The wind that shakes the barley: the role of East Asian cuisines on barley grain size

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ARTICLE

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ABSTRACT
This paper investigates the eastern movements of barley grains and their morphological variations in prehistory. By combining previously published and newly collected archaeobotanical grain measurements (*n* = 2,176), we explore the roles of culinary traditions underlying the morphological traits observed. We find that barley diminished in size as it moved from its origin in southwestern Asia to Central and East Asia between the third millennium BC and first millennium BC. In particular, the grains in Monsoonal China became greatly reduced in comparison to other regions as the crop was incorporated into eastern small grain cuisines. The reverse pattern is observed in the high-altitude Tibetan environment, which is attributed to the practicalities of cooking under low vapour pressure conditions. These results, demonstrating that barley moved eastward but western grinding and baking traditions did not, reveal the complexity of the eastern culinary system and raise awareness of decoupling of grains and their associated cuisines.

KEYWORDS
Barley; food globalization; ancient culinary practices; grain size; prehistory

Introduction

An increase in grain (caryopsis) size is often featured as a key measure of plants' 'domestication syndrome' (Zohary and Hopf 2000; Fuller et al. 2014, 2017). Larger grain size in the context of early cultivation is considered to reflect the productive benefits of the cultivated field compared to the wild habitat (Harlan, de Wet, and Glen Price 1973; Allaby et al. 2021). Between approximately the fifth and second millennia BC, however, the grain size of one of the world's most important crops, wheat, underwent a substantial reduction (Fuller et al. 2014; Liu et al. 2016). This pattern is likely the result of regional variations in eastern and western Eurasia as crops dispersed beyond their native ecological limits (Fuller et al. 2017). It is unclear, however, whether these variations reflect

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Supplemental data for this article can be accessed here.

phenotypic plasticity or underlining genetic adaptation for compactness of the grain shape and spike (MacKey 1966; Mori et al. 2013). Scholars have hypothesized that environmental adaptation could account for the observed trends (e.g. Spengler 2015; Fuller et al. 2017; Motuzaite-Matuzeviciute et al. 2018). In this paper, we shift the focus from the environment to cuisine and consider the role of eastern food preparation practices in grain size variation of another Fertile Crescent originated cereal: barley. The aim is to assess whether morphotypes of eastward spreading barley were directly influenced by eastern culinary practices.

Between approximately 5000 and 1500 cal. BC, movements of several cereal crops from distinct domestication centers linked distant communities to a web of connections that spanned the entire Eurasian landmass (e.g. Jones et al. 2011, 2016; Liu et al. 2019). As part of this prehistoric 'food globalization', free-threshing wheat (*Triticum* cf. *aestivum*) and naked and hulled barley (*Hordeum vulgare)* spread from origins in southwestern Asia, through Central Asia into East Asia (e.g. Frachetti et al. 2010; Liu et al. 2017). Much has been discussed regarding the routes and chronologies of wheat and barley dispersals (e.g. Flad et al. 2010; Frachetti 2012; Barton and An 2014; Betts, Weiming Jia, and Dodson 2014; Spengler et al. 2014; Liu et al. 2016; Zhao 2018; Motuzaite-Matuzeviciute et al. 2018, 2020ab; Zhou et al. 2020; Deng et al. 2020; Motuzaite Matuzeviciute et al. 2020; Tan et al. 2021; Tang et al. 2021), including the possibility of a very old maritime connection in the third millennium BC (Zhao 2009). During the second millennium BC, however, more substantial movements took place across the continent. A now well-documented trajectory is along the so-called 'Inner Asian Mountain Corridor', a piedmont zone spanning from Southwest Asia through the Pamir, Tianshan, Dzhungar and Altai Mountains, and subsequently connecting to the Hexi Corridor (Frachetti 2012; Spengler 2015; Liu et al. 2016; Stevens et al. 2016; Motuzaite Matuzeviciute et al. 2020ab; b; Zhou et al. 2020). Further, the initial expansion of wheat and barley cultivation into ancient China might not have occurred simultaneously, but through distinct processes that likely took place over millennia via several pathways, including one over the southern Tibetan Plateau (Liu et al. 2017; Lister et al. 2018).

In addition to the ongoing research on routes and chronologies, scholarly attention has focused on understanding the drivers underlining the 'Food Globalization' process. Among them, the social and culinary drivers and the context in which dietary innovation could occur have been debated (Jones et al. 2011; Boivin, Fuller, and Crowther 2012; Liu and Jones 2014). Central to our investigation are the differences in culinary traditions of early communities in East and West Asia: food processing techniques based on boiling and steaming of grain in the East, grinding grain and baking the resulting flour in the West (Sakamoto 1996; Fuller and Rowlands 2009). These deep-seated culinary differences, to some extent, explain the material distinction that has long been observed archaeologically between East and West Asia. While the Pre-Pottery Neolithic cultures of southwest Asia made extensive use of querns for flour production and constructed clay ovens for baking bread and roasting foods, communities in Neolithic (and Palaeolithic) China utilized elaborate pottery vessels for 'wet-cuisine' based on boiling and steaming. Fuller and Rowlands (2011) suggest these East-and-West culinary differences are deeply embedded, associated with Pleistocene hunter-and-gatherer food traditions, and are thus intertwined with the later domestication process and transition to agriculture.

Questions remain as to what happened when grains like wheat and barley, which originated in southwest Asia amidst longstanding baking and breadmaking traditions, were introduced into a different culinary arena, one that favored boiling and steaming whole grains. For wheat, archaeobotanical evidence shows that introduction of this grain into China may have involved selection for reduced grain size adapted to the eastern boiling-and-steaming tradition (Liu et al. 2016). Similarly, in southeast Asia, the preference for the cultivation of cereals that show within-species variation for stickiness of the cooked grains is typified by the eastern boiling-and-steaming cultures (Fuller and Castillo 2016).

Grain size is routinely recorded by archaeobotanists during analysis. It is thus well suited for macro-scale analyses across multiple sites and regions. It should be noted that it is a quantitative trait (rather than a qualitative one such as the presence of tough rachis) that can only be measured on the level of population/assemblage. Grain size analysis needs to take into consideration the effect of charring, which can lead to caryopsis distortion. Various experimental heating studies demonstrate that grain morphology is sensitive to charring conditions, especially temperature, which often leads to an increase in breadth and decrease in length (e.g. Stewart and Robertson III 1971; Ferrio et al. 2004; Braadbaart 2008; Charles et al. 2015). Charring conditions can be verified using a combination of grains' internal and external features. Given the geographical scope, such large-scale assessment is currently incomplete. However, the distorted grain type is infrequently the main grain state at well-preserved archaeological sites (Styring et al. 2013), which is the primary context under consideration in this study. Physiological differences also exist between major varieties and subspecies, including hull-less grains and multiple rows of fertile florets (Fuller and Weisskopf 2014). These aspects are considered in detail below.

We use grain measurements to track changes in barley grain size across Asia and hence to evaluate the role of regional cooking variations in morphotype differences. We find that, similar to free-threshing wheat, barley grain size was diminished as it moved from its origin in southwestern Asia eastward to East Asia.

Materials and methods

Materials

We assembled 2,176 carbonized barley grain measurements from published reports and previously unpublished data from South Asia (n = 277, 13 sites), Inner Asian Mountain Corridor (IAMC) (n = 965, 11 sites), Monsoonal China (n = 377, 34 sites) and Northeast Asia (n = 557, 72 sites), totaling 130 sites. Compiled samples range from the third millennium BC to the early first millennium AD. We collected measurements for the length, breadth, and height of the barley grains. The majority of the data report individual grain measurements (site n = 83). However, some source studies (site n = 47) did not report individual measurements, only site means, which we also included in this study in order to incorporate as much data as possible. The vast majority of these averaged samples come from Northeast Asia (n = 34) and are not a major focus of this study. We note that this could bias against sites with mean values only and acknowledge the limitations of the data. However, when the analysis is carried out using single grain measurements only, the pattern persists (Figure S4).

Length and breadth measurements were chosen as the focus of this study as all collected data included both of these measurements. It is documented that height (thickness) and breadth ratio could be linked to the domestication process (Fuller et al. 2017). Unfortunately, height measurements were not reported consistently in the compiled studies and would thus preclude a complete analysis. Husk types such as 'hulled' or 'naked' were collected when reported, along with associated elevation and location information. Six- and two-row barleys were not separated due to morphological overlap between the two forms and a lack of rachis evidence in many

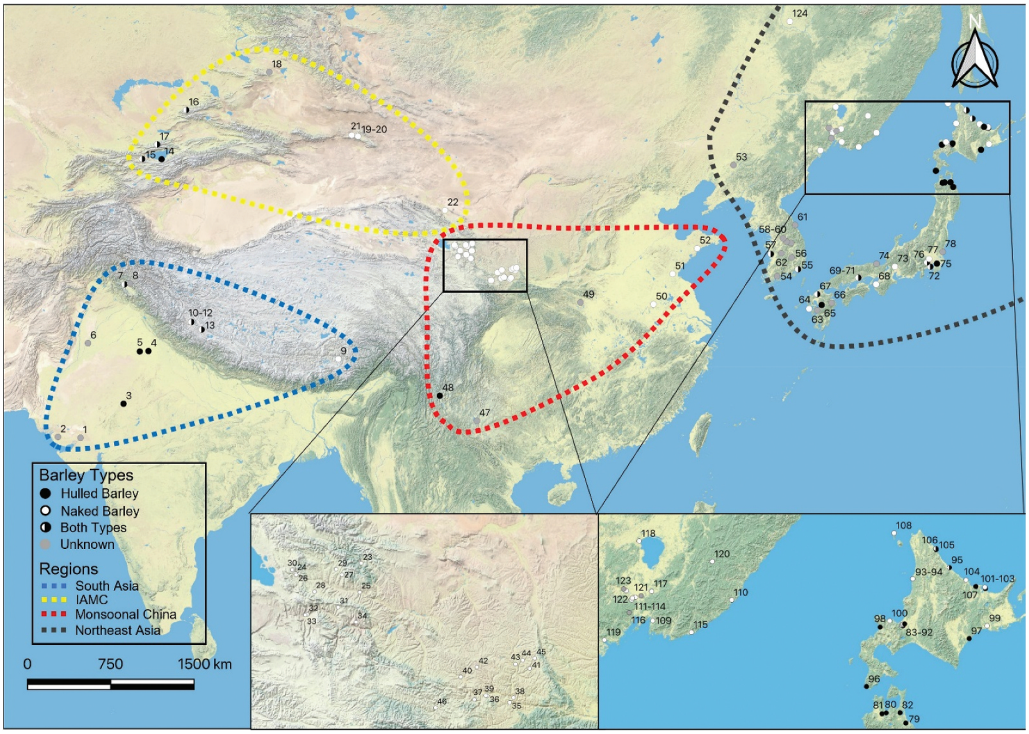

Figure 1. Map of sites analyzed. Regional boundaries are superimposed, and grain hull-type symbolized by point color. Site numbers are detailed in Table S1.

assemblages. The original archaeobotanical analysis and measurements of grains were performed at respective laboratories and final metadata analyses were compiled and analyzed at Washington University in St. Louis, Laboratory for the Analysis of Early Food-Webs. Figure 1 presents collected data and grain type by region, while Figures S1 and S2 present data by time period. Table S1 provides a summary of all data, with means and standard deviations given for sites where individual grains were originally reported. In the subsequent analyses, individual data points rather than summary statistics are used.

Methods

Data visualization and statistical analyses on assembled data were performed in R, version 3.6.1. A normal distribution test (Shapiro-Wilk) found the dataset to not be normally distributed. Therefore, a Kruskal–Wallis test (for non-normal analysis of variance) was conducted. Multiple comparison post-hoc tests examined the significance of variances. Welch's Two Sample *t*-test was conducted to examine the variance between regions through time. Full results can be found in Tables S2 and S3.

We categorized the data points based on their site origin and reported radiocarbon or typochronological date range. According to archaeological, geographical and cultural similarities, sites were grouped into the broader regions of South Asia (broader Indus, northwest India, western and southern Tibet), an extended Inner Asian Mountain Corridor (the piedmont zones spanning through

Pamir, Tianshan, Dzhungar and Altai Mountains and western Hexi corridor), Monsoonal China (eastern China under the influence of summer monsoons including the Loess Plateau, Yellow River and Yun-Gui Plateau) and Northeast Asia (South Korea, Japan, and the far East region of Russia) (Figure 1).

Broad geographical trends were assessed with all data regardless of time period. Furthermore, we analyzed a subset of the data whose chronology dated to after 1000 BC, when barley became widespread in eastern Asia (Liu et al. 2017). Our statistical analysis of these datasets indicates an even more pronounced trend in measurement differences between regional contexts in the post-1000 BC dataset (Table S2).

Results

Regional barley measurements

The smallest mean grains (by length) appear in Monsoonal China (length: 4.27 mm, breadth 2.72, height: 2.07) and the largest in South Asia (length: 5.02 mm, breadth: 3.09, height: 2.06). Monsoonal China has the most compact barley with a length/breadth ratio of 1.59 mm and Northeast Asia has the most elliptical with a length/breadth ratio of 1.70 mm. Visual representation of regional grain measurements shows a reduction in grain length from South Asia to Monsoonal China (roughly west to east) (Figure 2; Table 1). Northeast Asian grains are much larger than Monsoonal China, but similar to both South Asia and IAMC.

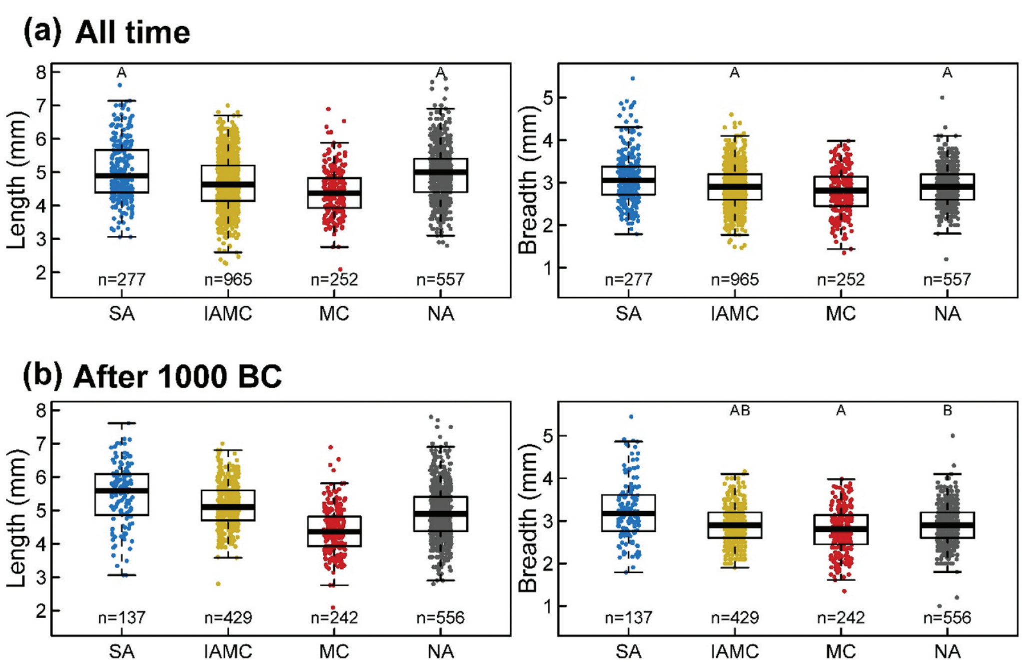

Figure 2. Boxplots of regional barley measurements: (a) from all times periods, (b) from after 1000 BC. Length measurements are in the left panel and breadth measurements are in the right panel. Nonsignificant relationships share letters, all other relationships are significant, $p < 0.05$.

Table 1. Summary of grain measurements from South Asia, IAMC, Monsoonal China, and Monsoonal Asia. Mean length, breadth, height and length/breadth ratio and total counts are reported, including how many are calculated mean measurements and how many are single grain measurements. Measurements are in mm.

Region	Length $\bar{X}$	Breadth $\bar{X}$	L/B $\bar{X}$	*N*	*N* Sites	*N* mean measurements	*N* single grain measurements
South Asia	5.02	3.09	1.65	277	13	0	277
IAMC	4.68	2.9	1.63	965	11	2	963
Monsoonal China	4.27	2.72	1.59	377	34	4	373
Northeast Asia	4.95	2.91	1.7	557	72	58	499
Total	4.72	2.9	1.64	2,176	130	64	2,112

To clarify these trends in grain size between regions, statistical analyses were used to assess differences in mean length and breadth measurements between regions. These and all the following statistical results are available in Tables S2 and S3. There is a statistically significant difference in mean grain size between regions for both length, $H(171.89) = 3$, $p = 2.20E{-}16$, and breadth, $H(55.586) = 3$, $p = 5.15E{-}12$. Post-hoc multiple-comparison tests specified that all length measurement relationships are significantly different except between South Asia and Northeast Asia ($p < 0.05$). For breadth, all measurement relationships are significantly different except between the IAMC and Northeast Asia ($p < 0.05$).

Elevation

We use a scatterplot to visualize the grain measurements in relation to site elevation (Figure 3, for breadth see Figure S3). The data points represent the calculated mean grain measurements for each site, which are color-coded based on the region. Northeast Asian grains were excluded from these analyses as the data are substantially later in time (most after 1000 AD) and few sites had reported elevational data available. While no clear relationship is seen between altitude and grain length in any of the regions, the grains originating at the highest altitude (Tibet, blue triangles) constitute some of the longest grains in the entire assemblage, particularly those from the sites of Dingdong, Bangga and Kaerdong.

Hulled and naked barley

The data show clear regional differences in husk types. In South Asia, IAMC, and Northeast Asia, both hulled and naked morphotypes were widespread, whereas in Monsoonal China, only naked grains were predominant (with the exception of sites in the Yun Plateau) (Figure 1). When we compare grain metrics across the regions, similar trends are present in both the hulled and naked morphotypes (Figure 4, Table S3). Both morphotypes reduce in length in the IAMC and Monsoonal China regions. These trends are present when all time periods are analyzed, Figure 4(a,c), and for after 1000 BC Figure 4(b,d).

Discussion

The data presented here enable two inferences. The first relates to the geographical (and temporal) variation of barley grain size as it was dispersing eastwards. The second relates to barley's adaptation to high-altitude environments across the Tibetan Plateau. These inferences allow us to reflect on how culinary traditions were spread out geographically in the second/first millennium BC.

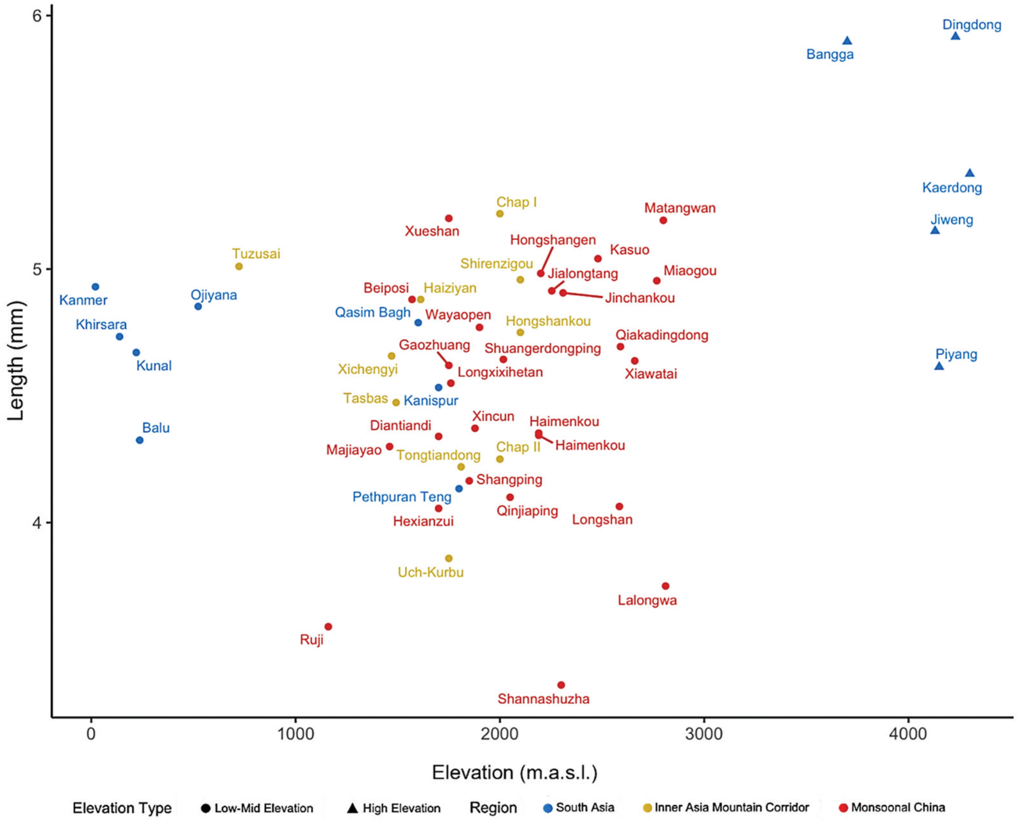

Figure 3. Scatterplot of relationship of mean grain length from all sites (excluding Northeast Asia), *y*-axis, and elevation of sites, *x*-axis. Sites are colored representing region, and points represent low-mid elevation and high elevation.

Grain size reduction as barley heads east

Our results show that the variation in barley grain sizes between the third millennium BC and the first millennium AD was primarily driven by regional differences. Generally, the length (and to a certain extent breadth) of the grain measurements decreased from the West to the East (not including the more recent historical grains from Northeast Asia), with the shortest caryopses found in Monsoonal China, shorter than those in the IAMC and South Asia (Figure 2). This observation resonates with the pattern of archaeological free-threshing wheat previously documented, which also shows a west-to-east reduction (Liu et al. 2016). In other words, the sizes of both wheat and barley decreased during their eastward expansion.

The extremely reduced grain size is best accounted for by a distinct culinary tradition in Monsoonal China. As previously noted, societies in eastern and central China have employed (since the Neolithic until this day) cooking styles primarily oriented around boiling and steaming and whole-grain meal preparation. This culinary system favors smaller grain sizes, which are often accompanied by genetic mutations that cause amylose-low/free (sticky or glutinous) starch for higher cooking efficiency (e.g. Hunt et al. 2013; Fuller and Castillo 2016). It is worth noting that prehistoric communities may not have considered *Triticum* and *Hordeum* varieties as separate crops. In the textual records dating

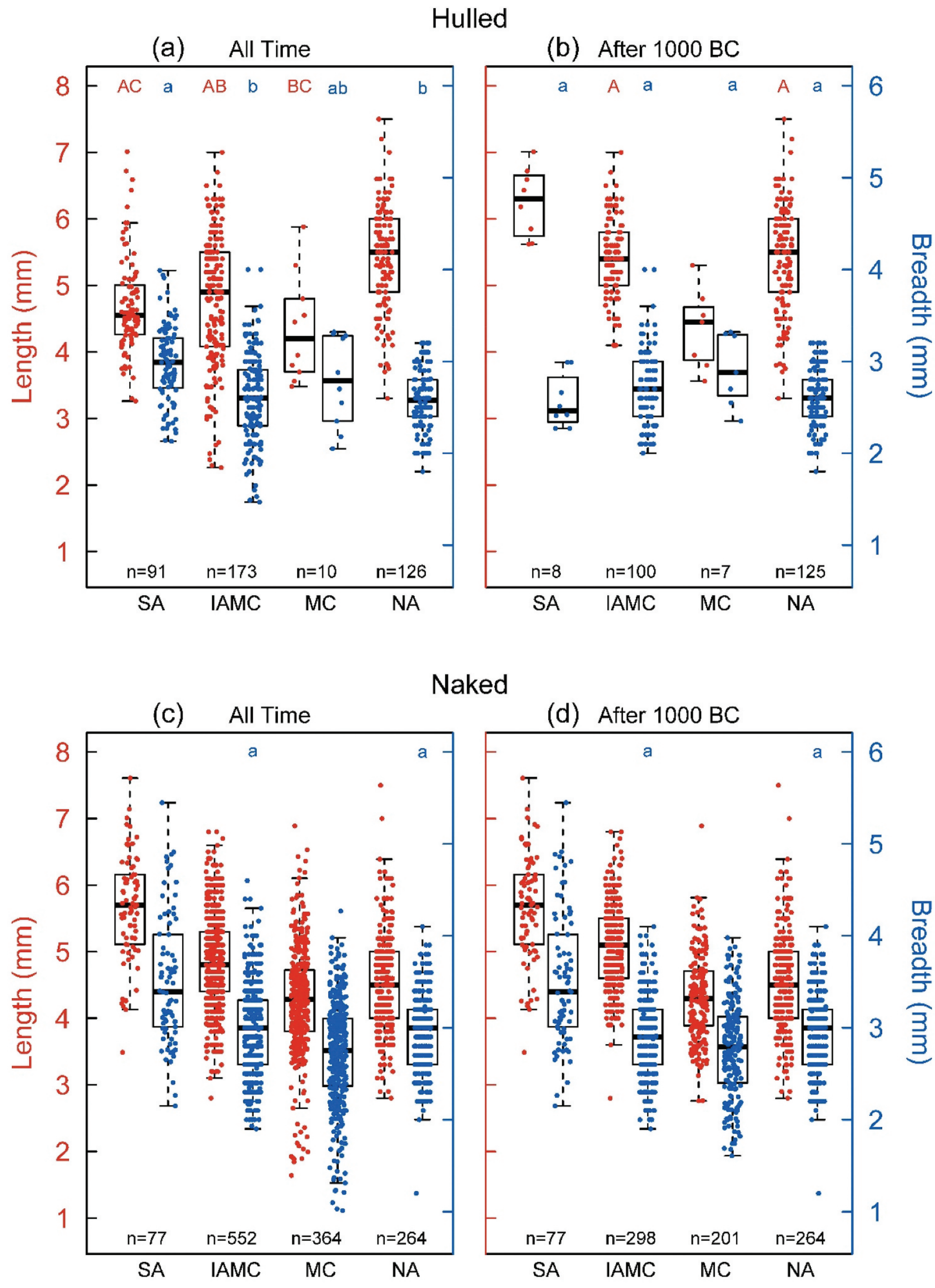

Figure 4. Boxplots of hulled All time (a) and hulled After 1000 BC (b), and naked All time (c) and naked After 1000 BC (d). Length measurements are visualized with the red boxplots and left y axis. Breadth measurements are visualized with blue boxplots and right *y*-axis. Pairs of measurements are grouped by region: SA = South Asia, IAMC = Inner Asian Mountain Corridor, MC = Monsoonal China, NA = Northeast Asia. Non-significant statistical relationships share letters, all other relationships are significant, $p < 0.05$. Uppercase red letters represent length relationships and lowercase blue letters represent breadth relationships.

to second/first millennium China, for example, the character *Mai* (麦) was used to denote wheat and barley collectively as it is used in modern Chinese today (Liu et al. 2017). Therefore, the selective constraints of food preparation practices could have applied uniformly across taxonomic differences as demonstrated by similar trends in *Triticum* and *Hordeum*. Our data suggest that selection for compact barley morphotypes was likely caused by modifications for the eastern cooking style.

Hulled, naked, two- and multiple row varieties

In addition, our data support previous observations of the preference for free-threshing grains in eastern Eurasia with naked barley being the almost exclusive type in Monsoonal China (Spengler 2015; Liu et al. 2017), hinting at a role of food preparation practice. Traditional farmers in Ethiopia, for example, often consider hulled barley less desirable as it is extremely time and labour intensive to process in domestic contexts, although it is less labour intensive in the field and provides relatively higher grain yield than naked types (Asfaw 1999). However, the general trend of average grain size reduction as barley moved eastwards was not likely driven by the increase of hull-less grains in the East. When the hulled and naked grains are considered separately, we see a strikingly similar pattern of west-to-east reduction for both groups (Figure 4). This indicates that they were subject to similar selective constraints that were relatively uniform across varietal and even taxonomic differences (considering a similar trend in *Triticum* (Liu et al. 2016)).

The observed patterns should also be viewed in the context of needing to better understand grain morphology at the subspecies-level. It has been suggested that six-row barley (*H. vulgare* subsp. *vulgare* L.) tends to produce stubbier and plumper grains in contrast to the narrow and thinner two-row barley (*H. vulgare* subsp. *distichum* L.) (Ros et al. 2014; Fuller et al. 2017). As noted, two- and multi-row barleys were not separated in this study due to the lack of sufficient rachis information in many assemblages. In general, both six- and two-row barleys were identified from sites along the IAMC. For example, Motuzaite Matuzeviciute and colleagues (2020b) report six- and two-row naked and hulled barleys from Chap I in Kyrgyzstan. In Kashmir, no rachis was recovered from Qasim Bagh, Pethpuran Teng and Kanispur, but Pokharia et al. (2017) noted twisted grains from Kanispur indicating multi-row barley. Archaeobotanical reports from China rarely discuss types of fertile florets and rachis evidence is limited. There are, however, a few visual reports of barley rachis internodes, including a six-row hulled form from Bangga in Tibet (Tang et al. 2021), a six-row naked form from Dongtianshan (Tian et al. 2018), both six- and two-row rachises from Sidaogou (X. Liu unpublished data) in Xinjiang, and a seemingly six-row hulled form from Xichengyi in Hexi Corridor (Fan 2016).

In terms of the caryopsis shapes, Tian et al. (2021) noted that twisted barley grains are the main type in Adunqiaolu, western Xinjiang, indicating the predominance of multi-row. This is consistent with the observation at Bangga and Kaerdong in Tibet, although symmetric types are also present (Song et al. 2018; Tang et al. 2021). It is harder to evaluate barley types in Monsoonal China due to the lack of consistent rachis reporting. One of the coauthors (X. Liu) sorted through some of those assemblages in selecting specimens for radiocarbon and isotopic measurements (Liu et al. 2017) and noted both asymmetric and symmetric grains in those assemblages with a ratio significantly lower than 2:1 (criteria commonly used to identify six-row barley). This perhaps indicates the coexistence of two- and multi-row barleys in prehistoric central China. Therefore, what the overall distribution of barley metrics suggests is that in addition to size reductions, there were also differences at the subspecies level. It is not easy, at this point, to evaluate the proportional contribution of multiple row types that the quantitatively. Nevertheless, future investigations will clarify the regional variations among major varietal and subspecies differences.

Tibetan boiling-steaming free zone

Our results show that Tibetan grains, situated at the highest altitudes, are the largest across the regions. Recent whole-genome sequencing has indicated substantial gene flow in the past between high-altitude adapted wild barley and cultivated varieties on the Tibetan Plateau (Dai et al. 2012; Zeng et al. 2018) Although scholarship has hardly reached a consensus on the origin of Tibetan *H. spontaneum* (e.g. Lister et al. 2018; Zeng et al. 2018) such hybridization is thought to contribute to the altitudinal adaptation of modern naked barley (e.g.Zeng et al. 2018; Tang et al. 2021). The shortest barley grains at high altitudes (e.g. Haimenkou in Yunnan, Jinchankou in Qinghai, Shannashuzh in East Gansu, Chap II and Uch-Kurbu in Kyrgyzstan) in the third and second millennium BC can be understood in this context. This possibility resonates with the recent discussion of high-altitude adaptation of foxtail millet (*Setaria italica*) during the third/second millennium BC in the eastern Tibetan Plateau that could have benefitted from hybridization with cold-tolerant weedy relatives such as *S. viridis* (Song et al. 2021; Tang et al. 2021). Many cereal crops, including maize and finger millet show variations in morphotypes in the context of adaptation in a range of high-altitude environments, and our data add to this growing literature (Goodman and Brown 1988; Asfaw 1999; Tsehaye et al. 2006).

Three of the largest average grain lengths are from sites in western Tibet (i.e. Dingdong, Bangga and Kaerdong). For example, at Dingdong, a site situated at c. 4000 m.a.s.l., the average grain length and breadth are 6.25 ± 0.52 mm and 2.56 ± 0.29 mm, significantly larger than the grain metrics from sites in other regions. It is interesting to note that the barley from these sites are likely of the multi-row type (with both hulled and naked forms) as noted above. The distinctive grain length is therefore not driven by the tallness of two-row type. Unlike cuisines in the rest of East Asia, Tibetan cuisine is characterized by its absence of boiling and steaming. This is due to the low vapour pressure at high elevations. The boiling point is about 86°C at 4000 m.a.s.l., which makes boiling and steaming not only less efficient but also fuel demanding. Tibetan cuisine utilizes a grinding (without boiling) technique for a flour-based cereal cuisine – which is different from culinary traditions in either East Asia and eastern South Asia utilizing boiling-steaming and whole grain-based cuisine. The most prevailing staple in modern day Tibet, tsampa, is a roasted milled/ground barley flour-based meal, and ceramic vessels with boiling-and/or-steaming function are absent at sites in central and western Tibet (Tang et al. 2021).

Towards a complex culinary system in eastern Eurasia

In their insightful exploration of the culinary frontiers, Fuller and Rowlands (2011) depict a clear-cut boundary – correlating with the geographic limit of Asian summer monsoons – between the boiling and steaming traditions of East Asia (and eastern South Asia) and the grinding and baking traditions that originated in southwest Asia. This hypothesis is supported by the spread of *tabun*- and *firin*-type bread ovens originating with barley and wheat in the Southwest Asian Pre-pottery Neolithic (Fuller and Carretero 2018) and the Neolithic Chinese ceramic tripod boiling (*Li/Ding/Guan*) and steaming (*Zeng/Yan*) kits across eastern Asia (Makibayashi 2008, 2014; Fuller and Rowlands 2011). Central Asia, including the Inner Asia Mountains and Tibetan Plateau, is placed in the grinding-and-baking zone (Fuller and Rowlands 2011). However, the Bronze Age eastern Central Asian cuisines were likely more complex than previously assumed with boiling technology integrated with the grinding and baking tradition. This culinary complexity can be supported by the varied material assemblage from the region, including stone querns, mudbrick ovens, and ceramic vessels with a boiling function

(Spengler, Frachetti, and Domani 2014; Rouse et al. 2019; Motuzaite-Matuzeviciute et al. 2020ab). However, the vessels used for boiling emerged from a different tradition than the eastern tripod-boiling artefacts that are prevalent in Neolithic and Bronze Age China (Makibayashi 2008; Han 2017). The eastern Central Asian boiling tradition is materially manifested by a type of round bottomed pottery vessel with multiple functions that include boiling which is prevalent across Central Asia (Han 2017). This type was probably rooted further west in cultures dated between sixth and fourth millennium BC. Lipid-reside from Botai in Northern Kazakhstan indicates dairying within ceramic vessels, which is likely connected with dairy-based culinary practices further west (Outram et al. 2012). In the second millennium BC, the round-bottomed vessels further developed into several regionally typological groups in the IAMC including the Tianshan, Altai region and the Hexi corridor, and could be used in multiple food preparation practices involving boiling (Han 2017).

It is not unreasonable to speculate that grains like barley were boiled in such vessels as a stew-type meal along with meat, dairy, grains, vegetables, and spices. Such cuisine is still favoured in this part of the world (Bacon 1954; Mack and Surina 2005; McLean 2012). In the medium of a stew, with the intensive cooking energy required for tenderizing meat, the size of the grain would not be of primary importance. Different sized grains, including the routinely found compact forms in the IAMC (e.g. Spengler, Frachetti, and Domani 2014; Spengler 2015; Motuzaite-Matuzeviciute et al. 2018, 2020ab; b), would then be useful for both boiling and baking recipes. This is dissimilar to the eastern Chinese whole-grain boiling–steaming traditions, where small grains are important for an efficient cooking of the desired porridge dish. This speculation can be further supported by the isotopic evidence for relatively high animal protein/dairy consumption in this region (Wang et al. 2019b; Xinyi and Reid 2020). The emerging picture suggests at least three culinary traditions co-existing in the eastern part of Eurasia during the second and first millennium BC: steaming–boiling whole-grain tradition in Monsoonal China, boiling-free flour-based cuisine in Tibetan Plateau, and a mix of cooking across the boiling–grinding–baking spectrum in the IAMC. Our data support this hypothesis of a more complex system of eastern Eurasian cuisines fairly well (Figure 5) and prompt further investigations into the deep-seated culinary traditions in the IAMC and Tibetan Plateau.

Conclusion

In this paper, we consider barley grain size and morphotype in the context of its eastern movement across Asia in association with culinary preference. Our results allow for three inferences concerning culinary practices and barley phenotypes. First, we find that barley diminished in size as it moved from its origin in southwestern Asia to Central and East Asia between the third and first millennium BC. In particular, barley grains in Monsoonal China became greatly reduced in comparison to other regions as the crop was incorporated into eastern small grain cuisines. The reverse pattern is observed in the high-altitude Tibetan environment, which is attributed to the practicalities of cooking under low vapour pressure conditions. Second, our results infer a complex culinary system in eastern Eurasia with the coexistence of three cooking traditions that have not been previously documented. Third, we draw attention to the value of recording rachis and caryopsis evidence in future research to distinguish between two- and multiple-row barleys and to better understand barley phenotypes at the subspecies level.

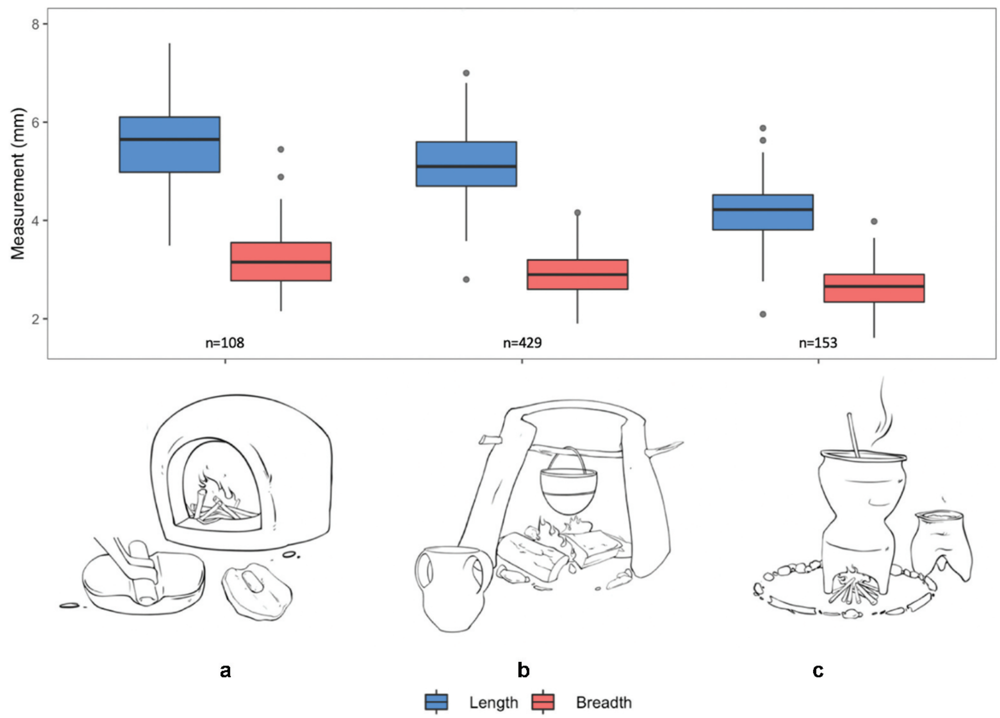

Figure 5. Length of barley grains from three hypothetical culinary zones in the first millennium BC: A) Tibetan Plateau boiling-and-steaming-free zone with grinding and oven-baking, B) a mix of grinding, baking, and boiling in the Inner Asian Mountain Corridor using multi-function oven for boiling and baking, and C) Monsoonal China boiling and steaming zone using tripod boiling vessels. All length relationships (blue) and breadth relationships (red) are pronounced, $p < 0.05$.

Together with previously published grain metrics of free-threshing wheat (Liu et al. 2016), our findings raise awareness of the geographic decoupling of grains and cuisines in the context of prehistoric food globalization, such that wheat and barley travelled into eastern and central China during the second and first millennium BC, but the grain morphotypes and the western grinding-and-baking cuisines did not. These results resonate with the recent discussion of the disaggregation of the eastern Neolithic grains and their associated culinary approach: millet grains moved westwards along the Hexi and Inner Asian Mountain Corridor and beyond even though their sticky genotypes did not (Hunt et al.,in press). Our results further question the role of grain size in measuring the domestication process and infer the transcontinental nature of domestication itself.

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