with increasing aridity (Rovira Buendía, 2007; Stika & Heiss, in press). Another interesting detail for both regions is the increasing importance of hulled barley after c. 2000 BCE, outnumbering the naked variety during the following centuries. The beginning of this phenomenon coincides with dry episodes in both regions, which would probably have been favourable for both barley varieties, but hulled barley is more resistant to diseases and easier to store (Riehl, 2019). Perhaps, these were some of the reasons for the increasing prominence of hulled barley in both regions (Rovira Buendía, 2007).

Apart from these overall long-term developments between climate and cereal cultivation in both study areas, the short-term fluctuations reveal variable patterns in each region. Focusing on NC Europe, we can observe that free-threshing wheat proportions increase during the first dry and cool episode from 3800 to 3500 BCE (Fig. 6.4). Favourable climate could have acted as a trigger for this development, if we assume that the free-threshing wheat cultivated at the time here was *T. durum*. Naked barley increased, perhaps at the expense of emmer, at 3600 BCE, coincident with the onset of cooler air temperatures. This is in line with barley being more adapted to cool temperatures than emmer (Riehl, 2019; van der Veen & Palmer, 1997). Additionally, a contemporaneous increase in barley cultivation during cooler conditions has also been noted on the British Isles (Bevan et al., 2017). The next notable increase in naked barley and decrease in emmer in NC Europe between 2800 and 2300 BCE is also contemporaneous with a period of cooler air temperatures between 3000 and 2600 BCE and a subsequent reduction in precipitation levels (2600–2300 BCE). When dry conditions are accompanied by higher air temperatures, this could have increased soil evaporation and, thus, salinity in certain areas. In this view, the increased barley cultivation in NC Europe between 2800 and 2300 BCE would have taken advantage of the prevailing climatic conditions. The time after 2200 BCE is characterised by the diversification of the cereal spectrum in NC Europe, the continuous increase in spelt and hulled barley and greater importance of free-threshing wheat and einkorn until 1500 BCE. Air temperatures remained high throughout this period (Fig. 6.4). Precipitation levels varied, however, with an increase at 2300 BCE and a sudden decrease after 2100 BCE, culminating at 1900 BCE. The farmers may have diversified their cereal spectrum in order to account for the variable precipitation pattern. The diversification of the cereal repertoire would have been facilitated by the expanding social networks characteristic of this period (Effenberger, 2018b; Müller & Vandkilde, 2020; Nørgaard et al., 2021). After 1600 BCE, cooler conditions manifested until 500 BCE, with the exception of a brief warming episode around 900/800 BCE. Again, during this cooler period, there were phases of increase in barley – 1500–1100 BCE and 900–500 BCE. The introduction of broomcorn millet, which is known for its great adaptation potential to dry conditions (Miller et al., 2016), at 1300 BCE in NC Europe coincides with a reduction in precipitation levels (Fig. 6.4). In the following centuries, the quantities of millet in the region are higher than initially, and the precipitation is also higher than before. The millet from this period is found mainly in storage deposits, which might be due to its lower ability to become carbonised. If there was a connection between climate conditions and millet cultivation, it might be that the growing of millet became less reliable and incentivised its storage (in greater quantities).

In addition to the long-term decreasing trend in precipitation, people in SE Iberia were also confronted with short-term fluctuations in precipitation and air temperature. According to the archaeobotanical proportions, the first major change occurred at around 2700 BCE, when barley supersedes free-threshing wheat as the dominant cereal taxon. This is coincident with the onset of an aridity trend and a sudden decrease in air temperatures (Fig. 6.5). However, the air temperature reconstructions are just based on four datasets and, thus, have a large uncertainty. Furthermore, it can be assumed that dropping air temperatures did not cause regular frosts in SE Iberia. Accordingly, if we assume climate played a role, precipitation probably has to be considered as the main driver in this development. This having been said, it is worth noting that during the abrupt dry event around 3300 BCE no respective increase in barley has been noted. However, until c. 3000 BCE just a few sites provided archaeobotanical data (Fig. 6.3). Another increase in (hulled) barley during a reduction in precipitation is obvious at around 900 BCE. Accordingly, the common patterns in precipitation levels and barley suggest that precipitation variability was the main driver for long-term and short-term developments within the cultivation of barley in SE Iberia. On the other hand, increased free-threshing wheat (and decreased barley) proportions between c. 1900 and 1600 BCE are obviously confronting such a general dependency as precipitation levels during this period are very low. However, as noted in the previous chapter the reason for increased free-threshing wheat cultivation during this period is probably not climate-driven. Intra-regional differences are one possible explanation (Montes Moya, 2014; Pérez-Jordà, 2013). Another potential explanation might actually point towards an adaptation of agricultural habits to aridity. This is because free-threshing wheat might have been grown primarily in the fertile river lowlands of the Guadiana during that period, where at the so-called 'motillas' people managed to extract groundwater from the subsurface (Aranda et al., 2008; Benítez de Lugo Enrich & Mejías, 2017). Using groundwater for irrigation would have enabled the people to cultivate free-threshing wheat even during very dry periods. As the 'motillas-culture' is proposed to be connected to the El Argar culture, the free-threshing wheat products could be easily distributed among multiple sites in the study area (Aranda et al., 2008; Benítez de Lugo Enrich et al., 2022). The increased cultivation of einkorn and emmer between 2600 and 1800 BCE has been hypothesised to be related to drought (Rovira Buendía, 2007). Indeed, we note increasing aridity during this period. However, such a simple dependency is questioned during 1400–900 BCE, when increased emmer and einkorn proportions are coincident with more humid conditions. However, an increase in air temperatures is also indicated during this time, which could have counteracted the higher precipitation levels. Still, a general relationship on this regional scale of emmer and einkorn cultivation to climate in SE Iberia remains questionable. Today, emmer and einkorn are often cultivated together (Jones & Halstead, 1995), which would explain their congruent developments. Both taxa have also been proposed as resistant to diseases and poor soil conditions (Nesbitt & Samuel, 1996). Because of this, they have likely been cultivated (as fodder) until recent times in the mountainous environments in SE Iberia (Peña-Chocarro, 1996). Thus, their increased cultivation during 2600–1800 BCE and 1400–900 BCE could have been as well related to either increased cultivation practices in mountainous regions or to their resistivity against diseases. Similar to NC Europe, the introduction of millet at around 1000 BCE is coincident with a reduction in precipitation and possibly decreasing air temperatures (Fig. 6.5). However, for a detailed evaluation of whether millet cultivation in SE Iberia was related to climatic conditions, the record is simply too short.

6.5 Conclusion

This chapter has evaluated potential adaptation strategies of past human societies in south-east Iberia (SE Iberia) and north-central Europe (NC Europe) to climatic variability between 4000 and 500 BCE. This was achieved by designing a specific approach that enables standardisation and direct comparison of the archaeobotanical and palaeoclimatic data. Our results capture the main archaeobotanical developments in each of the regions. They confirm the findings of previous archaeobotanical studies, but go beyond and add more detail to certain archaeobotanical developments, including the refinement of the chronology.

The main findings of our analysis are the overall dominance of free-threshing wheat in SE Iberia, of emmer in NC Europe, and of barley in both regions. It is possible that the prevailing climatic conditions in SE Iberia and NC Europe shaped the spectrum of cereals, depending on how suitable they were for individual species and landraces. Importantly, there was a fundamental shift around 2800/2700 BCE in both regions, when naked barley superseded the main wheat taxon. This change and the similar later developments – the increase in barley in both regions – suggest a potential relationship between barley and climate variability in both regions. Interestingly, the possibly determining climatic parameter differs between the regions. In SE Iberia, phases of increase in barley appear closely linked to reductions in precipitation. In NC Europe, phases of barley increase mainly coincide with times of cooler air temperatures. Additionally, interrelation between higher air temperatures and reduced precipitation may have also promoted barley in NC Europe. We further observe that the almost contemporaneous increase in hulled barley around 2000/1900 BCE in both regions, as well as the introductions of millet (both regions) and spelt (NC Europe), coincide with times of potential environmental stress in both regions, principally due to reduced precipitation levels.

Our comparison of the long-term trajectories of cereal cultivation and climate within the two regions is an initial attempt at identifying changes in agricultural methods and practices as possible reactions to changing climates. We recognised several periods during which climate conditions may have been favourable for growing some species but not others. This study offers a basis from which further, more detailed considerations can follow, particularly those looking at smaller temporal and spatial scales.

Acknowledgements We sincerely acknowledge the help of Tanja Reiser (Institute for Prehistoric and Protohistoric Archaeology, Kiel University) in the compilation and standardisation of the archaeobotanical data.

Appendix (Figs. 6.A1, 6.A2, 6.A3, 6.A4, 6.A5, 6.A6, 6.A7, and 6.A8)

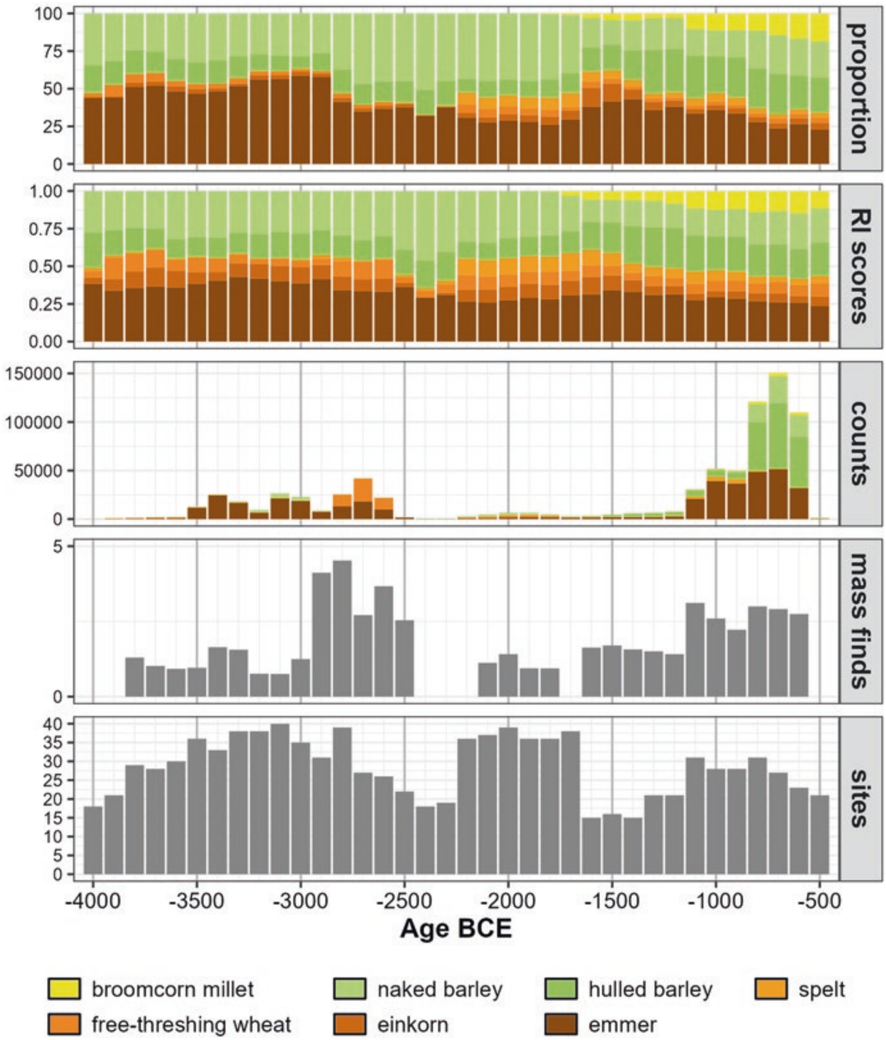

Fig. 6.A1 Archaeobotanical results from north-central Europe applying no threshold

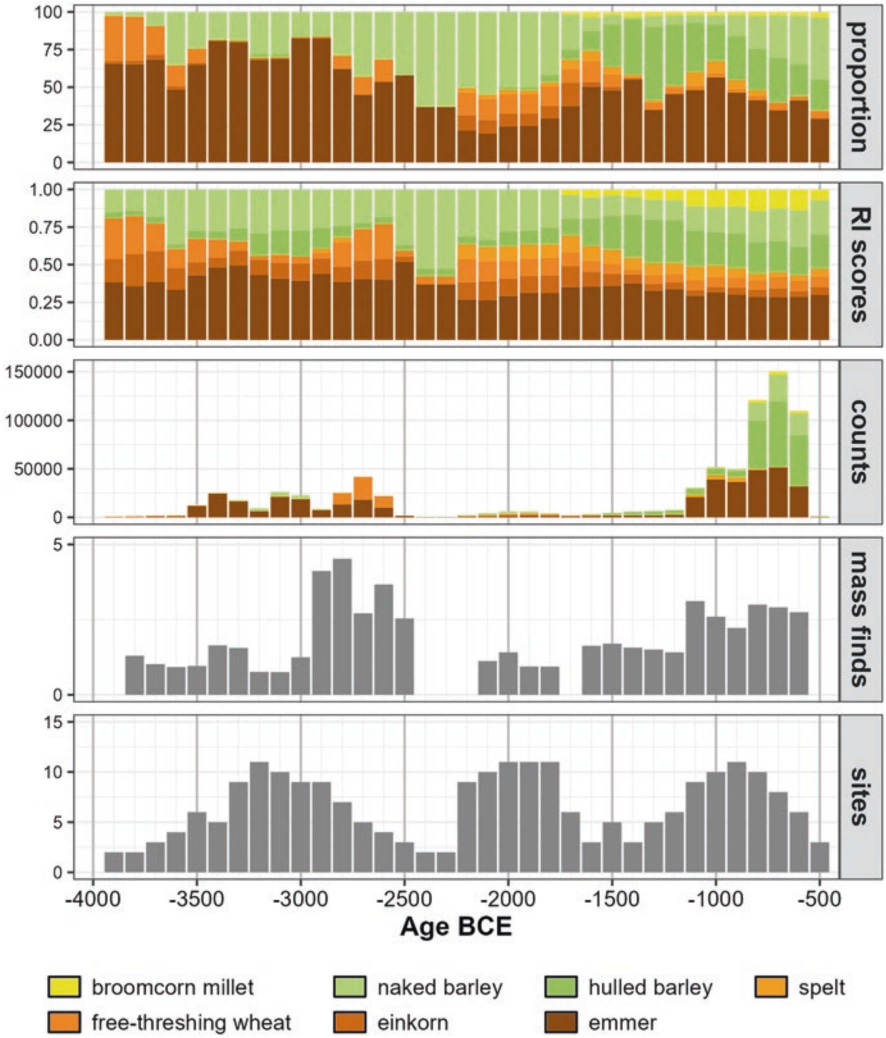

Fig. 6.A2 Archaeobotanical results from north-central Europe applying a threshold of 100 minimum counts

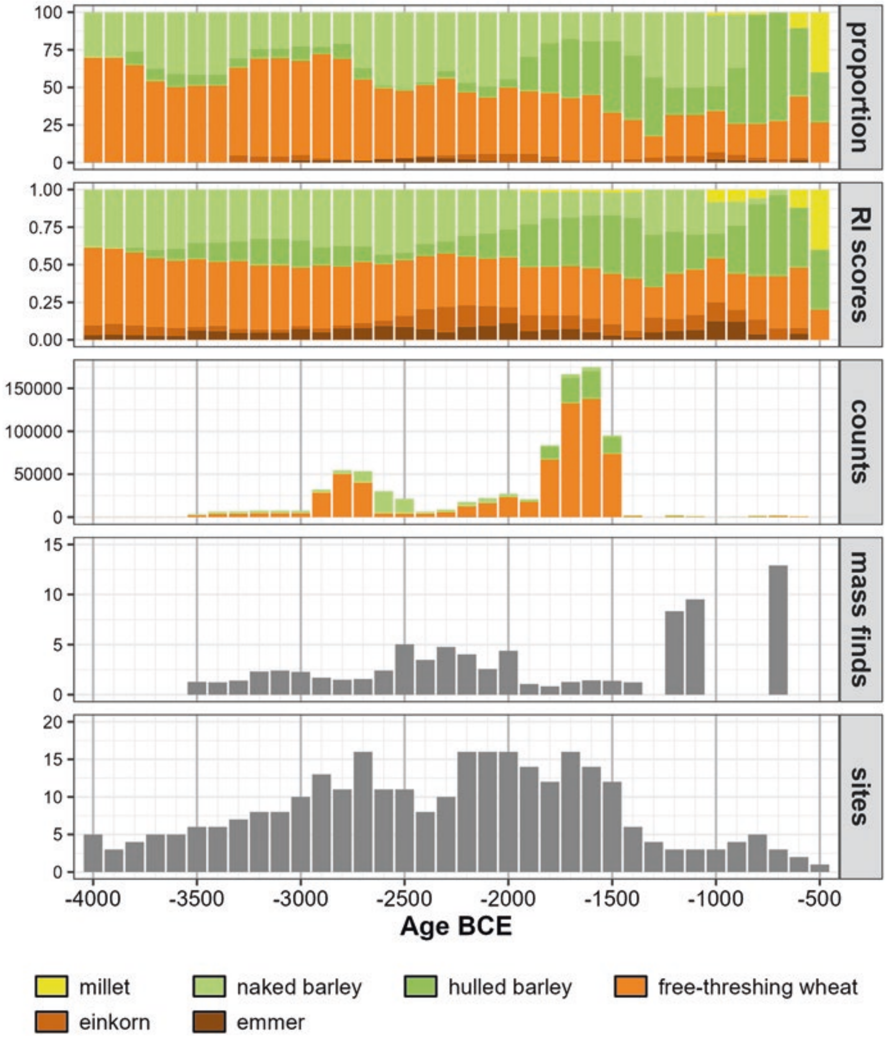

Fig. 6.A3 Archaeobotanical results from south-east Iberia applying no threshold

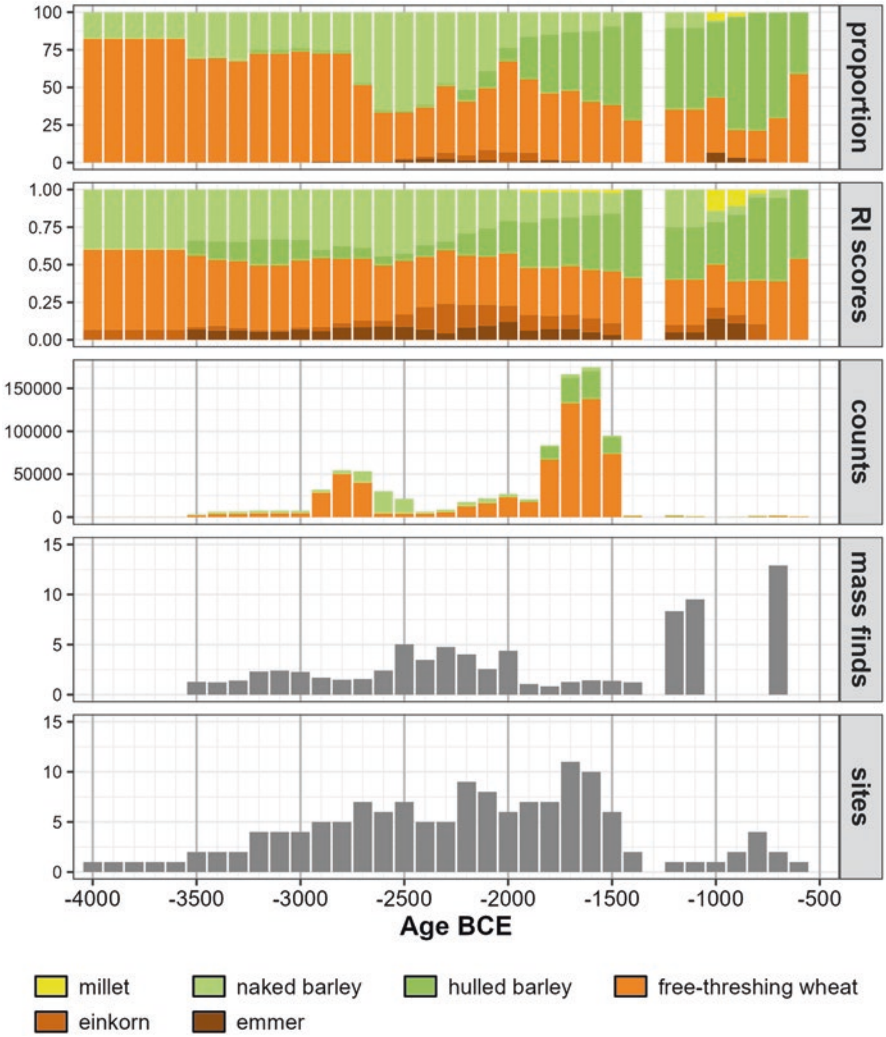

Fig. 6.A4 Archaeobotanical results from south-east Iberia applying a threshold of 100 minimum counts

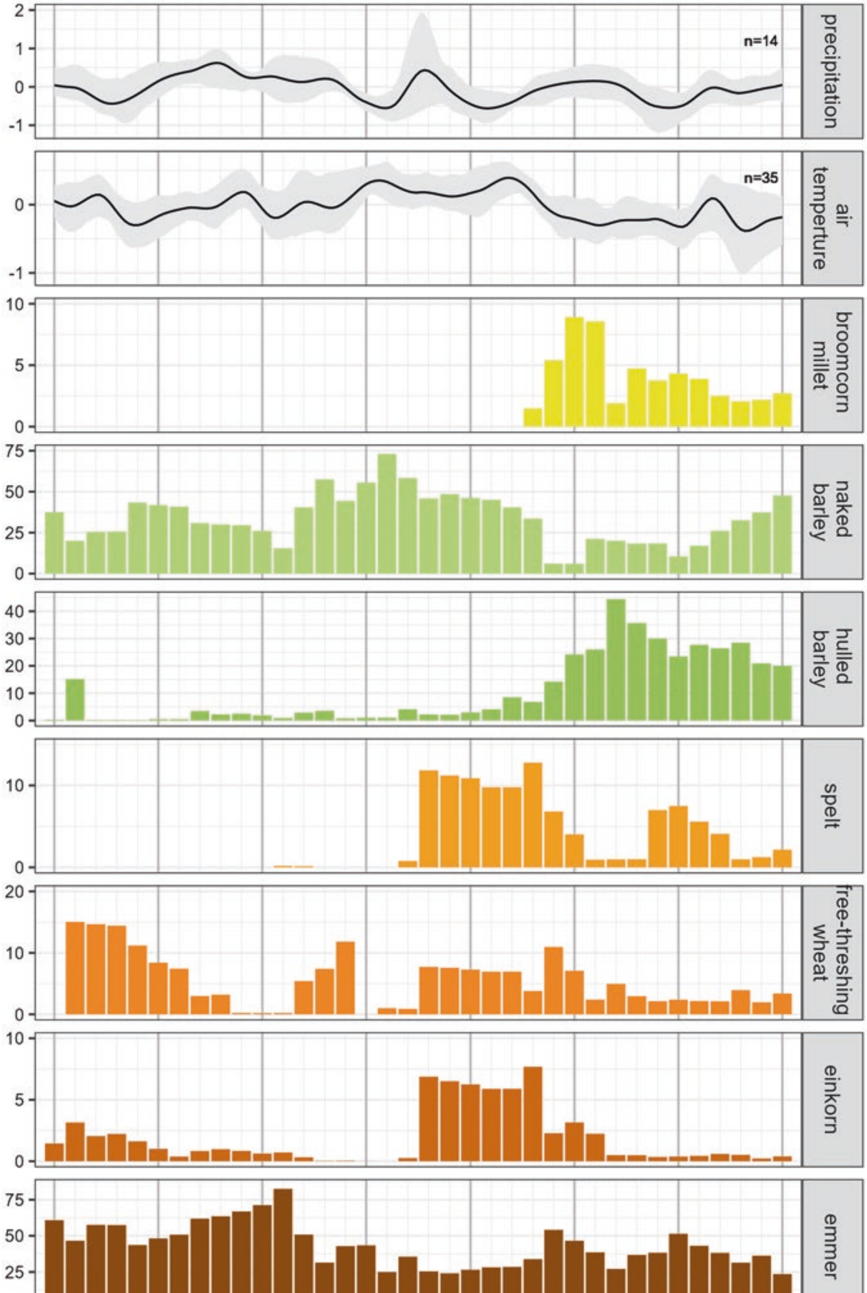

Fig. 6.A5 Archaeobotanical proportions for NC Europe applying a filter of 20 minimum counts separated per taxon

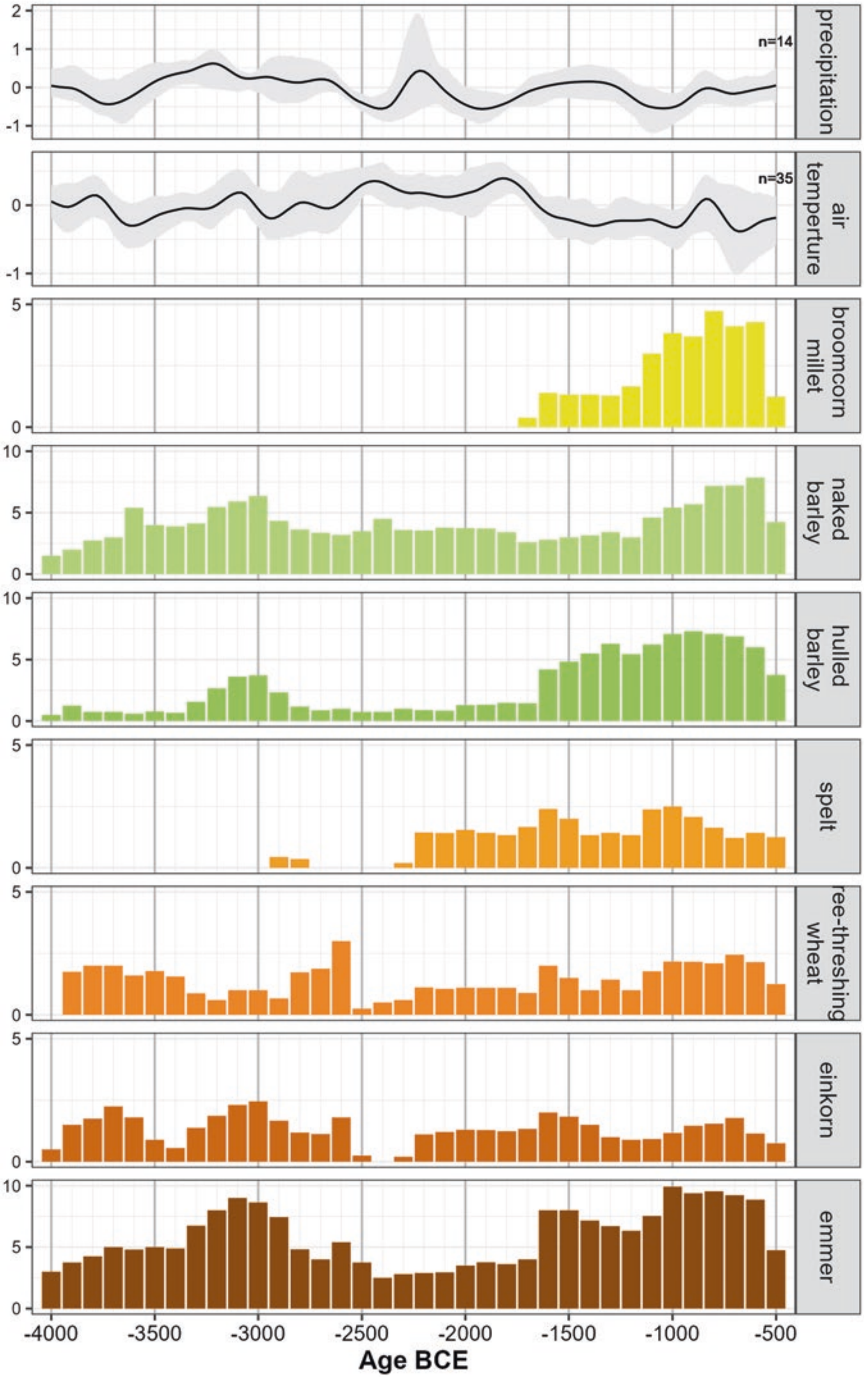

Fig. 6.A6 Archaeobotanical RI-scores for NC Europe applying a filter of 20 minimum counts separated per taxon

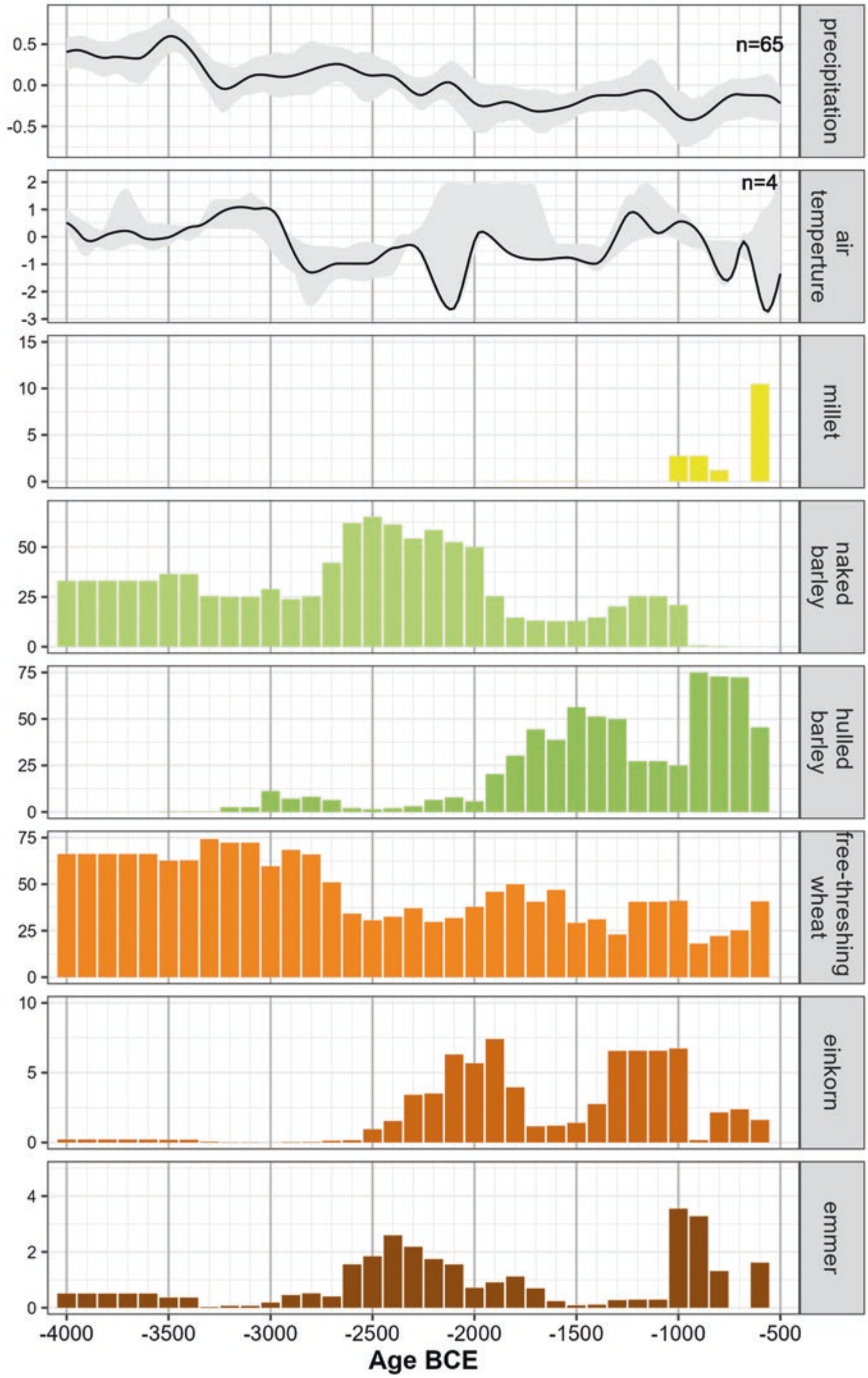

Fig. 6.A7 Archaeobotanical proportions for SE Iberia applying a filter of 20 minimum counts separated per taxon

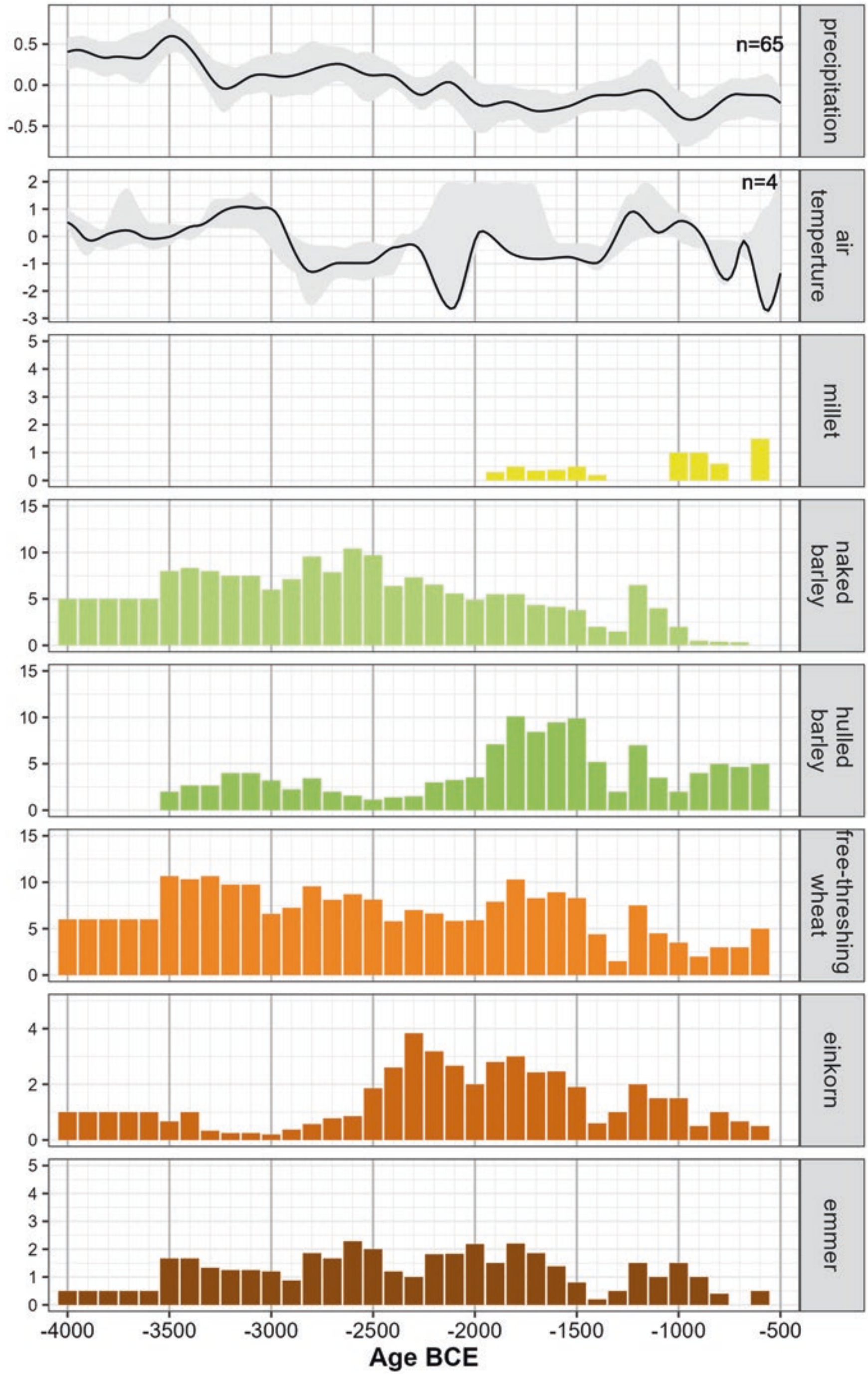

Fig. 6.A8 Archaeobotanical RI-scores for SE Iberia applying a filter of 20 minimum counts separated per taxon

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