Quaternary International xxx (2016) 1–13

Contents lists available at ScienceDirect

Quaternary International

journal homepage: www.elsevier.com/locate/quaint

The virtues of small grain size: Potential pathways to a distinguishing feature of Asian wheats

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ARTICLE INFO

Article history:
Available online xxx

Keywords:
Wheat
Grain size
Domestication
Radiocarbon dating

ABSTRACT

Increase in grain/seed size recurrently features as a key element in the 'domestication syndrome' of plants (*cf.* Zohary and Hopf 2000; Fuller et al. 2014). In the context of its spread across Eurasia, however, the grain size of one of the world's major crop species underwent a substantial reduction. Between the fifth and second millennia BC, the grain length in a number of species of *Triticum*, collectively known as free-threshing wheat, decreased by around 30%. In order to understand and help account for this trend, we have obtained direct radiocarbon measurements from 51 charred wheat grains and measured the dimensions of several hundred grains from Asia to establish when and where that size diminution occurred.

Our results indicate that the pace of a eastward/southward spread was interrupted around 1800 BC on the borders of the distinct culinary zone recognized by Fuller and Rowlands (2011), but regained pace around 200–300 years later in central-east China with a diminished grain size. We interpret this as evidence of a period of active crop selection to suit culinary needs, and consider whether it constitutes a distinct episode in the general character of genetic intervention in domesticated species.

1. Introduction

Recent developments in archaeobotanical research have shed fresh light on the processes of plant domestication and agricultural origins. Among domestication traits expressed in various crop species, two have received much scholarly attention, non-shattering cereal ears and seed/grain size (*cf.* Zohary and Hopf, 2000; Fuller et al. 2014). Non-shattering cereal ears have typically been studied in the context of a growing reliance on humans for seed dispersal. The increase in seed/grain size repeatedly observed in crop species is presumed to increase production yield as well as aid seedling establishment in the context of deeper burial, and is the most widely documented change in archaeobotanical assemblages (*cf.* Harlan et al. 1973; Purugganan and Fuller, 2009).

In this study, we consider the change in grain size of one of the world's major crops. As free threshing wheat spread eastward from a Southwest Asian region of origin, that change can be seen on several archaeological sites. However, in contrast to the classic domestication trajectory, the grains as they spread eastward became not larger, but smaller.

There has been an increase in scholarly interest in the nature and pathways of the eastward spread of wheat and barley (Jin, 2007; Li et al., 2007; Zhao, 2009; Flad et al., 2010; Frachetti et al., 2010; Zhao,

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http://dx.doi.org/10.1016/j.quaint.2016.02.059
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2011; Betts et al., 2013; Dodson et al., 2013; Barton and An, 2014; Liu et al., 2014; Spengler et al., 2014a). In light of these studies, and in order to understand the variation of wheat grain size in the context of food globalisation, we have directly radiocarbon dated 51 charred wheat grains and measured the dimensions of several hundred grains from China, India and Pakistan to establish when and where that size diminution occurred. By "direct radiocarbon dating" we mean that the wheat grains themselves have been analyzed rather than dating distinct organic items from the same contexts.

We will address two issues in this paper. Firstly, we will consider the pace of an eastward/southward spread. Secondly, we will attempt to understand the nature of the reduction in grain size, and consider whether it constitutes a distinct episode of human choice that drives changes in domesticated species.

2. Spread of wheat

It is now clear that by late prehistory a series of connections between human populations had been established across Eurasia. From the evidence of early horse management, metallurgy and a range of associated artifacts, we may trace the origins of these connections in the latter part of the second millennium BC (Levine, 1999; Mei, 2003; Sherratt, 2005; Linduff and Mei, 2009; Rawson, 2013). Archaeobotanical evidence from cereal crops has the potential to push this date back yet further into at least the third millennium BC or even earlier, when exchanges between the various sectors of Eurasia have been documented. This process has been referred as 'food globalisation in prehistory' (*cf.* Jones et al., 2011, in press; Liu and Jones, 2014) or the 'trans-Eurasian exchanges of crops' (Boivin et al., 2012). During the course of the third and second millennia BC, some of the crops that originated in the Fertile Crescent spread from southwest Asia to eastern China.

By *c.*1500 BC, the geographical range of one of the southwest Asian crops, free threshing wheat, extended from the Pacific to the Atlantic Ocean. In the context of early Chinese wheat, Zhao (2009) suggested three candidates for a trans-Asian route. One was a proto-Silk Route – essentially the topographically most convenient and economic land route between East and West. The second drew from discussions of shared traditions of pastoralism, horse management and metallurgical traditions and was characterized as the northern steppe route. The third related to the near-coastal position of some of the earliest wheat appearing in the east, raising the possibility of a sea route. These three potential routes presented a set of initial hypotheses that have stimulated useful discussion around the issue of the spread of wheat (Betts et al., 2013; Dodson et al., 2013; Barton and An, 2014; Spengler et al., 2014a). Discussion has now moved beyond the scope of dates and routes, and has addressed such issues as social drivers, the pace of crop movement and dietary conservatism (Lightfoot et al., 2013; Liu and Jones, 2014; Liu et al., 2014; Jones et al., in press).

The pattern of the eastern movement of wheat from southwest Asia has also become clear. Early evidence for cultivation and domestication of various wheat species appears in southwest Asia from at least 8000 BC (*cf.* Weiss and Zohary, 2011). Wheat species (both free threshing and hulled) are documented in western Central Asia around 4000–3000 BC at Jeitun and Anau North (Miller, 2003; Harris, 2010) and in western South Asia by around 5000 BC in Mehgarh (Costantini, 1984; Meadow, 1996; Petrie, 2015). After these initial dispersals, the subsequent, more extensive movement of different types of wheat appears to be restricted to free threshing forms. To the north of the Iranian Plateau, free threshing wheats have been documented in Turkmenistan sites such as Anau South and Gonur Depe around 2000 BC (Moore et al., 1994; Miller, 1999), and Ojakly/1211 around 1500 BC (Spengler et al., 2014a). They appeared in Tajikistan between 3500 and 2000 BC at Sarazm (Spengler and Willcox, 2013), and in Afghanistan at Shortugai 2500–2000 BC (Willcox, 1991), and in Kyrgyzstan at Aigyrzhal-2 around 1800 BC (Motuzaite Matuzeviciute et al., 2015). Records from the south-eastern and eastern parts of the greater Iranian Plateau are even older. For example, free threshing wheat (often in association with hulled wheat) was recovered from Pakistani sites such as Sheri Khan Tarakai, Miri Qalat and Shahi Tump dating back to the fifth/fourth millennium BC (Tengberg, 1998; Desse et al., 2008; Petrie et al., 2010; Thomas and Cartwright, 2010). From there, it is plausible that these crops moved further east and south into the Indus region during the third millennium BC, and subsequently, into the Ganges and South India (Fuller and Madella, 2001; Fuller, 2006; Pokharia, 2011; Pokharia et al., 2011).

Recent research suggests that the 'Inner Asian Mountain Corridor' connecting the mountain territories of the Iranian Plateau and the Pamir Plateau played a key role in the dispersal of free threshing wheat to the east (and broomcorn millet to the west) during the third millennium BC (Frachetti, 2012). Work in eastern Central Asia reveals that both free threshing wheat and broomcorn millet were present from the same archaeological contexts in the middle third millennium BC (Frachetti et al., 2010; Spengler et al., 2014a; Spengler, 2015). Currently, the earliest recorded wheat grain in Central Asia is from Tasbas, 4010 ± 30 (radiocarbon years) BP, which calibrates to 2617–2468 cal. BC at the 95.4% probability range (Doumani et al., 2015).

The 'Inner Asian Mountain Corridor' may be extended further eastwards to China along the foothills of the Tianshan Mountains and the Hexi Corridor (i.e. along the northern edge of the Tibetan Plateau), and finds of archaeobotanical wheat are distributed along these mountain ranges. Notwithstanding the debate around some allegedly older specimens (Li and Mo, 2004), recent studies have suggested that free threshing wheat probably did not appear in northwest China until very late in the third or early in the second millennium BC (Flad et al., 2010; Dodson et al., 2013; Liu et al., 2014). It is worth noting, however, that hexaploid free threshing wheat is also reported from the third millennium BC site of Longshan culture in eastern China (Zhao, 2009). At Zhaojiazhuang in Shandong, for example, a wheat grain has been directly dated to 3905 ± 50 (radiocarbon years) BP, which calibrates to 2562–2209 cal. BC at 95.4% probability (Jin et al., 2008).

3. Variation in grain size

Turning from chronology to plant morphology, Fuller et al. (2014) have suggested that most seeds increased by 20–60% in one or two dimensions during the course of domestication. While there may be some variation in the precision and accuracy of the published measurements of early wheat, the following trends are regarded as secure. Emmer wheat, for example, increased in thickness from approximately 1.7 mm to more than 2.5 mm over a time period of between 9000 and 5000 BC. The breadth of einkorn wheat increased from about 1.2 mm to 1.8 mm between 10,000 and 6000 BC (Fuller et al. 2014, Fig. 2). It is worth noting though that einkorn and emmer measurements are not always reliable because of identification issues. Fuller et al. (2014) also noted that after the episode of initial increase, grain size became variable, fluctuating both up and down.

Grain shape and the compactness of the spike are important variables used in the taxonomy of hexaploid wheat (MacKey, 1966). Archaeobotanists have frequently observed a more compact form of wheat grain and chaff in regions east of the Fertile Crescent. For example, a compact form is recorded from Mehrgarh in Pakistan by at least the mid-fifth millennium BC (Costantini, 1984; Zohary and Hopf, 2000) and later in third/second millennium BC sites in the greater Indus and Ganges regions (Weber, 1991; Miller, 1999; Fuller et al., 2008; Pokharia, 2008, 2009, 2011; Pokharia et al., 2009;

Please cite this article in press as: Liu, X., et al., The virtues of small grain size: Potential pathways to a distinguishing feature of Asian wheats, Quaternary International (2016), http://dx.doi.org/10.1016/j.quaint.2016.02.059