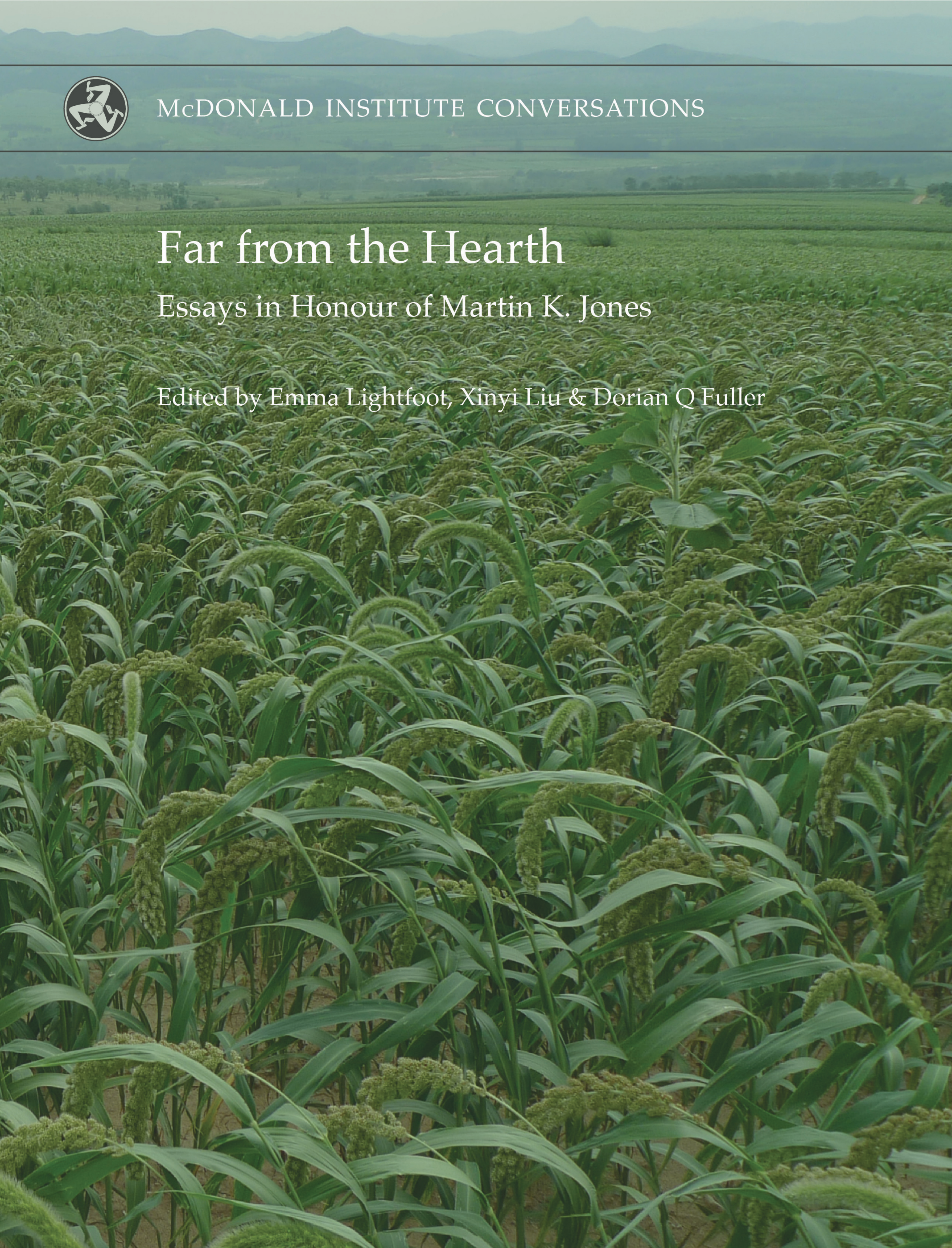
McDONALD INSTITUTE CONVERSATIONS

Far from the Hearth

Essays in Honour of Martin K. Jones

Edited by Emma Lightfoot, Xinyi Liu & Dorian Q Fuller



Far from the Hearth

(Above) Martin Jones at West Stow, 1972 (with thanks to Ian Alister, Lucy Walker, Leonie Walker, and West Stow Environmental Archaeology Group); (Below) Martin Jones in a millet field, Inner Mongolia, 2010. (Photograph: X. Liu.)

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Cover image: *Foxtail millet field near Xinglonggou, Chifeng, China, photographed by Xinyi Liu, September 2014.*

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Figures

Tables

Acknowledgements

The initial idea of editing this volume grew out of a conversation between Xinyi Liu and Graeme Barker at St John's College, Cambridge in June 2016. The editors subsequently discussed the provisional layout of the volume. By April of the following year, our list of agreed contributors was complete. Abstracts followed, and the chapters themselves soon after. First of all, the editors would like to pay tribute to our 36 authors, whose excellent work and timely contributions made it all possible.

For the last two-and-a-half years, the volume has been known as 'Fantastic Beasts' in order to keep it a secret from Martin. As we enter the final stage, we wish to extend our thanks to all who have ensured Martin remains blissfully unaware, including Lucy Walker, and we offer her our sincere thanks. We are extremely grateful to Harriet Hunt, Diane Lister, Cynthia Larbey and Tamsin O'Connell, who are kindly organizing the gatherings to mark Martin's retirement and the publication of this volume.

With respect to the volume's production, we would like to thank the McDonald Institute for Archaeology Research for financial support. The McDonald Monograph Series Editor James Barrett oversaw and encouraged all aspects of this project, and we offer him sincere thanks. We would also like to acknowledge the support of Cyprian Broodbank, not least for allowing us to host the workshop at the institute, but also for his encouragement throughout all phases of the volume's implementation. Particular thanks must go to several key individuals: Anne Chippindale, Ben Plumridge, Emma Jarman, Simon Stoddart and Samantha Leggett. Finally, we are also grateful to the anonymous reviewers who recommended changes that have greatly enhanced the final version of this volume.

Xinyi Liu, Emma Lightfoot and Dorian Fuller
August 2018

Foreword

The 28-year term of Martin Jones as the first George Pitt-Rivers Professor of Archaeological Science witnessed, and in part created, a transformation in the fields of environmental and biomolecular archaeology. In this volume, Martin's colleagues and students explore the intellectual rewards of this transformation, in terms of methodological developments in archaeobotany, the efflorescence of biomolecular archaeology, the integration of biological and social perspectives, and the exploration of archaeobotanical themes on a global scale. These advances are worldwide, and Martin's contributions can be traced through citation trails, the scholarly diaspora of the Pitt-Rivers Laboratory and (not least) the foundations laid by the Ancient Biomolecules Initiative of the Natural Environment Research Council (1989–1993), which he chaired and helped create. As outlined in Chapter 6, Martin's subsequent role in the bioarchaeology programme of the Wellcome Trust (1996–2006) further consolidated what is now a central and increasingly rewarding component of archaeological inquiry. Subsequently, he has engaged with the European Research Council, as Principal Investigator of the Food Globalisation in Prehistory project and a Panel Chair for the Advanced Grant programme. As both practitioner and indefatigable campaigner, he has promoted the field in immeasurable ways, at critical junctures in the past and in on-going capacities as a research leader.

The accolades for Martin's achievements are many, most recently Fellowship of the British Academy. Yet it is as a congenial, supportive—and demanding—force within the Pitt-Rivers Laboratory that the foundations of his intellectual influence were laid. Here, each Friday morning, the archaeological science community would draw sticks to decide who would deliver an impromptu research report or explore a topical theme. Martin is among the most laid-back colleagues I have worked with, yet simultaneously the most incisive in his constructive criticism. As a provider of internal peer-review he was fearless without being unkind. The themed Pitt-Rivers Christmas parties were equally impactful—on one occasion Alice Cooper appeared, looking ever so slightly like our professor of archaeological science.

Martin's roles as a research leader extended to several stints as head of the Department of Archaeology, chairing the Faculty of Archaeology and Anthropology and serving as a long-term member of the Managing Committee of the McDonald Institute for Archaeological Research. Having started his professional career as an excavation-unit archaeobotanist in Oxford, he was a long-standing proponent of the highly successful Cambridge Archaeological Unit. In the wider collegiate community, he is a Fellow (and was Vice-Master) of Darwin College and was the staff treasurer of the Student Labour Club. In all roles he fought valiantly and often successfully for the interests of his constituency. His capacity to fight for deeply held priorities while recognizing the value of diverse perspectives was of utmost importance. His nostalgic enthusiasm for the debate with archaeological science that was engendered by the post-processual critique is one signal of an underlying appreciation of plurality. His active support for the recent merger of the Divisions of Archaeology and Biological Anthropology, within our new Department of Archaeology, is another. As a scientist (Martin's first degree, at Cambridge, was in Natural Sciences) he values the peer-reviewed journal article above all scholarly outputs, yet has authored as many highly regarded books as a scholar in the humanities. His *Feast: Why humans share food* has been translated into several languages and won Food Book of the Year from the Guild of Food Writers. He views academia and society as a continuum, campaigning for archaeobotanical contributions to global food security (e.g. by promoting millet as a drought-resistant crop) and working with world players such as Unilever to encourage archaeologically informed decisions regarding food products.

That Martin's achievements and influence merit celebration is clear. That his colleagues and students wish to honour him is equally so. Yet does the McDonald Conversations series publish *Festschriften*? This is a semantic question. As series editor I am delighted to introduce a collection of important papers regarding the past, present and future of archaeobotany, representing its methodological diversity and maturity. That this collection concurrently pays respect to a treasured colleague is a very pleasant serendipity.

Dr James H. Barrett

Chapter 16

The Adoption of Wheat and Barley as Major Staples in Northwest China During the Early Bronze Age

Haiming Li & Guanghui Dong

Introduction

The history and impact of food globalization in prehistory has been increasingly contested and discussed in recent years (Dong *et al*. 2017b; Jones *et al*. 2011; 2016; Liu & Jones 2014). It is an important process that can be described as bringing the Fertile Crescent 'Neolithic founder crops' to the East and Chinese domesticates such as millets to the West (Diamond & Bellwood 2003; Dong *et al*. 2017a; Hunt *et al*. 2008; Jones & Liu 2009; Liu *et al*. 2016; Spengler *et al*. 2014; Stevens *et al*. 2016). With the application of plant flotation technology and ancient crop direct dating in the last 10 years, the chronology and pathways of these prehistoric agricultural expansions have become increasingly clear (e.g. Jones *et al*. 2011). For example, previous research shows that broomcorn millet (*Panicum miliaceum*) spread to the western side of Eurasia possibly during the sixth and fifth millennia BC (Hunt *et al*. 2008), while updated research based on single grain radiocarbon analyses indicated that both Chinese and southwest Asian crops were present in the late third millennium BC (directly dated 2461–2154 cal. BC) in Begash in east Kazakhstan (Liu *et al*. 2016; Motuzaite-Matuzeviciute *et al*. 2013; 2015; Spengler 2015). In addition, a recent archaeobotanical study suggests that the eastward spread of free-threshing wheat (*Triticum* cf. *aestivum*) and naked barley (*Hordeum vulgare*) were through different routes, wheat following a northern route (via the Inner Asian mountain corridor) and barley passing through more a southerly route (south of the Tibetan Plateau) into China from southwest Asia during the late third and early second millennia BC (Frachetti 2012; Frachetti *et al.* 2010; Liu *et al*. 2016; 2017). These studies provide valuable clues for reconstructing the timelines and routes of agricultural interactions across Eurasia in prehistoric times. However, the specific timing in which these foreign crops replaced local staple foods, and the driving forces of these transformations, remains unclear.

Although the timelines and routes of the eastward movement of wheat and barley into China are controversial, it is almost certain that wheat was introduced into Shangdong between 2500 and 2000 BC (Jin *et al*. 2011), and wheat and barley dispersed into northwest China around 2000 BC (Dong *et al*. 2017a; Liu *et al*. 2016). However, the time taken for these exotic crops to become the primary staples in China varies from region to region. For example, stable isotopic and radiocarbon data show that wheat became a staple food in the Central Plains by 500 BC (Atahan *et al*. 2014), while wheat and barley became important staples in northwest China during the Early Bronze Age (Atahan *et al.* 2011; Ma *et al*. 2016; Zhang 2006). The archaeobotanical and stable isotope evidence indicates that wheat was introduced into the Hexi Corridor around 2000 BC (Dong *et al*. 2017a; Liu *et al*. 2014; Zhao 2009; Zhou *et al*. 2016), and rapidly replaced millet to become a staple crop after 1700 BC (Zhou *et al*. 2016). Stable carbon and nitrogen isotopic data also suggest that human diets shifted from C_4 (presumably foxtail millet and broomcorn millet) to mixed C_4 and C_3 (probably through the inclusion of wheat and barley into the diet) in the northeastern Tibetan Plateau (NETP) after 1600 BC (Ma *et al*. 2016), but a detailed history of the adoption of these exotic crops as major staples in the area remains unclear, due to the absence of systematic archaeobotanical study from excavation of Early Bronze Age sites.

In this chapter, we present the results of archaeobotanical analysis and direct radiocarbon dates of charred crop seeds unearthed from the excavation of Lijiping site in the Hehuang basin of NETP, and compare the results with previous archaeobotanical analyses and published radiocarbon dates in the NETP and the adjacent Hexi Corridor, to explore when and where wheat and barley were accepted as staple crops in northwest China, as well as the influencing factors behind the process.

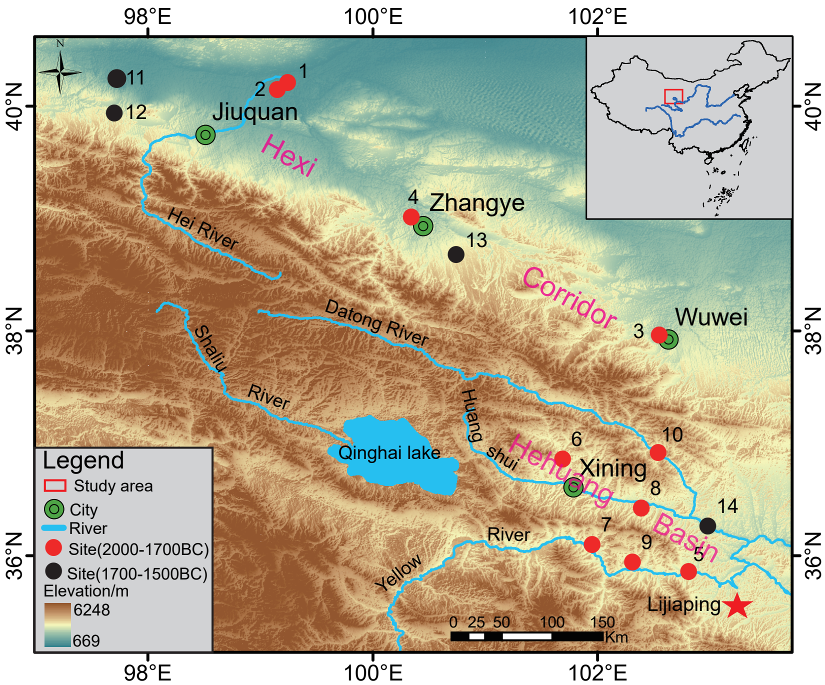

Figure 16.1. *Distribution of prehistoric sites with archaeobotanical analysis and AMS dates in the NETP and Hexi Corridor. (1) Huoshiliang; (2) Ganggangwa; (3) Huangniangniangtai; (4) Xichengyi; (5) Lajia; (6) Ajiacun; (7) Zhaongtan; (8) Zhaojiazhuang; (9) Gongshijia; (10) Jinchankou; (11) Shaoguoliang; (12) Huoshaogou; (13) Donghuishan; (14) Wayaotai.*

Study area

The Hehuang basin (Fig. 16.1) is located on the NETP and connects the Tibetan Plateau, Hexi Corridor and the Loess Plateau. This area covers the upper reaches of the Yellow River and the Huangshui and its tributaries. The climate of this region is characterized as semi-humid and semi-arid. The average annual precipitation in the Hehuang basin is 240–600 mm and decreases from southeast to northwest. The mean annual temperature varies between 2.2°C and 10.6°C with an average annual temperature of 5.8°C. Major crops in this region today include wheat, barley, maize, potato and broad bean.

The Lijiaping site (35°33'55.6"N, 103°13'5.4"E) is located in southeast Linxia county with an altitude of 2508 m a.s.l (Fig. 16.1). It is an important cultural relic protection unit of Gansu Province in China. Linxia county experiences a continental monsoon climate today, with a mean annual temperature of 5.9°C, mean annual precipitation of 631 mm and an annual frost-free period of about 150 days. A total of 54 Neolithic and Bronze Age sites were found in Linxia county, 43 of which are Qijia sites (Bureau of National Cultural Relics 2011). The Lijiaping site was excavated in 2011 by Gansu Province Institute of Cultural Relics and Archaeology and the Museum of Linxia County. The site covers an area of 210 sq. m, including four trial pits of 5×5 sq m (T1, T2, T3, T6), two trial pits of 5×10 sq. m (T4, T5) and a trial trench of 2×5 sq. m (G1). Plenty of pots and pottery sherds that display typical Qijia characteristics (such as double-ear jars), stone artefacts and bones were excavated. Many ash pits and trenches were found during the excavation of the site.

Methods

In total, 13 samples were collected from ash pits that were found in the excavation of the Lijiaping site, which were then floated by washover flotation in a bucket. Carbonized remains were collected by a sieve with #80 mesh (aperture size of 0.2 mm), then dried in the shade and sorted. Charred plant seeds were identified in the Paleoethnobotany Laboratory, Institute of Archaeology, Chinese Academy of Social Sciences.

Two charred seed samples were dated via accelerator mass spectrometry (AMS) at Peking University in Beijing, China, and another charred seed sample was dated via the AMS method by Beta Analytic, Miami, USA. Results were calibrated using Calib (v. 7.0.2; Stuiver & Reimer 1993) and the IntCal13 calibration curve (Reimer *et al.* 2013). All ages are reported as 'cal. BC'.

Results

Chronology

All of the radiocarbon dates from Lijiaping are listed in Table 16.1, including previously published dates. The three calibrated ^{14}C ages from remains of barley and wheat at the Lijiaping site reveal that the age of the site is mainly distributed between *c.* 1700 cal. BC

Table 16.1. *Calibrated radiocarbon data in the Hehuang Basin and Hexi Corridor.*

Site	Lab. no.	Dating material	Radiocarbon age (BP)	Calibrated age (cal BC; Reimer *et al.* 2013)		Location	Reference
				1 sigma	2 sigma		
Lijiaping	BA120213	Barley seed	3370±35	1729–1623	1748–1536	Hehuang Basin	This study
	BA120214	Barley seed	3380±35	1733–1630	1759–1561	Hehuang Basin	This study
	Beta-324458	Wheat seed	3240±30	1598–1453	1610–1440	Hehuang Basin	This study
Ajiacun	Beta-314717	Foxtail millet seed	3640±30	2106–1950	2132–1920	Hehuang Basin	Chen *et al.* 2015
Zhongtan	Beta-303694	Foxtail millet seed	3640±30	2106–1950	2132–1920	Hehuang Basin	Chen *et al.* 2015
Gongshijia	Beta-303689	Barley seed	3620±30	2023–1945	2117–1894	Hehuang Basin	Chen *et al.* 2015
Zhaojiazhuang	BA110904	Foxtail millet seed	3595±25	2010–1913	2022–1891	Hehuang Basin	Chen *et al.* 2015
Wayaotai	BA120199	Broomcorn millet seed	3410±30	1745–1665	1864–1627	Hehuang Basin	Chen *et al.* 2015
Jinchankou	BA110913	Barley seed	3595±20	2008–1917	2020–1892	Hehuang Basin	Chen *et al.* 2015
Huangniangniangtai	OZK418	Wheat seed	3570±60	2021–1781	2126–1746	Hexi Corridor	Zhou *et al.* 2012
Huoshiliang	OZK603	Wheat seed	3635±45	2118–2097	2135–1894	Hexi Corridor	Dodson *et al.* 2013
Ganggangwa	OZK658	Wheat seed	3560±50	2008–1780	2029–1754	Hexi Corridor	Dodson *et al.* 2013
Xichengyi	QAS1311	Wheat seed	3430±25	1754–1690	1873–1660	Hexi Corridor	Zhang *et al.* 2015
	QAS1312	Wheat seed	3460±25	1872–1699	1879–1693	Hexi Corridor	Zhang *et al.* 2015
	QAS1314	Wheat seed	3390±30	1736–1643	1750–1620	Hexi Corridor	Zhang *et al.* 2015
	QAS1315	Wheat seed	3355±30	1685–1619	1739–1535	Hexi Corridor	Zhang *et al.* 2015
	QAS1316	Wheat seed	3385±25	1732–1642	1743–1624	Hexi Corridor	Zhang *et al.* 2015
	QAS1317	Wheat seed	3400±25	1740–1663	1749–1631	Hexi Corridor	Zhang *et al.* 2015
Shaguoliang	OZK668	Wheat seed	3450±60	1877–1689	1915–1623	Hexi Corridor	Dodson *et al.* 2013
	OZK669	Wheat seed	3390±50	1744–1626	1875–1533	Hexi Corridor	Dodson *et al.* 2013
Huoshaogou	OZK672	Wheat seed	3430±50	1870–1663	1881–1628	Hexi Corridor	Dodson *et al.* 2013
Donghuishan	OZK653	Wheat seed	3260±45	1611–1498	1629–1436	Hexi Corridor	Zhou *et al.* 2012
	OZK654	Wheat seed	3405±50	1754–1630	1879–1565	Hexi Corridor	Zhou *et al.* 2012
	OZK655	Wheat seed	3425±40	1859–1664	1877–1629	Hexi Corridor	Zhou *et al.* 2012
	OZK656	Wheat seed	3410±50	1764–1635	1881–1611	Hexi Corridor	Zhou *et al.* 2012

and 1500 cal. BC (1 sigma). According to the results of the radiocarbon dates, the age of these sites in the NETP and Hexi Corridor can be divided into two periods (Figs 16.2 & 16.3; Table 16.1): the first period (2000–1700 BC) including the sites Huoshiliang, Ganggangwa, Huangniangniangtai, Xichengyi, Lajia, Ajiacun, Zhongtan, Zhaojiazhuang, Gongshijia and Jinchankou, and the second period (1700–1500 BC) including the sites Shaguoliang, Huoshaogou, Donghuishan, Xichengyi, Wayaotai and Lijiaping (Chen *et al*. 2015; Dodson *et al*. 2013; Zhang *et al*. 2015; Zhou *et al*. 2012).

Carbonized plant remains from Lijiaping site

We identified 3402 charred grains in 13 samples taken during the excavation of the Lijiaping site in 2011 (Fig. 16.4; Table 16.2). Remains of four crops were identified, including 1989 foxtail millet (*Setaria italica*), 561 broomcorn millet (*Panicum miliaceum*), 286 barley (*Hordeum vulgare*) and 8 wheat (*Triticum aestivum*) grains, accounting for 58.4, 16.5, 8.4 and 0.2 per cent of the total identified charred plant seeds, respectively. The ubiquities of charred foxtail millet, broomcorn millet, barley and wheat in the 13 floated samples are 100, 92.31, 84.62 and 23.08 per cent, respectively. Seventeen other grass seed types were also present in those samples; 388 bristlegrass (*Setaria sp.*) seeds and 79 grains belonging to the pea family (Leguminosae) were also identified in seven and nine samples, respectively, which account for 11.41 and 2.32 per cent of total identified charred grains, respectively. In addition, 91 charred grains were identified as a

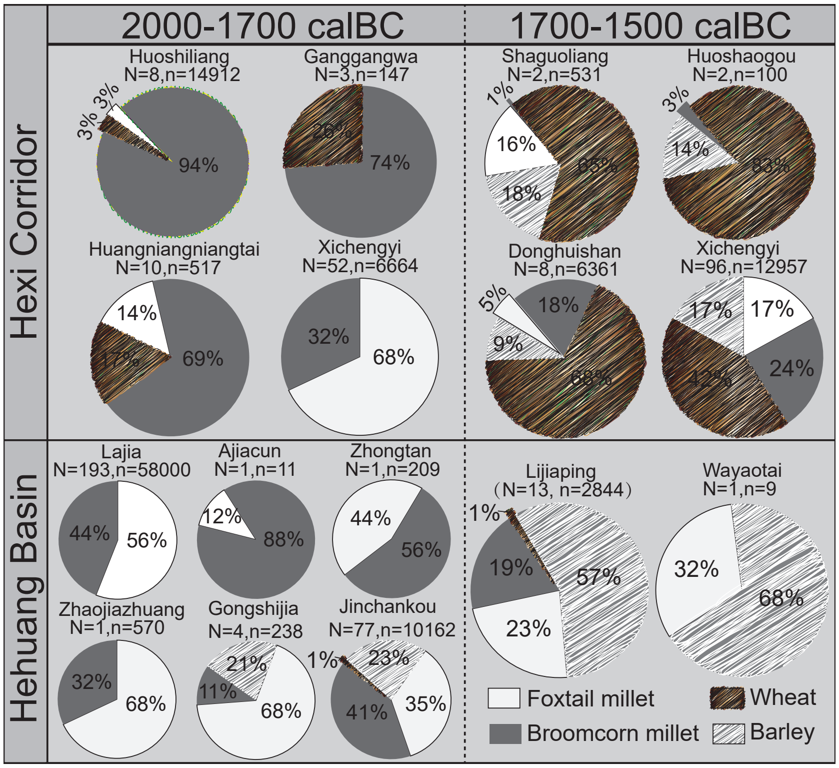

Figure 16.2. *The actual yield percentage of the sites in the NETP and Hexi Corridor.*

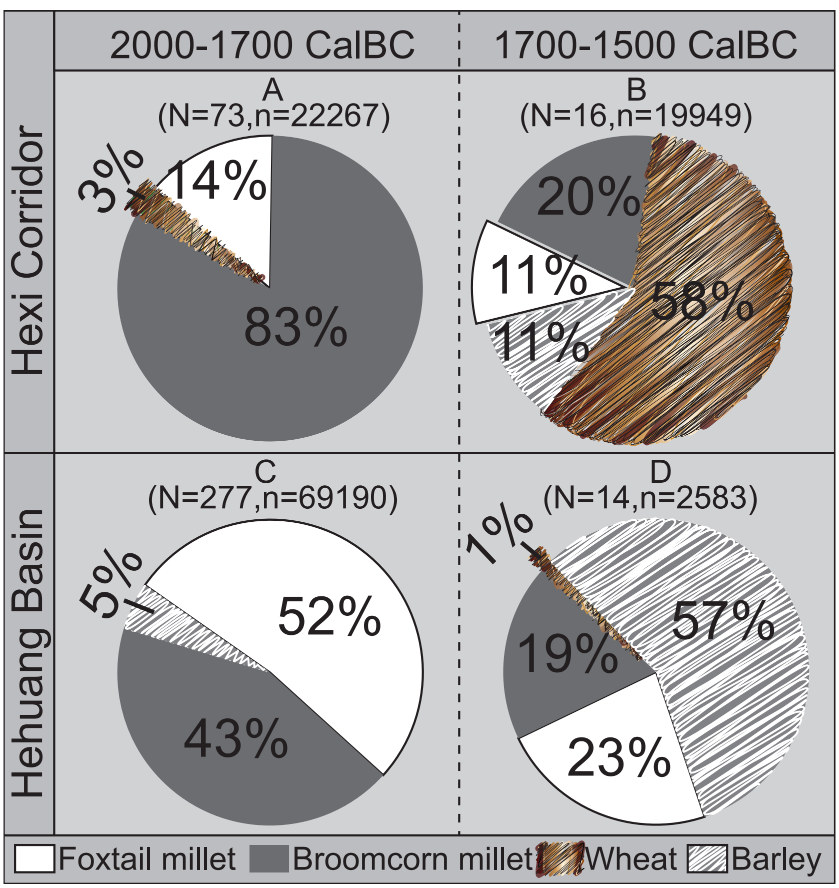

Figure 16.3. *Sum of the actual yield percentage of the sites in the NETP and Hexi Corridor. (A) Sum actual production of Huoshiliang, Ganggangwa, Huangniangniangtai and Xichengyi; (B) Sum actual production of Shaguoliang, Huoshaogou, Donghuishan and Xichengyi; (C) Sum actual production of Lajia, Ajiacun, Zhongtai, Zhaojiazhuang, Gongshijia and Jinchankou; (D) Sum actual production of Lijiaping and Wayaotai.*

Table 16.2. *Charred seeds from the Lijiaping site, Linxia county, Gansu Province, China.*

Sample no.	**LM LT2 H1**	**LM LT3 H2**	**LM LT6 H1①**	**LM LT6 H1②**	**LM LT6 H1③**	**LM LT6 H1④**	**LM LT6 H1⑤**	**LM LT6 H2**	**LM LT6 H3**	**LM LT6 H4**	**LM LT4 G1a**	**LM LT4 G1b**	**LM LT5 G1**	**Total**	**Unearthed probability**
Flotation quantity (L)	9	9	11	15	10	9	10	10	9	12	8	7	8	127	
Setaria italica	29	1	378	191	241	497	43	96	15	399	54	8	37	1989	100%
Panicum miliaceum	3		48	82	104	215	25	23	2	28	7	3	21	561	92%
Hordeum vulgare		1	60	22	27	19	25	40		65	1	1	25	286	85%
Triticum aestivum							2		1	5				8	24%
Avena fatua L.				3		12								15	15%
Setaria sp.	1		11		10	25	337			1	3			388	54%
Gramineae			2	2										4	15%
Herba Agastaches				1		2		1						4	24%
Leguminosae	2		8	6	19	27	5	1		10			1	79	69%
Hippophae						1								1	8%
Peganum harmala L.					1									1	8%
Violaceae			2			3								5	15%
Malvaceae			1			1		1						3	23%
Compositae			1											1	8%
Polygonaceae				1		1								2	15%
Chenopodiaceae				2	1									3	15%
Chenopodium L.			1	4	2	24								31	31%
Salsola L			5	3										8	15%
Rosaceae			2	1		4								7	24%
Rubus							1							1	1
Cruciferae						5								5	5
Unknown			4	18		4		3						29	29
Total	***35***	***2***	***523***	***336***	***405***	***840***	***438***	***165***	***18***	***508***	***65***	***12***	***84***	***3431***	

variety of taxa. Some of those grains can be assigned to the genus/species level, such as *Avena* sp., *Herba Agastaches*, *Peganum harmala* (esfand), *Chenopodium* sp., *Salsola* sp. and *Rubus* sp., and the others can be only assigned to the family, such as Gramineae, Violaceae, Polygonaceae and Cruciferae. Results of the archaeobotanical identification are listed in Table 16.2, with images presented in Figure 16.4.

Lijiaping and contemporary sites

Between 2000 and 1000 BC, there was a global climatic transition from the Middle Holocene Megathermal to the relatively cold Late Holocene (Wanner *et al*. 2008). The monsoon system in Asia weakened, which led to many local agricultural systems becoming unstable and eventually changing in different parts of the Old World. The Hehuang basin of NETP and Hexi Corridor are located on the margin of the Asian monsoon region and are highly sensitive to climate change (Chen *et al*. 2010; Wu 1980). Over the last few decades, systemic chronological and archaeobotanical studies have been carried out at Lijiaping and contemporary sites from the NETP and Hexi Corridor dating to 2000–1000 BC (Chen *et al*. 2015; Yang *et al*. 2016; Zhang *et al*. 2013; Zhou *et al*. 2016), which can give us a clear understanding of the transformation time of agricultural structures in these two regions. According to the results of radiocarbon dating of these sites in the NETP and Hexi Corridor, combined with the actual yield percentage calculated by Zhou *et al*. (2016), in the study area, the different patterns of agricultural transformation in the Hehuang basin of NETP and Hexi Corridor can be observed (Figs 16.2 & 16.3). Between *c*. 2000 and 1700 BC, in both the Hexi Corridor and in the NETP, the actual yield percentages of broomcorn millet and foxtail millet are over 70 per cent in all sites, which indicates that millets were the dominant crop; while from 1700 to 1500 BC, wheat began to appear as an important crop in Hexi Corridor and barley was the dominant crop in the NETP. In the Hexi Corridor, wheat makes up the largest percentage of the production ratio, up to 58 per cent. However, the largest

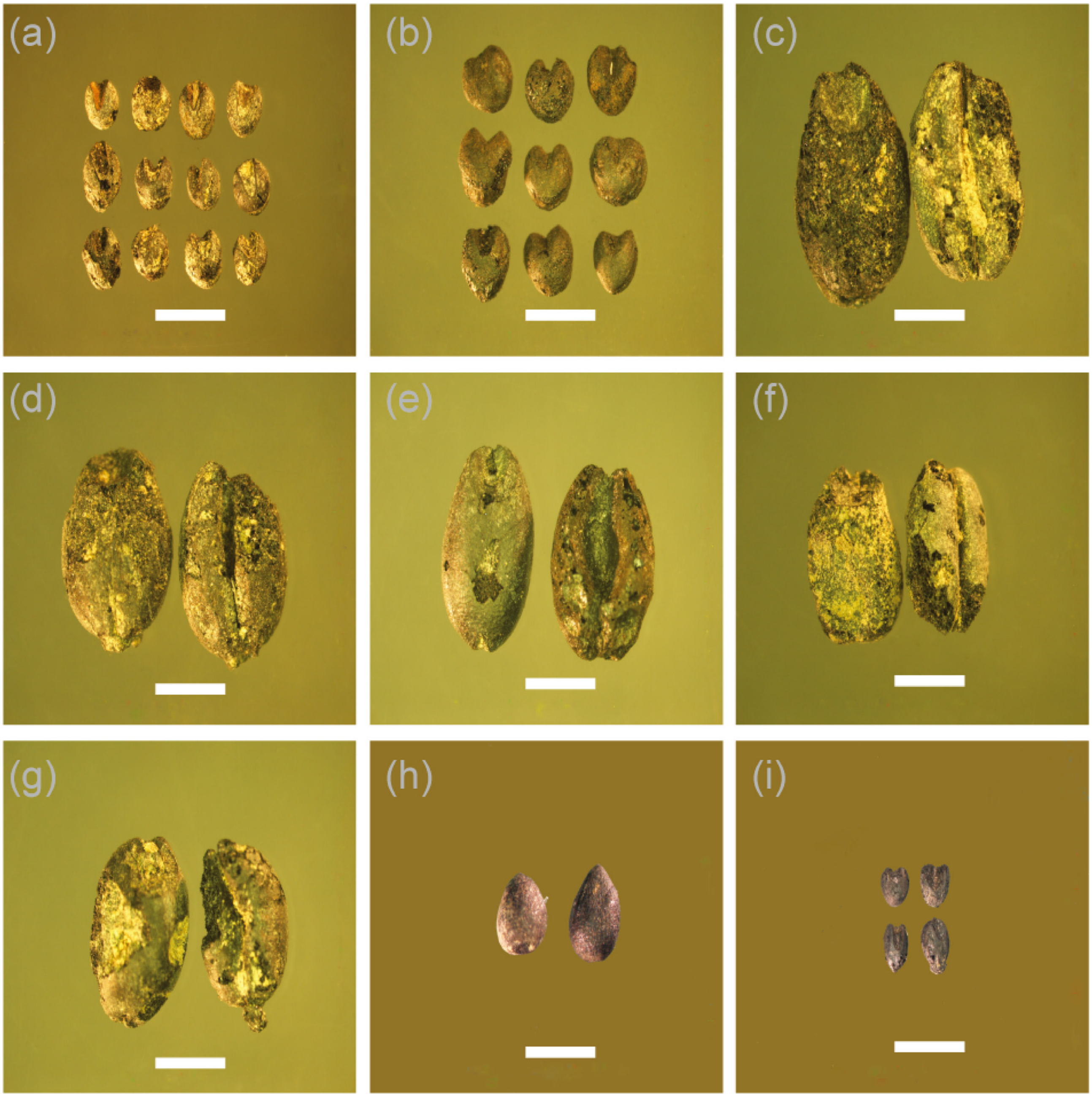

Figure 16.4. *Carbonized plant seeds collected from Lijiaping Site. (a) Foxtail millet (*Setaria italica*); (b) Broomcorn millet (*Panicum miliaceum*); (c, d, e) Barley (*Hordeum vulgare*); (f, g) Wheat (*Triticum aestivum*); (h) Mallow family (Malvaceae); (i) Bristlegrass (*Setaria *sp.).*

percentage of the production ratio in the NETP was barley, up to 57 per cent (Fig. 16.3).

Discussion

The stability of agricultural systems in various ecological environments is critical for understanding ancient cultural development in the context of a changing climate (Riehl 2009). Studies of the structural changes in agricultural systems, combined with accurate radiocarbon dating, may help us better understand the adaptation strategies of ancient human societies worldwide. Based on the archaeobotanical and radiocarbon dating results from Lijiaping, barley was the most important cultivated crop at the site between *c.* 1700 and 1500 cal. BC. Other utilized crops include foxtail millet, broomcorn millet and wheat. As shown in Figure 16.2, barley comprised the largest proportion of the production ratio in the Lijiaping site, up to 57 per cent, whereas the actual yield percentage of millets and wheat only comprise 43 per cent in total. Another macrofossil analysis also indicated that barley was the primary cultivated crop in the NETP from 1700 BC to 1500 BC (Chen *et al*. 2015). Additionally, stable isotopic evidence also suggested that more C_3 foods (probably wheat, barley and animals fed with C_3 foods) were added to human diets after 1600 BC in Gansu and Qinghai provinces (Ma *et al*. 2016). In contrast, millets were the main crops in most of the sites in the eastern Gansu province during the whole Qijia cultural period (2300–1500 BC: Jia *et al*. 2012; Wang 2012; Yang 2014; Zhou *et al*. 2011).

Compared with the Hehuang basin in the NETP, wheat-based agriculture was the primary subsistence strategy in the Hexi Corridor between 1700 and 1500 BC (Fig. 16.2; Fan 2016; Flad *et al*. 2010; Zhou *et al*. 2016). For example, the actual yield percentages of wheat in Shahuoliang, Huoshaogou, Donghuishan and Xichengyi are 65, 83, 68 and 42 per cent, respectively (Fig. 16.2; Zhou *et al*. 2016). However, whether in the NETP or in the Hexi Corridor, millets dominate the charred plant assemblages between 2000 and 1700 BC (Fig. 16.2). For instance, millets comprise 97, 74, 83 and 100 per cent of the production ratio at Huoshiliang, Ganggangwa, Huangniangniangtai and Xichengyi in the Hexi Corridor, respectively (Fig. 16.2). Foxtail and broomcorn millet also remained the main crops at all six sites in the NETP (Fig. 16.2).

To describe the crop assemblage in these two regions more clearly, we summarized the crops of all sites in the same area in one pie chart (Fig. 16.3). It can be seen very clearly that barley and wheat make up the largest percentage of the production ratio in the NETP and Hexi Corridor between 1700 and 1500 BC, up to 57 and 58 per cent, respectively (Fig. 16.3), whereas between 2000 and 1700 BC, the actual yield percentage of millets is 97 per cent in the Hexi Corridor, accounting for 95 per cent in the NETP. Stable carbon isotope research from these two areas also shows that C_4-type millets were the dominant food from 2000 to 1700 BC (Atahan *et al*. 2011; Ma *et al*. 2016). Therefore, we can conclude that humans had adopted barley and wheat as the primary staples in the NETP and Hexi Corridor, respectively, between 1700 and 1500 BC. But prehistoric people in these two regions mainly engaged in the cultivation of millet crops from 2000 BC to 1700 BC. In brief, the agriculture structure changed significantly in the NETP and Hexi Corridor around 1700 BC. The impetus for this change is likely a response to changes in the climate, as millet production is vulnerable to temperature drops (Brink 2006; Cappers *et al.* 2010; Kamkar *et al*. 2006), which occurred during this period (e.g. An *et al*. 2005). Barley and wheat are more resistant to lower temperatures than millets (Klepper *et al*. 1998; Saseendran *et al*. 2009; Stoskopf 1985) and were likely quickly accepted by the local people as staple cereal grains.

Why did wheat become a staple crop after 1700 BC and rapidly replace millet after 200 to 300 years in the Hexi Corridor, while barley was the dominant crop in the NETP between 1700 and 1500 BC? This spatial difference might be caused by temperature decline and different hydrothermal condition in these two areas. As we all know, millets are frost-sensitive crops which need to grow in a warmer and wetter environment (Chai 1999; Guedes & Butler 2014; Wang 1994). The NETP is an extremely harsh environment with high altitude, low temperature and low oxygen level, which creates difficult conditions for plants and human to survive. More importantly, multiple climate records have demonstrated that the climate was wetter and warmer during the middle Holocene, and became cooler and drier after 2000 BC in Gansu and Qinghai provinces (An *et al*. 2004; 2005; Chen *et al*. 2015; Marcott *et al*. 2013; Wang *et al*. 2005; Zhao & Yu 2012). Therefore, millet production might have decreased, since it can hardly survive in such cooler and drier climate conditions after 2000 BC. However, barley has a longer growing season and is more frost-hardy than millets (Páldi *et al*. 2001). The climate model of Guedes (2015) also shows that growing degree days of millets has higher temperature requirements than wheat and barley (Guedes 2015). Thus, the low-temperature tolerance of barley enables it to be cultivated in higher-altitude regions such as the NETP. Finally, barley replaced millet as a staple crop between 1700 and 1500 BC in the NETP. Recent archaeobotanical studies also found that barley-based agriculture facilitated permanent prehistoric human settlements in the areas above 2500 masl after 1600 BC in the NETP, where temperatures are lower (Chen *et al.* 2015; Dong *et al*. 2016). The plant macrofossil analysis results also suggest that humans were heavily reliant on barley-based agriculture in northeast Qinghai province during the Kayue culture period (1600–500 BC; Wang 2012; Zhang & Dong 2017; Zhao 2010). Besides, the optimal (wetter and warmer) climate during the middle Holocene might have led the population to grow rapidly in the western Loess Plateau (Bureau of National Cultural Relics 1996; 2011; Ma *et al*. 2016; Zhou *et al*. 2016). The large population might have migrated from the western Loess Plateau to the NETP when the climate became cooler and drier after 2000

BC (Chen *et al*. 2015). However, the yields of wheat and naked barley are higher than millets (Dong & Zheng 2006), and barley is a crop that is more suitable for growth in lower temperatures than wheat (Klepper *et al*. 1998; Saseendran *et al*. 2009; Stoskopf 1985). As a result, the low yield of millets may have been inadequate to feed large populations, and led to barley becoming a staple crop in the NETP.

In the Hexi Corridor, recent research has found that its climate and landscape environment were similar to the Near East (Zhou *et al*. 2016). As mentioned above, compared to rain-fed millet cultivation, the yields of wheat and naked barley are higher (Dong & Zheng 2006). Meanwhile, wheat is a C_3-type plant, and water supply is the most important factor for maintaining its high yield (Klepper *et al*. 1998; Saseendran *et al*. 2009). In contrast to the valley and hilly regions in most parts of NETP, the oasis regions of the Hexi Corridor have a lot of flat areas (Zhou *et al*. 2016). Water supply is dependent upon irrigation by rivers, and farmlands can be easily irrigated via access to shallow underground water supplies in the oasis (Zhou 2002). Therefore, these flat lands in the Hexi corridor are better suited for the cultivation of wheat than barley. Moreover, bronze mining and smelting were introduced to the Hexi Corridor during the Bronze Age and developed significantly (Dodson *et al*. 2009; 2013; Yang *et al*. 2016; Zhang *et al*. 2017). The development of mining and smelting requires an external labour force and a food supply. In addition, based on the results of the Second National Archaeological Survey, the number of sites in the Hexi Corridor is large, which shows the high intensity of human settlement during the Early Bronze Age (Bureau of National Cultural Relics 2011). These high-intensity human settlements require more food supplies in this area. Hence, high-yield wheat might have been chosen to meet the labour force needed in the bronze mining and smelting industry, and consequently replaced traditional lower-yield millet agriculture in the Hexi Corridor after 1700 BC.

In summary, cooler and drier climate conditions after 2000 BC, as well as the characteristics of barley's low-temperature tolerance, promoted the cultivation of barley in the NETP between 1700 and 1500 BC. The easily irrigated oasis flat land in the Hexi Corridor and development of a bronze mining and smelting industry enabled people to choose high-yield wheat agriculture from 1700 BC to 1500 BC. The decrease in temperature after 2000 BC and the different hydrothermal conditions in different regions may be the two key factors contributing to the various agricultural structures in the NETP and Hexi Corridor.

Conclusion

Archaeobotanical analysis and radiocarbon dating from the excavation of the Lijiaping site suggest that humans mainly cultivated barley, and supplemented this with millet and wheat during the period *c*. 1700–1500 BC. Combined with previous archaeobotanical studies in the NETP and Hexi Corridor, we argue that humans adopted barley and wheat, respectively, in these two areas approximately 300 years later than the introduction of these two exotic crops to northwest China around 2000 BC. The evident cooling trend in the Early Bronze Age may have led to unstable production of millets, which are sensitive to lower temperatures. The rapid transition from rain-fed agriculture to farming mainly based on the cultivation of cold-tolerant crops, and the spatial variation in adoption of barley and wheat, are likely a result of different hydrothermal conditions in the Hexi Corridor and the NETP.

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