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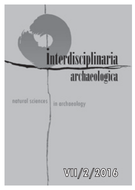

Kernel Weights of Triticum, Hordeum, Avena, Secale and Panicum Species can be used for Better Estimation of Importance of Different Cereal Species in Archaeobotanical Assemblages

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A B S T R A C T

The importance of different cereals for human and animal nutrition in different historical periods has been frequently estimated according to the proportion of grains of individual cereal species from the total number of recorded grains in the archaeological assemblage. However, such presentations do not respect the differences in grain size among particular species. The aim of this study was to compare the kernel weights of cereal species planted in Europe since the Neolithic up to the first half of the 20th century and to propose recalculation coefficients for their relevant comparison. Thousand kernel weights (TKW) of cereals were obtained from the Evigez database and from the available literature. Taking the TKW of *Triticum aestivum* (44.6 g) as 100%, the descending order of cereal species in terms of their TKW in relation to *T. aestivum* was *T. spelta* (100%), *T. turgidum* (99%), hulled *Hordeum vulgare* (97%), *T. durum* (92%), *T. dicoccum* (88%), naked *H. vulgare* (81%), *Secale cereale* (79%), *T. dicoccoides* (76%), *T. monococcum* (67%), hulled *Avena sativa* (66%), naked *A. sativa* (64%) and finally *Panicum miliaceum* (12%). We recommend the use of these proposed recalculation coefficients for the comparison of proportions of cereal grains in archaeobotanical assemblages. The recalculated values better reflect the importance of the different cereal species for human economies and nutrition rather than simple proportions of the recorded grains of an individual species. The recalculation coefficients are particularly important in the case of a high proportion of *P. miliaceum* in an archaeological assemblage, as its grain size differs the most from the other frequently-recorded cereals.

1. Introduction

The grains of cereals belong to the most frequently recorded remains of cultural plants in archaeological assemblages. Since the start of agriculture in the European Neolithic up to Roman Times, the main cereals were hulled wheats, diploid *Triticum monococcum* (einkorn, 2n=14, Zaharieva, Monneveux 2014) and tetraploid *T. dicoccum* (emmer, 2n=28, Kreuz *et al.* 2005; Zaharieva *et al.* 2010). Since the Neolithic or Bronze age, respectively, hulled and naked *Hordeum vulgare* (barley) together with *Panicum milliaceum* (common millet) were also commonly planted, and *T. dicoccum* was still the main staple crop (Hajnalová 1993; Bernardová *et al.* 2010; Šálková *et al.* 2012; Festi *et al.* 2011; Zohary *et al.* 2012; Dreslerová *et al.* 2013). Hexaploid wheat species such as hulled *T. spelta* (spelt, 2n = 42) and naked *T. aestivum* (baker wheat, 2n = 42) appeared in central Europe from the Late Bronze Age (Beneš, Přikrylová 2008; Kočár, Dreslerová 2010). Since the La Tène period, the intentional planting of the formerly weedy cereal species *Secale cereale* (rye), *Avena sativa* (oat), and *Hordeum vulgare* (barley) became more common (Zohary *et al.* 2012; Dreslerová *et al.* 2013). Roman Times were characterised by the planting of *H. vulgare*, followed by *T. dicoccum*, *Panicum*, and by naked wheat (probably *T. aestivum*), *Avena* and *Secale* (Preiss *et al.* 2005; Dreslerová, Kočár 2013). From the Migration period, naked wheat (*T. aestivum* the most probably) prevailed

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followed by *Hordeum*, *Secale*, *Avena* and *T. dicoccum* (Brombacher, Hecker 2015). At the start of the 20th century, *Secale* was the main crop (having the largest cropping area in the Czech Republic), followed by *Avena* (Figure 1). The cropping area of *T. aestivum* and *Hordeum* was lower than half of the cropping area of *Secale* and *Avena* in the 1930s. The proportion of individual cereal crops completely changed after World Word II, and since the 1960s up to the present the main cereal crop has been *T. aestivum* followed by *Hordeum*; *Avena* and *Secale* have both become marginal crops with negligible cropping area. The planting of *T. monococcum* and *T. dicoccum* has completely disappeared. In the 21st century, the renaissance of hulled wheat planting (*T. monococcum*, *T. dicoccum* and *T. spelta*) in Europe has been connected with the spread of organic farming and the increased interest in products with a high nutritional quality (Marino *et al.* 2009, 2011; Konvalina *et al.* 2012a). Although hulled *Hordeum* varieties dominate in contemporary Europe, hull-less (naked) varieties have been planted in the past and used for food production (Lister, Jones 2013). In central Europe, their planting was popular during the Bronze Age and then its use steeply declined (Šálková *et al.* 2012). In northern Europe, naked barley represented approximately 50% of the Neolithic and Bronze Age barley records (Lister, Jones 2013). In mountain regions of Asia, such as the uplands of China, India, Nepal, Pakistan, Japan, both Koreas and Tibet, naked varieties of *Hordeum* are still planted and used as a staple crop for food production (Saisho, Purugganan 2007). In central Europe, naked barley was recorded as a relict of traditional mountain agriculture in an archaeobotanical assemblage from the 18th century AD (Beneš, Kočár 2000).

The importance of different cereals for human and animal nutrition in different historical periods is a key point in archaeobotanical investigations, but there are vital methodological issues in its evaluation. It has been frequently estimated according to the proportion of grains of an individual cereal species from the total number of recorded grains in the archaeological assemblage. This is the simplest and most frequently-used way of presenting the data, but comes with low predictive value as to which cereal species are/were important for human and animal nutrition, thus making interpretations problematic. The problem with such a presentation is that it disregards the differences in grain size among particular species. For example, the grain of *Panicum* is much smaller than the grain of *T. aestivum*. The value of one *Panicum* grain for human nutrition is therefore substantially lower than the value of one grain of *T. aestivum*. To make an adequate comparison of the grains of different cereal species in archaeological assemblages, a recalculation of their numbers according to their importance for human nutrition or economy is necessary. The simplest way to do this is to use the kernel (grain) weights. In agronomy, a thousand kernel weight (TKW – the weight of a 1000 seeds) is one of the basic agronomic traits used to characterize the grain size of different crops and their varieties (*e.g.* Peleg *et al.*, 2011; Guarda *et al.*, 2004).

Taking account of the missing recalculation coefficients for the comparison of different cereals, the aim of this study was to compare the kernel weights of cereal species planted in Europe since the Neolithic up to the first half of the 20th century and to propose recalculation coefficients for their relevant comparison. As an example, we then

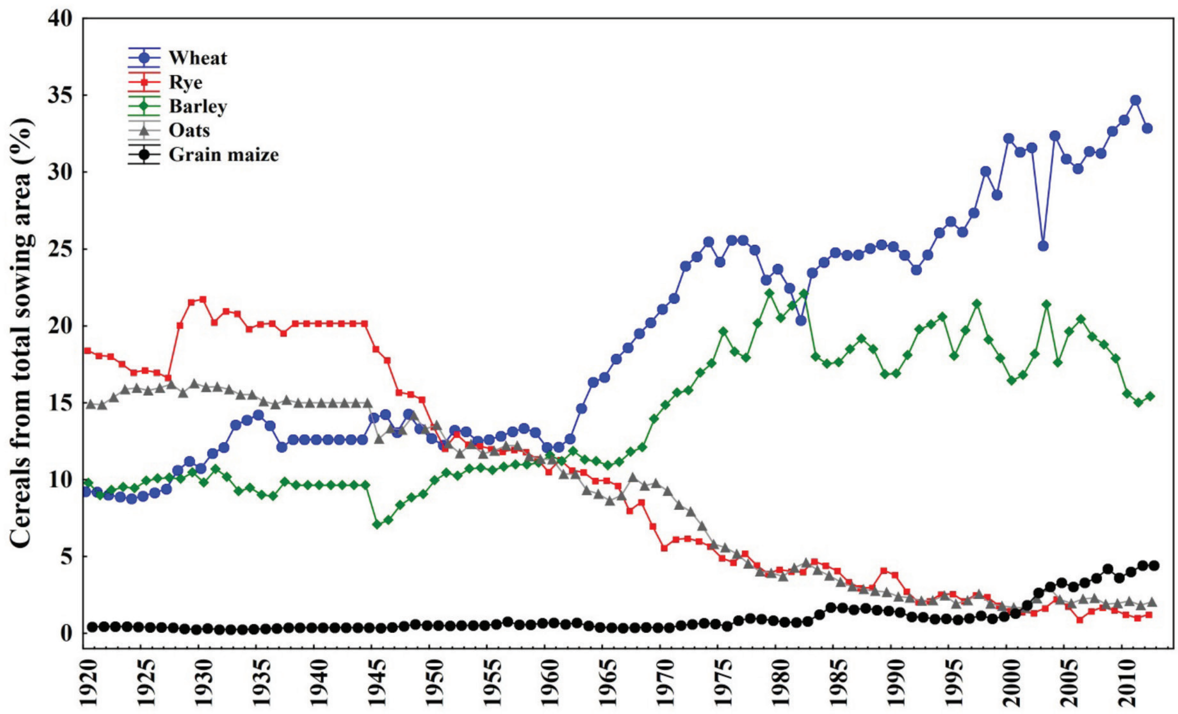

Figure 1. Proportion of cropping area of *Triticum aestivum* (wheat), *Secale cereal* (rye), *Hordeum vulgare* (barley), *Avena sativa* (oats) and *Zea mays* (grain maize) from total cropping area in the Czech Republic from 1920 to 2012 (according to Czech Statistical Office).

used an archaeological assemblage from the Late Bronze Age to demonstrate the application and importance of the recalculation coefficient.

2. Material and methods

2.1 Thousand kernel weights of different cereals and recalculation coefficients

To provide a comparison of the kernel weights of cereal species planted in Europe since the Neolithic up to the first half of the 20th century, we assembled data on about a thousand kernel weights (TKW) of old varieties of cereals registered up to 1960s – as these would be minimally affected by modern breeding methods. In the case of marginal cereal species such as *T. monococcum* and *T. dicoccum*, we also used modern varieties as these have generally only been subjected to limited breeding in comparison to the frequently-planted *T. aestivum* with its many varieties. The TKW of cereals were obtained from the gene bank of the Crop Research Institute Prague – Ruzyně, the database Evigez (plant genetic resources documentation in the Czech Republic, http://genbank.vurv.cz/genetic/resources/asp2/default.htm) – and from the available literature (Codianni *et al.* 1996; Karagöz, Zencirci 2005; Troccoli, Codianni 2005; De Vita *et al.* 2006; Marino *et al.* 2009, 2011; Pagnotta *et al.* 2009; Ünal 2009; Brandolini *et al.* 2011; 2013; Arduiny *et al.* 2014). The TKW for each species was visualized in the form of frequency histograms in order to demonstrate the range of values and their distribution (Figures 2, 3 and 4). For each

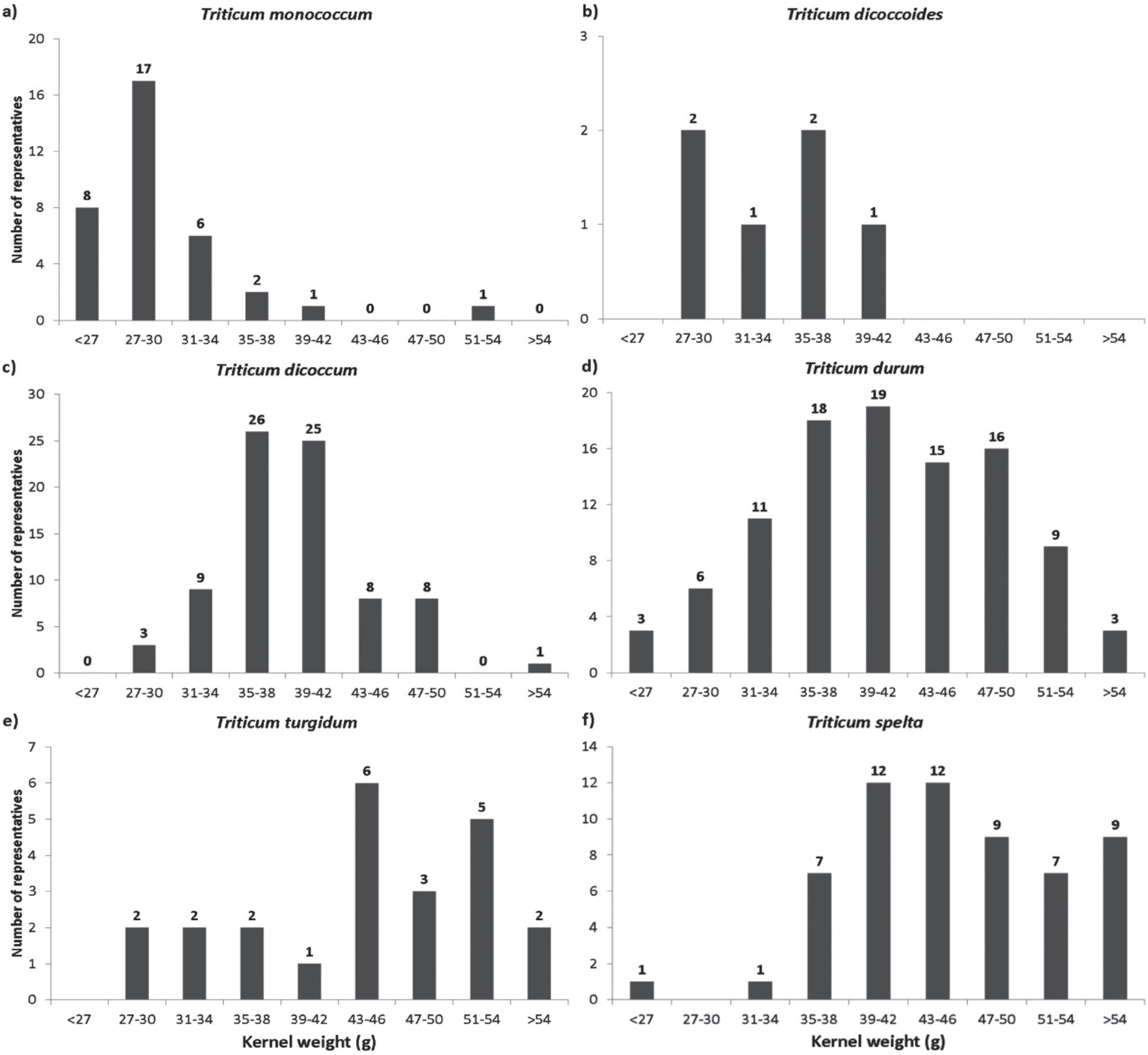

Figure 2. Distribution of thousand kernel weights of (a) *Triticum monococcum*, (b) *T. dicoccoides*, (c) *T. dicoccum*, (d) *T. durum*, (e) *T. turgidum* and (f) *T. spelta*.

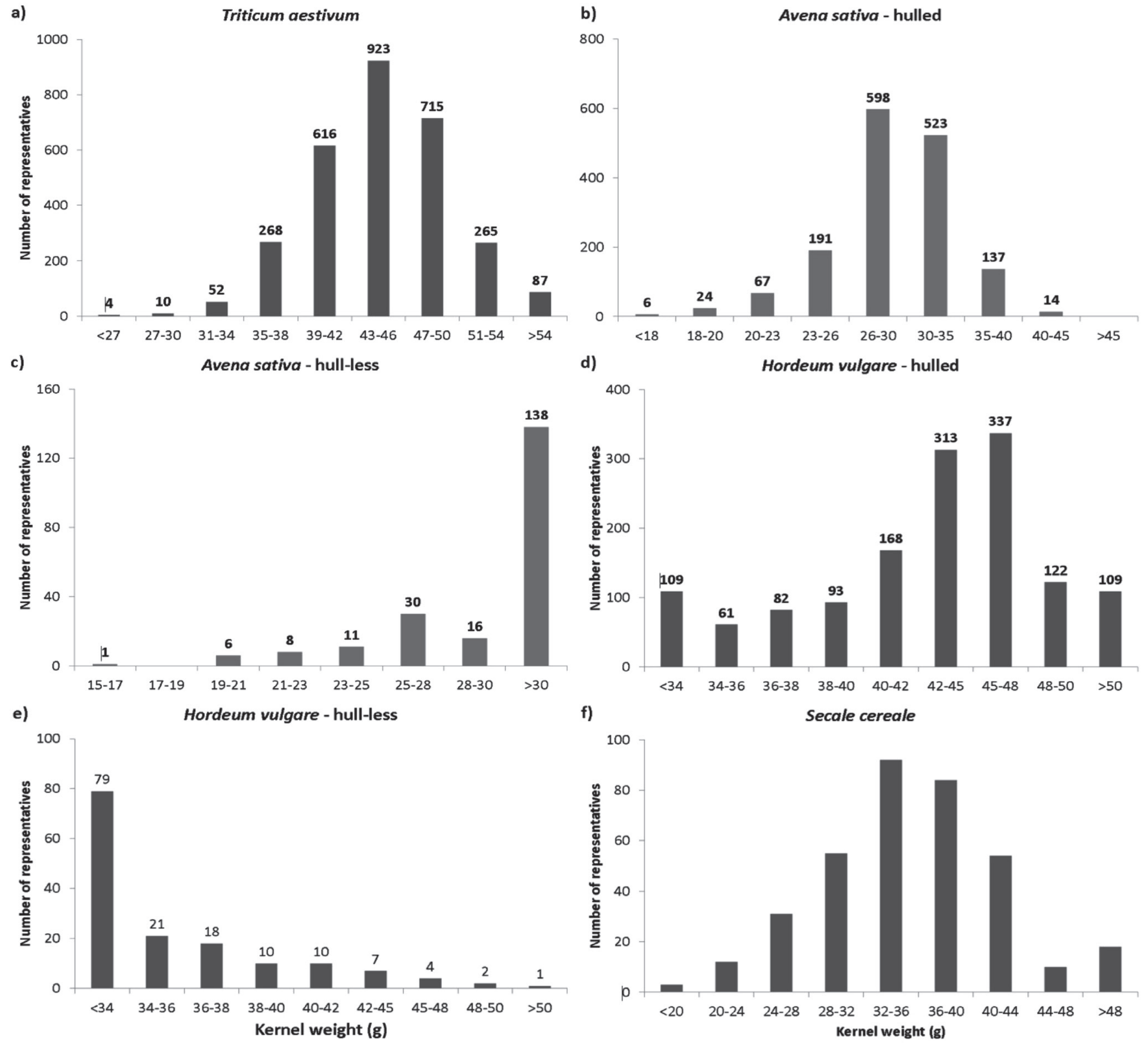

Figure 3. Distribution of thousand kernel weights of (a) *Triticum aestivum*, (b) hulled *Avena sativa*, (c) naked *A. sativa*, (d) hulled *Hordeum vulgare*, (e) naked *H. vulgare* and (f) *Secale cereale*.

species, we calculated the mean and median values, standard deviation (SD) and their coefficients in their relation to *T. aestivum* based on their mean and median values. We used the TKW of *T. aestivum* as the standard for our comparison with other cereal species because *T. aestivum* is the most important cereal species in widespread use today. Therefore, the coefficients were calculated as a ratio of the TKW of a particular cereal species to the TKW of *T. aestivum*.

2.2 An example of grains in an archaeological assemblage

A practical application of the recalculation coefficient can be well demonstrated with an archaebotanical assemblage, because in the prehistory of Europe, before written historical records, our knowledge of particular cereal values is exclusively based on archaeobotanical assemblages. The model assemblage consists of the analyzed macroremains of cereals gained during the archaeological excavations of the Late Bronze Age sites in the Bechyně region (South Bohemia, Czech Republic, altitude approx. 450 m asl). To demonstrate the importance of recalculation coefficients, grain samples from three settlements were used: Černýšovice – stage Br D – stages according to Jiráň (2008), 13th century BC, Hvožďany – stage Ha A2, 11th century BC and Březnice – stage Ha A2/B1, 1050–1000 BC. Twenty contexts (146 samples, 1556 litres of feature infills and cultural layers) were analysed (for details, see Chvojka *et al.* 2011; Chvojka, Šálková 2012). Macroremains were determined based on basic literature (Hajnalová 1999; Jacomet 2006) and the reference collection of the Laboratory of Archaeobotany

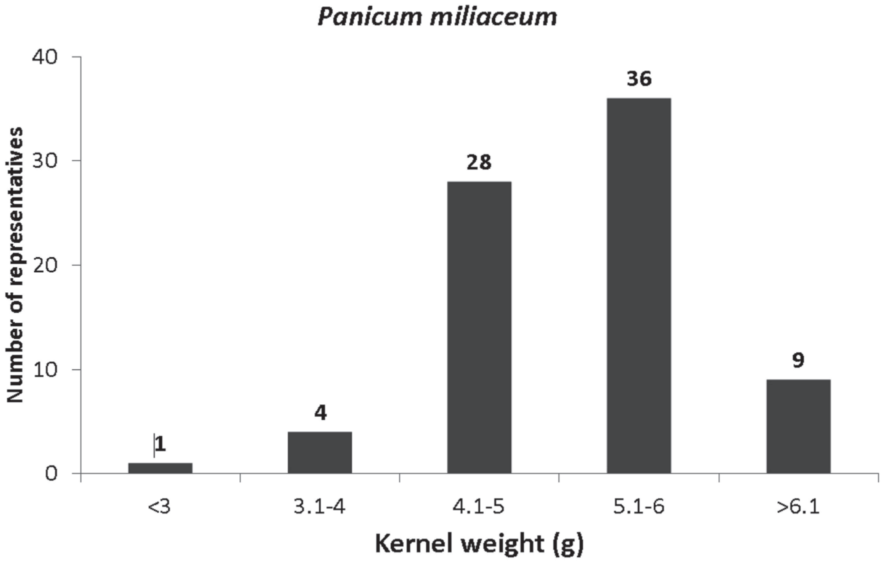

Figure 4. Distribution of thousand kernel weights of *Panicum miliaceum*.

and Paleoecology, University of South Bohemia in České Budějovice. The Number of Identified Specimens (NISP) of caryopsis and rachis were counted. Data were transformed; inaccurate identifications were counted (*e.g. Triticum* cf. *spelta* was counted as *T. spelta*; *Triticum spelta/dicoccum* were divided based on their real proportion in studied sites). Naked *Triticum* caryopses were considered as *T. aestivum* in this study. The proportions of grains of different species were presented as percentages of the total number of recorded cereal grains for all three studied localities together.

3. Results

3.1 The thousand kernel weights of different cereals

The highest TKW from all the investigated cereal species was recorded for both the hexaploid wheat species *T. spelta* and *T. aestivum* followed by the tetraploid *T. turgidum*. The median values of TKW were the same (44.5 g) for all the above-mentioned *Triticum* species. The mean TKW of other cereal species decreased in the following order: hulled *H. vulgare* > *T. durum* > *T. dicoccum* > hull-less *H. vulgare* > *S. cereale* > *T. dicoccoides* > *T. monococcum* > hulled *A. sativa* > hull-less *A. sativa* > *P. miliaceum*. The median values of TKW were similar with the mean values for the majority of species and therefore recalculation coefficients based on mean and median values were almost the same (Table 1). There was high variability in the TKW for all the studied species (Figures 2–4). We recorded almost a normal distribution for the TKW of *T. durum*, *T. spelta, T. aestivum,* hulled *A. sativa*, *S. cereale* and *P. miliaceum*. Highly positively-skewed distributions were found for the TKW of *T. monococcum* and hull-less *H. vulgare*. On the other hand,

Table 1. Thousand kernel weight (TKW – weight of thousand caryopses) of cereals obtained from the literature and database Evigez. n – number of cases, mean – mean value of TKW, mean coef. – coefficient for comparison of different cereals based on mean TKW, median – median value of TKW, median coef. – coefficient for comparison of different cereals based on median TKW, SD – standard deviation.

	n	Mean (g)	Mean coef.	Median (g)	Median coef.	SD
Triticum aestivum	2940	44.62	1	44.5	1	5.03
T. monococcum	35	30.09	0.67	28.8	0.65	5.95
T. dicoccoides	6	33.83	0.76	34.5	0.78	1.98
T. dicoccum	80	39.45	0.88	39.35	0.88	5.08
T. durum	100	41.14	0.92	40.5	0.91	7.43
T. turgidum	23	44.28	0.99	44.5	1	8.23
T. spelta	61	44.75	1	44.5	1	0.87
hulled *Avena sativa*	1560	29.6	0.66	28	0.63	4.33
naked *A. sativa*	210	28.44	0.64	30	0.67	2.75
hulled *Hordeum vulgare*	1394	43.12	0.97	43.5	0.98	4.78
naked *H. vulgare*	152	36.35	0.81	34	0.76	3.68
Secale cererale	359	35.35	0.79	34	0.76	6.32
Panicum miliaceum	78	5.17	0.12	5.17	0.12	0.72

a highly negatively-skewed distribution was found for the TKW of hull-less *A. sativa*.

3.2 Example of grains in archaeological assemblage

In the original data obtained from three Late Bronze Age sites, *P. milliaceum* represented 51% of all cereal caryopses, but after recalculation, it was only 12% (Figure 5). As the proportion of *P. milliaceum* decreased substantially after recalculation, the importance of other cereal species increased: *H. vulgare* from 19% to 36%, *T. dicoccum* from 18% to 31%, *T. spelta* from 6% to 11%, *T. monococcum* from 3% to 4%, *T. aestivum* from 2% to 4%, *Avena sp.* from 0.3% to 0.4% and *S. cereale* from 0.1% to 0.2%.

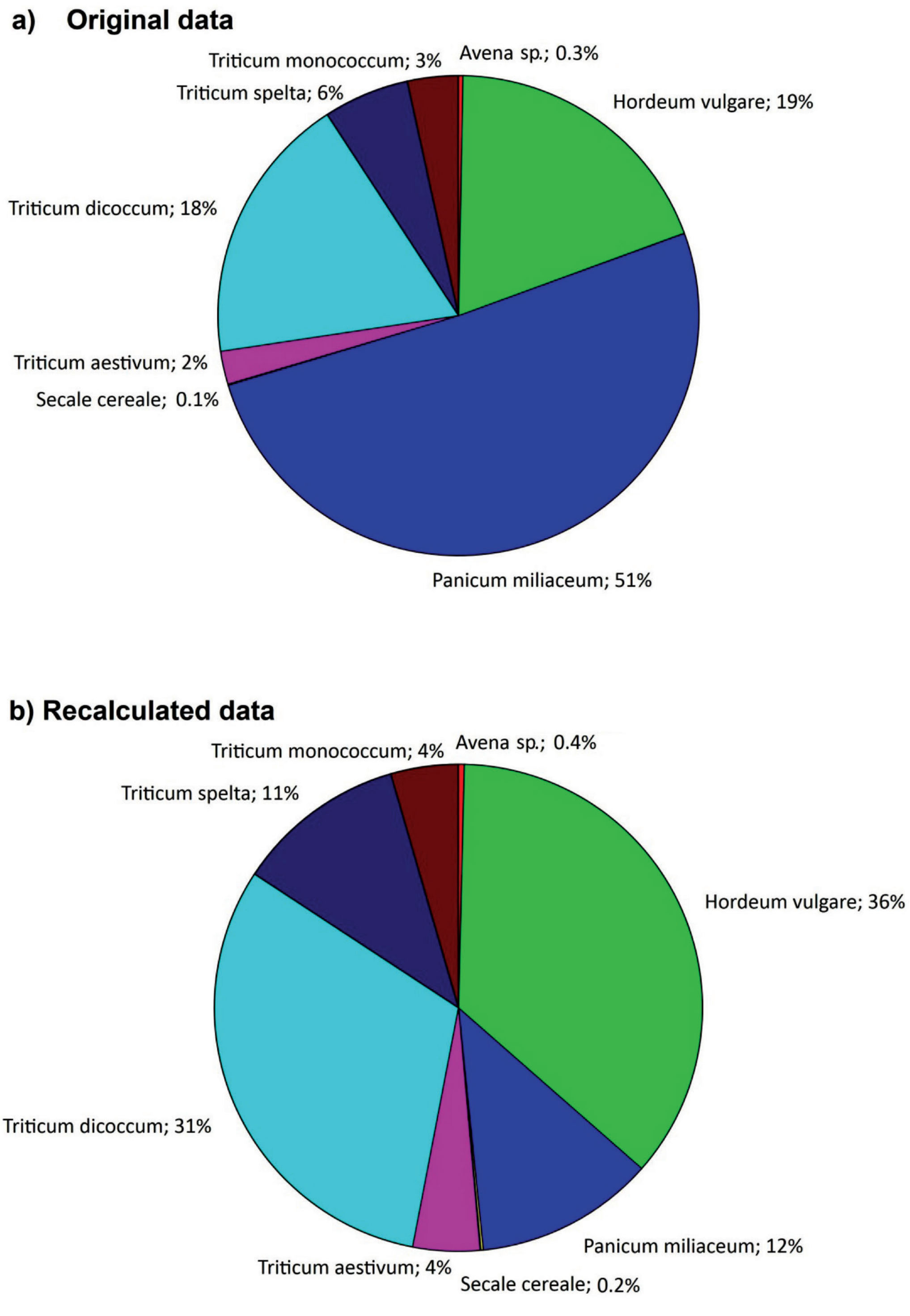

Figure 5. Proportion of grains of individual species from total number of cereal grains in the archaeological assemblage from the Late Bronze Age based on a) original proportions of grains and b) recalculated according to proposed coefficients. Coefficients for hulled varieties were applied for recalculations of *Avena sativa* and *Hordeum vulgare*.

4. Discussion

The main message of our study is that there are large differences in kernel weights among the basic cereal species planted in Europe. We thus recommend the use of recalculation coefficients based on the weight of grains of the different cereal species in studies of their importance for human economies and human and animal nutrition. As the recalculation coefficients based on mean and median values of TKW were almost the same for all species, we recommend to use mean values: the mean is a generally better-known and more widely-used statistical value than the median. Taking the TKW of *T. aestivum* (44.6 g) as 100%, the cereal species in relation to *T. aestivum* according to their TKW, in descending order, is the following: *T. spelta* (100%), *T. turgidum* (99%), hulled *H. vulgare* (97%), *T. durum* (92%), *T. dicoccum* (88%), naked *H. vulgare* (81%), *S. cereale* (79%), *T. dicoccoides* (76%), *T. monococcum* (67%), hulled *A. sativa* (66%), naked *A. sativa* (64%) and, finally, *P. miliaceum* (12%). It can be argued that there is high variability in the kernel weights within each cereal species and that recalculation coefficients are therefore not sufficiently accurate. However, the answer is that though there was really high variability in kernel weights within each cereal species, the mean values of TKW characterize the grain weight of each species relatively well as the mean and median values were almost the same. In spite of these potential limits, it is hard to find a better parameter than TKW as an estimator of crop yield, and hence suitable for comparison of the importance of different cereal species in human subsistence. Recalculation coefficients are particularly important in cases where there is a high proportion of *P. miliaceum* in the archaeological assemblage, as its grain size differs the most from other frequently recorded cereals. This was well demonstrated using the example from the Late Bronze Age: without recalculation, the most important seemed to be *P. miliaceum*, but after recalculation, it proved to be *H. vulgare* followed by *T. dicoccum,* and the importance of *P. miliaceum* decreased more than four times. There are two main sources of variability in TKW within each species: (1) genetic; and (2) phenotypic plasticity. (1) The genetic component is highly important as there are known varieties, or landraces, with both low and high kernel weights. For example, the TKW of *T. monococcum* is higher in Mediterranean countries than in central European countries. The mean TKWs of *T. monococcum* landraces from Austria and Morocco planted together on the same locality were 25 and 36 g, respectively (Brandolini *et al.* 2013). A similar gradient can be recorded as well for *T. dicoccum*. In the Czech Republic, for example, the mean TKW of *T. dicoccum* landraces ranged approximately from 31 to 34 g (Konvalina *et al.* 2012b; 2012c) compared to a mean value of 39 g recorded by De Vita *et al.* (2006) or 48 g recorded by Marino *et al.* (2011) in Italy. These south-north differences in the grain weights of landraces of different cereal species indicate that the recalculation coefficients can be potentially made more precise by using the Mediterranean and central European landraces and varieties separately; but this requires further in-depth research. In both *T. mocococcum* and *T. dicoccum*, there exist landraces with extraordinary high TKWs, but such landraces are rare (see Figures 2a and 2c). Evidently, there was a long-term selection for TKW in both species dependent on latitude – bigger grains in the Mediterranean compared to northern regions. In addition, selection for the extraordinary high TKW was probably not undertaken, as the grain yield per area cannot be a positive function of TKW because of the very high grain yield compensation ability in both species. High grain yields can also be achieved with small grains but with high grain numbers per area (see Hejcman, Hejcmanová 2015 for grain yield compensation ability of *T. dicoccum* and *T. aestivum*). Whether the same north–south gradient of TKW in *T. monococcum* and *T. dicoccum* also existed in different historical periods has, according to the information of the authors, never been studied. As landraces of *T. dicoccum*, but also *H. vulgare*, might retain a phylogeographical structure that reflects ancient events (Saisho, Purugganan 2007; Isaac *et al.* 2010), we believe that the north–south gradient of TKW can also be recorded for grains from different historical periods, but this hypothesis requires further testing using ancient grains.

There also exists high phenotypic plasticity in the TKW. For instance, in the experiment by Hlisnikovský *et al.* (2015), the TKW ranged from 39.5 to 53.5 g for the same variety of *T. aestivum*. High TKWs were recorded under high N-application regimes under optimum water supply and low TKWs were recorded under no fertilizer application in an extraordinary dry year. There were also differences in TKW between localities with different soil types. Hejcman, Hejcmanová (2015) recorded low TKW for *T. dicoccum* (25 g) in stands with a high seeding rate and therefore with too a high spike density.

5. Conclusion

Despite the high variability in TKW within each cereal species, we believe that the proposed recalculation coefficients for the comparison of grains of different cereal species are meaningful and correct as they are based on a meta-analysis of large amounts of available data from the available literature and records from the Evigez database, and not just on a single experiment with a restricted number of genotypes for individual cereal species. We recommend the use of these proposed recalculation coefficients for the comparison of proportions of cereal grains in archaeobotanical assemblages. The recalculated values better reflect the importance of different cereal species for human and animal nutrition, as opposed to the simple proportions of recorded grains of individual species from their total amounts.

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References

ARDUINY, I., MASONI, A., MARIOTTI, M., PAMPANA, S., ERCOLI, L. 2014: Cadmium uptake and translocation in durum wheat varieties differing in grain-Cd accumulation. *Plant, Soil and Environment* 60, 43–49.

BENEŠ, J., KOČÁR, P. 2000: Novověké obilnářství vsi Lažiště (okr. Prachatice) v Pošumaví na základě archeobotanické makrozbytkové analýzy. *Archeologické výzkumy v jižních Čechách* 13, 185–196.

BENEŠ, J., PŘIKRYLOVÁ, P. 2008: *Analýza uhlíků a zuhelnatělých rostlinných makrozbytků ze sídliště mladší doby bronzové v Hostivici u Prahy.* LAPE, České Budějovice – Praha.

BERNARDOVÁ, A., KOMÁRKOVÁ, V., PROSTŘEDNÍK, J., BENEŠ, J. 2010: Fragmented barley grains from the Late Bronze Age Turnov-Maškovy zahrady site in North Bohemia. *Interdisciplinaria Archaeologica – Natural Sciences in Archaeology* I/1–2/2010, 37–44.

BRANDOLINI, A., HIDALGO, A., PLIZZARI, L., ERBA, D. 2011: Impact of genetic and environmental factors on einkorn wheat (*Triticum monococcum* L. subsp. *monococcum*) polysaccharides. *Journal of Cereal Science* 53, 65–72.

BRANDOLINI, A., HIDALGO, A., VACCINO, P., PLIZZARI, L. 2013: Phenotypic variation of a Triticum monococcum L. core collection. Poster presented at the EUCARPIA Genetic Resources section meeting, 11–13 June 2013, Alnarp, Sweden.

BROMBACHER, C., HECKER, D. 2015: Agriculture, food and environment during Merovingian times: plant remains from three early medieval sites in northwestern Switzerland. *Vegetation History and Archaeobotany* 24,331–342.

CHVOJKA, O., BENEŠ, J., FRŐLICH, J., JOHN, J., MICHÁLEK, J., ŠÁLKOVÁ, T., BERNARDOVÁ, A., HOUFKOVÁ, P., KŘIVÁNEK, R., MAJER, A., NOVÁK, J., NOVÁKOVÁ, K., TALAROVIČOVÁ, E. 2011: Osídlení doby bronzové v povodí říčky Smutné v jižních Čechách. *Archeologické výzkumy v jižních Čechách. Supplementum* 8, 308–325.

CHVOJKA, O., ŠÁLKOVÁ, T. 2012: Zur Deutung der urnenfelderzeitlichen streifenformigen Siedlungsobjekte. In: *Peregrinationes archaeologicae in Asia et Europa Joanni Chochorowski dedicatae.* 183–191.

CODIANNI, P., RONGA, G., DI FONZO, N., TROCCOLI, A. 1996: Performance of selected strains of ʿfarroʾ (*Triticum monococcum* L., *Triticum dicoccum* Schübler, *Triticum Spelta* L.) and durum wheat (*Triticum Durum* Desf. cv. *Trinakria*) in the difficult flat environment of Southern Italy. *Journal of Agronomy and Crop Science* 176, 15–21.

DE VITA, P., RIEFOLO, C., CODIANNI, P., CATTIVELLI, L., FARES, C. 200: Agronomic and qualitative traits of *T. turgidum* ssp. *dicoccum* genotypes cultivated in Italy. *Euphytica* 150, 195–205.

DRESLEROVÁ, D., KOČÁR, P. 2013: Trends in cereal cultivation in the Czech Republic from the Neolithic to the Migration period (5500 B. C. – A. D. 580). *Vegetation History and Archaeobotany* 22,257–268.

DRESLEROVÁ, D., KOČÁR, P., CHUMAN, T., ŠEFRNA, L., PONIŠTIAK, Š. 2013: Variety in cereal cultivation in the Late Bronze and Early Iron Ages in relation to environmental conditions. *Journal of Archaeological Science* 40, 1988–2000.

FESTI, D., TECCHIATI, U., STEINER, H., OEGGL, K. 2011: The Late Neolithic settlement of Latsch, Vinschgau, northern Italy: subsistence of a settlement contemporary with the Alpine Iceman, and located in his valley of origin. *Vegetation History and Archaeobotany* 20, 367–379.

GUARDA, G., PADOVAN, S., DELOGU, G. 2004: Grain yield, nitrogen-use efficiency and baking quality of old and modern Italian bread-wheat cultivars grown at different nitrogen levels. *European Journal of Agronomy* 21, 181–192.

HAJNALOVÁ, E. 1993: *Obilie v archeobotanických nálezech na Slovensku.* Acta Interdisciplinaria Archaeologica VIII, Nitra.

HAJNALOVÁ, E. 1999: *Archeobotanika pestovaných rastlín.* Slovenská poľnohospodárska univerzita, Nitra.

HEJCMAN, M., HEJCMANOVÁ, P. 2015: Yield and nutritive value of grain, glumes and straw of *Triticum dicoccum* produced by prehistoric technology in comparison to *T. aestivum* produced by modern technology. *Interdisciplinaria Archaeologica, Natural Sciences in Archaeology* VI/1/2015, 31–45.

HLÍNIKOVSKÝ, L., KUNCOVÁ, E., HEJCMAN, M., DVOŘÁČEK, V. 2015: Effect of fertilizer application, soil type, and year on yield and technological parameters of winter wheat (*Triticum aestivum*) in the Czech Republic. *Archives of Agronomy and Soil Science* 61, 33–53.

ISAAC, A. D., MULDOON, M., BROWN, K. A., BROWN, T. A. 2010: Genetic analysis of wheat landraces enables the location of the first agricultural sites in Italy to be identified. *Journal of Archaeological Science* 37, 950–956.

JACOMET, S. 2006: *Identification of cereal remains from archaeological sites*. 2nd edition. Basel.

JIRÁŇ, L. (Ed.) 2008: *Archeologie pravěkých Čech – Svazek 5. Doba bronzová*. Archeologický ústav AV ČR, Praha.

KARAGŐZ, A., ZENCIRCI, N. 2005: Variation in wheat (*Triticum* spp.) landraces from different altitudes of three regions of Turkey. *Genetic Resources and Crop Evolution* 52, 775–785.

KOČÁR, P., DRESLEROVÁ, D. 2010: Archaeobotanical finds of cultivated plants in the prehistory of the Czech Republic. *Pamatky archeologické* 101, 203–242.

KONVALINA, P., CAPOUCHOVÁ, I., STEHNO, Z. 2012a: Agronomically important traits of emmer wheat. *Plant, Soil and Environment* 58, 341–346.

KONVALINA, P., CAPOUCHOVÁ, I., STEHNO, Z., KÁŠ, M., JANOVSKÁ, D., ŠKEŘÍKOVÁ, A., MOUDRÝ, J. 2012c: *Pěstování a využití pšenice dvouzrnky v ekologickém zemědělství*. Výzkumný ústav rostlinné výroby, Praha.

KONVALINA, P., CAPOUCHOVÁ, I., STEHNO, Z., MOUDRÝ, J. 2012b: Differences in yield parameters of emmer in comparison with and new varieties of bread wheat. *African Journal of Agricultural Research* 7, 986–992.

KREUZ, A., MARINOVA, E., SCHÄFER, E., WIETHOLD, J. 2005: A comparison of early Neolithic crop and weed assemblages from the Linearbandkeramik and the Bulgarian Neolithic cultures: differences and similarities. *Vegetation History and Archaeobotany* 14, 237–258.

LISTER, D. L., JONES, M. K. 2013: Is naked barley an eastern or a western crop? The combined evidence of archaeobotany and genetics. *Vegetation History and Archaeobotany* 22, 439–446.

MARINO, S., TOGNETTI, R., ALVINO, A. 2009: Crop yield and grain quality of emmer populations grown in central Italy, as affected by nitrogen fertilization. *European Journal of Agronomy* 31, 233–240.

MARINO, S., TOGETTI, R., ALVINO, A. 2011: Effects of varying nitrogen fertilization on crop yield and grain quality of emmer grown in a typical Mediterranean environment in central Italy. *European Journal of Agronomy* 34, 172–180.

PAGNOTTA, M. A., MONDINI, L., CODIANNI, P., FARES, C. 2009: Agronomical, quality, and molecular characterization of twenty Italian emmer wheat (*Triticum dicoccon*) accessions. *Genetic Resources and Crop Evolution* 56, 299–310.

PELEG, Z., FAHIMA, T., KOROL, A. B., ABBO, S., SARANGA, Y. 2011: Genetic analysis of wheat domestication and evolution under domestication. *Journal of Experimental Botany* 62, 5051–5061.

PREISS, S., MATTERNE, V., LATRON, F. 2005: An approach to funerary rituals in the Roman provinces: plant remains from a Gallo-Roman cemetery at Faulquemont (Moselle, France). *Vegetation History and Archaeobotany* 14, 362–372.

TROCCOLI, A., CODIANNI, P. 2005: Appropriate seeding rate for einkorn, emmer, and spelt grown under rainfed condition in southern Italy. *European Journal of Agronomy* 22, 293–300.

SAISHO, D., PURUGGANAN, M. D. 2007: Molecular phylogeography of domesticated barley traces expansion of agriculture in the old world. *Genetics* 177, 1765–1776.

ŠÁLKOVÁ, T., BENEŠ, J., KOMÁRKOVÁ, V., VANĚČEK, Z. 2012: History of barley (*Hordeum vulgare*) in Central Europe according to archaeobotanical findings. *Kvasný průmysl* 58, 215–227.

ÜNAL, H. G. 2009: Some physical and nutritional properties of hulled wheat. *Tarim bilimleri dergisi* 15, 58–64.

ZAHARIEVA, M., AYANA, N. G., AL HAKIMI, A., MISRA, S. C., MONNEVEUX, P. 2010: Cultivated emmer wheat (*Triticum dicoccon* Schrank), an old crop with promising future: a review. *Genetic Resources and Crop Evolution* 57, 937–962.

ZAHARIEVA, M., MONNEVEUX, P. 2014: Cultivated einkorn wheat (*Triticum monococcum* L. subsp. *monococcum*): the long life of a founder crop of agriculture. *Genetic Resources and Crop Evolution* 61, 677–706.

ZOHARY, D., HOPF, M., WEISS, E. 2012: *Domestication of plants in the old world*, 4th edition. Oxford University Press, Oxford.