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Starch grain analysis for groundstone tools from Neolithic Baiyinchanghan site: implications for their function in Northeast China

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ABSTRACT

Large numbers of groundstone tools have been uncovered from archaeological sites in the Early Neolithic period in China. Traditionally they are often regarded as agricultural tools for processing cereals. In this paper we report preliminary starch grain analysis of groundstone tools from Baiyinchanghan site to gain a better understanding of use of these tools in the Northeast China. We found that starch grains on these groundstone tools are most likely from *Quercus* sp. The result of this study indicates that many groundstone tools for the Early Neolithic period were used to process wild and domesticated plants alike.

1. Introduction

Groundstone tools are commonly recovered from prehistoric sites in China. However, there has been considerable debate regarding how these tools functioned in Neolithic societies. Traditionally groundstone tools were regarded as tools for processing cereals. Other researchers have suggested that based on ethnographic and archaeological evidences many Neolithic groundstone tools were used in some cases for processing acorns (Liu, 2008). Addressing the debate requires more direct evidences for the use of these tools.

The identification of ancient starch has become a significant new direction in archaeological residue analysis (Torrence and Barton, 2006). Moreover starch grains have been extracted from different kinds of archaeological contexts such as sediments, dental calculus and artifacts and from a wide range of time-periods (Balme and Beck, 2002; Fullagar et al., 2006; Mercader, 2009; Piperno and Dillehay, 2008; Perry, 2002; Pearsall et al., 2004; Shibutani, 2009; Zarrilo et al., 2008; Yang et al., 2009a, 2010a). Starch grain analysis is an appropriate technique for the identification of stone tool function (Barton et al., 1998; Loy et al., 1992; Perry, 2004). Starch grains have been successfully extracted from grinding stones from the Upper Palaeolithic sites in Israel, Australia and Europe (Aranguren et al., 2007; Fullagar and Field, 1997; Fullagar et al., 2008; Piperno et al., 2004). These included starch grains derived from grass seeds, roots and tubers. The identification of characteristic starch grains provides direct evidence that some grinding stones from the Upper Palaeolithic were used to process wild plant foods in many areas of the world. The analysis of starch grains recovered from the surfaces of groundstone tools is an appropriate technique for reconstructing patterns of subsistence in Neolithic contexts in China.

Recently residue analyses for groundstone tools in some Chinese sites have been done (Liu et al., 2010a, 2010b; Yang et al., 2009a) and gave us some direct evidences of function of these tools. They were used for processing gathered wild plants and possibly cultivated plants as well. Yang et al. (2009a) revealed that at Shangzhai site were used for processing cereals and other seeds including acorns and possibly roots. Liu's work (Liu et al., 2010a, 2010b) also suggested that acorns were processed using groundstone tools from sites in north China and the middle Yellow River valley. These results indicate the groundstone tools should not be regarded as agricultural tools exclusively associated with the processing of cereals. Furthermore the presence of groundstone tools is more likely to suggest a broad-spectrum subsistence economy (Liu et al., 2010b). But until recently there has been no attempt to analyze residues in order to

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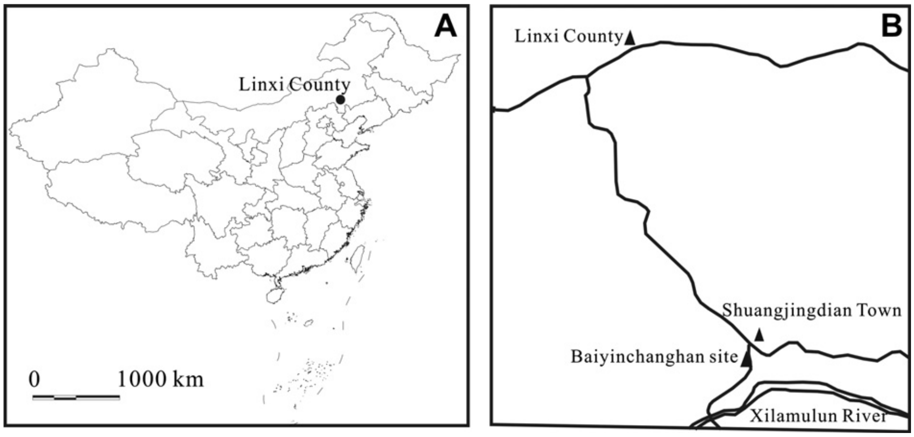

Fig. 1. The map of the location of the Baiyinchanghan site (A) The location of Linxi County in China. (B) The location of Baiyinchanghan site.

investigate the function of the groundstone tools in Northeast China. Groundstone tools are frequently found at Early to Middle Neolithic sites in Northeast China and constitute a high proportion of stone tool assemblages in some archaeological cultures, especially the Xinlongwa Culture (6200–5400 BC). Northeast China is an important area for investigating the transition from foraging to agriculture (Liu et al., 2010a; Liu et al., 2010b). However except for work at the Xinglongwa and Xinglonggou sites, there have been few studies that address subsistence during the earlier Neolithic period (Zhao, 2005). One method of investigating ancient subsistence is to study the function of groundstone tools. In this paper, we will present the analysis of starch grains from four groundstone tools from the Baiyinchanghan site, and discuss the function of groundstone tools in Northeast China during the Early Neolithic period.

2. Material and method

The Neolithic Baiyinchanghan site is located in Baiyinchanghan village, Shuangjingdian Town, Linxi County, Chifeng City of Inner Mongolia, on the north bank of Xilamulun River (Fig. 1). The Chifeng District is characterized by a continental monsoon climate of middle medium latitudes, with an annual precipitation of 350–450 mm and an annual temperature of 5–8° centigrade. Pollen analysis in this region has demonstrated the climate during most of the occupation of the site (8400–6200BP) was warm and wet. The botanical record is characterized by high frequencies of herbaceous pollen Artemisia of with some *Birch*, *Pinus* and *Quercus*. Prairie vegetation is predominant although deciduous broad-leaved forests also existed nearby (Xu et al., 2002).

The site was excavated by the Institute of Relics and Archaeology, Inner Mongolia Autonomous Region in 1988, 1989, and 1991. 7264 square meters of the Baiyinchanghan site were excavated, including houses, pits and burials. Artifacts recovered during excavations include pottery, stone and bone tools.

The Baiyinchanghan site represented multiple occupations that were divided into five archaeological occupations (IRAIM, 2004). The earliest occupation of the site is characterized by undecorated pottery, a few houses and pits, which were located on the higher

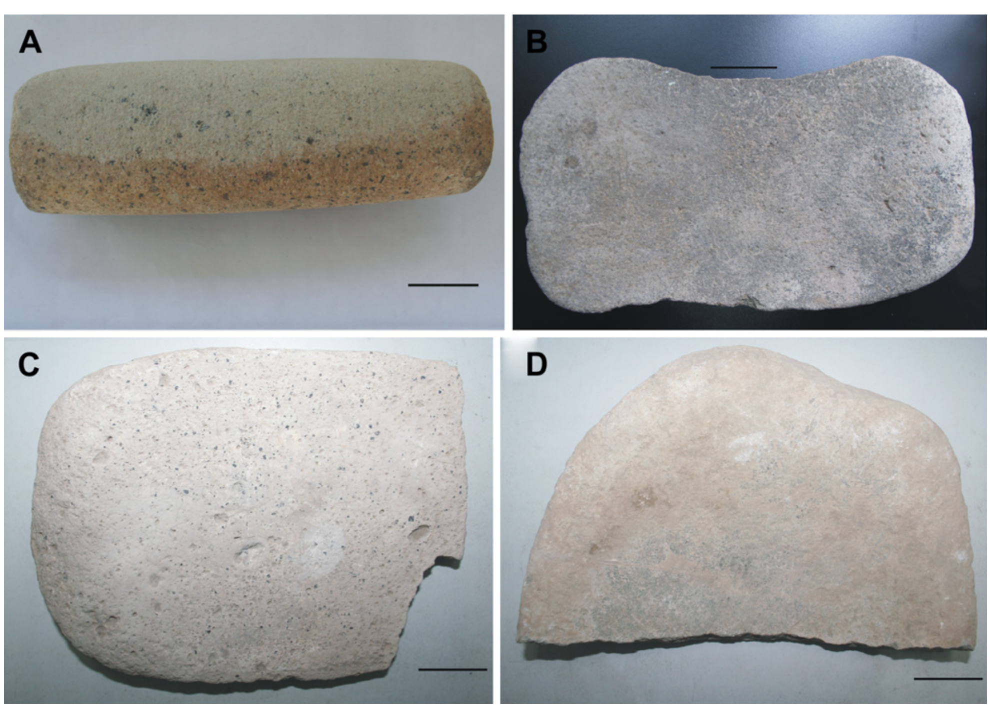

Fig. 2. Groundstone tools from Baiyinchanghan site: (A) 91LBBF64②:2; (B) 91LBBF63②:8; (C) 91LBBF30②:4; (B) 91LBBF61④:7. (Scale bar: 3 cm).

southern end of the site. Three houses: No.42, No.64 and No.65 and two pits relating to the earliest occupation of the site were excavated. The only pottery vessels are cylinder pot without any decoration except simple plastic design. These remains from the first phase belonged to the earliest archaeological culture named Xiaohexi Culture (before 6200 BC) in the Liaoxi region (IRAIM, 2004; Suo, 2005). To date no independent radiometric dating has been undertaken for the Xiaohexi Culture. Fortunately the definite stratigraphical connection exists between house No.63 and house No.64 in Baiyinchanghan site. House No.63 which belongs to Xinlongwa Culture (6200–5400 BC) truncated house No.64 (Fig. 3B), so the date of house No.64 is earlier than house No.63.The remains from the second phase was composed of two types, "Nantaizi Type" and "Baiyinchanghan Type." The former was similar to the remains found from Nantaizi site of Keshiketeng Banner; the latter were similar to materials found from the Chahai site at Fuxin City. These

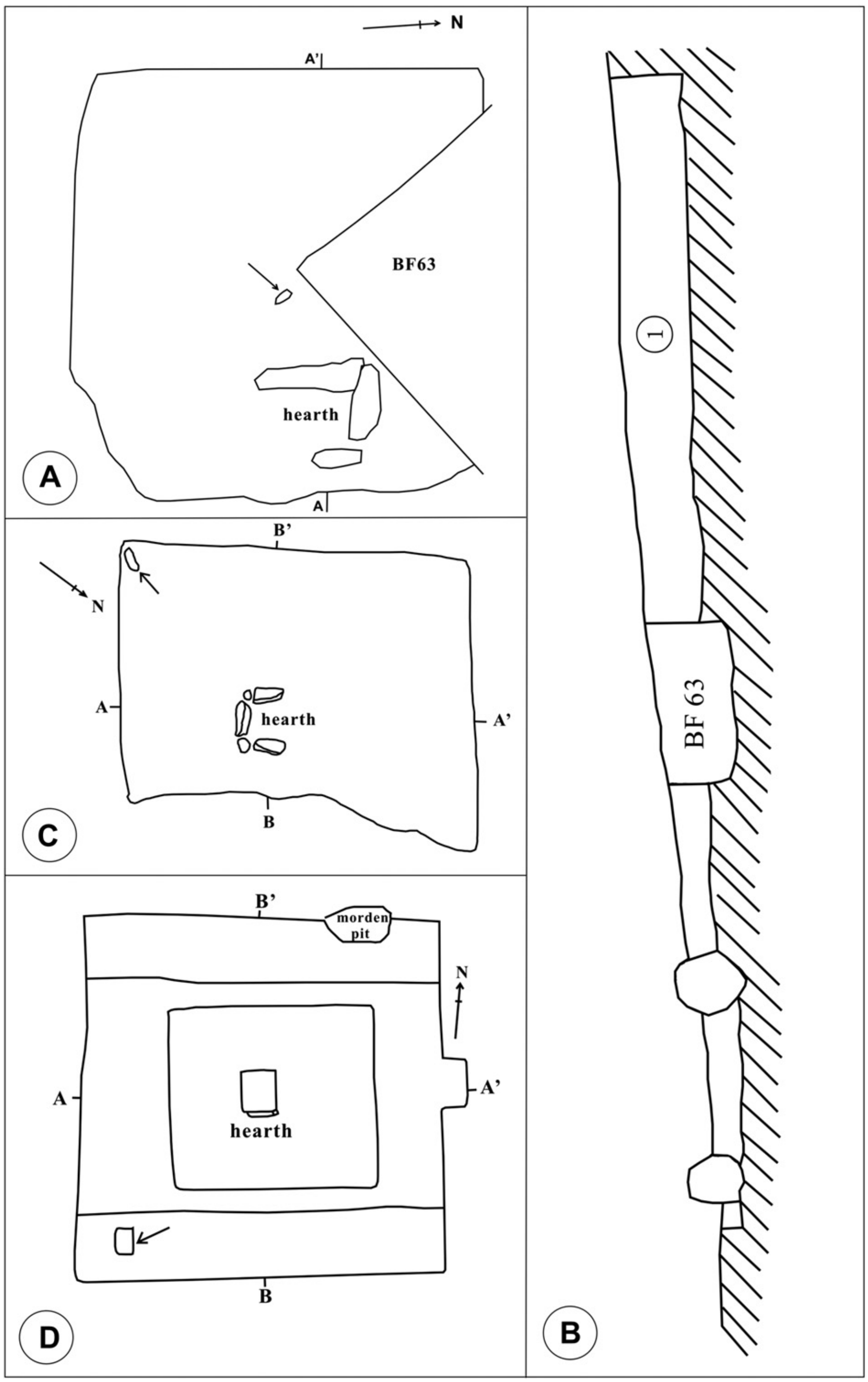

Fig. 3. Line drawings of houses where the groundstone tools were unearthed. (A) House No.64, showing the handstone (arrow) in the west of the hearth; (B) Northern section of House No.64, indicating house No.64 was interrupted by house No.63; (C) House No.63, showing the grinding stone (arrow) in the southwest of the hearth; (D) House No.61, showing the grinding stone (arrow) in the southwest of the hearth. (adapted from IRAIM, 2004).

Table 1
Groundstone tools from Baiyinchanghan site.

Tool no.	Sample no.	Tool type	Archaeological unit	No. used surfaces& shape
91LBBF64②:2	F64A* F64B*	Handstone	House No.64	Two; flat-sphere
91LBBF63②:8	F63A F63B	Grinding stone	House No.63	One; concave
91LBBF30②:4	F30A F30B	Grinding stone	House No.30	One; concave
91LBBF61④:7	F61A F61B	Grinding stone	House No.61	One; concave

*: A means the used surface, and B means the unused surface.

two types of remains both belong to Xinglongwa Culture (6200–5400 BC). Three later periods representing different archaeological cultures are also present at the Baiyinchanghan site and will not be discussed here.

Many groundstone tools were uncovered from the site, mostly belonging to the second phase, the Xinlongwa Culture. The groundstone tools selected for starch grain analysis included one handstone and three grinding stones from the first two phases (Table 1). Residue samples were collected from areas in which starch residues would likely preserve such as deep crevices and cracks in the tools (Piperno et al., 2000, 2004; Perry, 2004). When such an area was located, 40 μl of deionized water was applied to this area. The water was allowed to soak into the cervice and was repeatedly agitated using a disposable tip attached to a pipette. The suspended mixture of residue and water was withdrawn from the tool with a pipette and ejected onto a slide. Before the residue had dried, one drop of 50:50 water/glycerin mounting medium was placed on the slide. A cover glass was deposited on top of the mixture and the edges sealed with nail polish. The slide was examined under polarized and unpolarized light at 500×.

Taxonomic identification of archaeological starch grains is based on the attributes which are proved to be useful in identification such as size, overall shape, position and form of the hilum, fissure, and presence or absence of lamellae and other features visible on the grains. For example, the hilum is usually located near the middle of the grain, but it can be eccentric in location and morphology. Lamellae which are growth layers are visible in many large grains and are characteristic for some species (e.g., *Dioscorea*) (Torrence and Barton, 2006). In addition to comparative plant samples collected by the authors, many studies about starch grain morphology are also consulted to further support any identification (Reichert, 1913; Yang et al., 2009a, 2009b, 2010a; Yang and Jiang, 2010b; Liu et al., 2010a, 2010b).

Four well-preserved groundstone tools from the first two occupation periods of the site were examined. All of the groundstone tools from the Baiyinchanghan site were uncovered in contexts near the hearths within the houses. Starch grains were clearly observed on all of four artifacts. Our reference collection includes examples of *Setaria italica*, *Panicum miliaceum* and different nuts including Quercus, *Lithocarpus*, *Cyclobalanopsis* and these are discussed in detail. Starch grains from millets are polygonal in shape (Fig. 5A, B). Yang et al. (2010a) has conducted morphological characterization of starch grains from two domesticated millets (*Setaria italic* and *Panicum miliaceum*) and their wild relatives including green foxtail grass (*Setaria viridis*), *Panicum bisulcatum* and *Eriochloa villosa* in North China. This study showed that starch grains from broomcorn millet have smooth surfaces, mostly without fissures, whereas starch grains of foxtail millet mostly have open hila with characteristic fissures. It is also indicated by Yang et al. (2010a) that starch grains whose sizes are smaller than 11 μm might be either of broomcorn millet if they have more than 40% grains without fissures or of *Setaria* if they have more than 30% of starch grains with fissures. The starch grains from acorns have different morphologies depending on their species. Starch grains from *Quercus* are mostly oval shaped and some have longitudinal fissures across the hila (Yang et al., 2009b; Fig. 5D). Starch grains from *Lithocarpus* and *Cyclobalanopsis* are oval and irregular, bigger than those from *Quercus* and some have shallow fissures (Table 2; Fig. 5H, I; Liu et al., 2010a, 2010b). Starch grains from *Cyclobalanopsis* are semi-compound (Fig. 5I).

2.1. 91LBBF64:2

This handstone is an elongated slab with two use surfaces which were heavily ground; the cross-section is trapeziform and dimensions are: 17 cm long, 5.2 cm wide and 5 cm thick (Fig. 2A). It was found on the house floor of House No.64 which belongs to the Xiaohexi Culture (before 6200 BC) (Suo, 2005), west of the hearth (Fig. 3A). The white macroscopic residue can be observed on the use surfaces (Fig. 2A). Samples F64A and F64B yielded nineteen and seven starch grains respectively (Table 3). Three starch grains from F64A were polygonal. Their sizes are 8, 9 and 8 μm respectively. They have circular hila with a smooth surface (Fig. 4A). These starch grains show similarities to *Panicum miliaceum* (Fig. 5A), but the

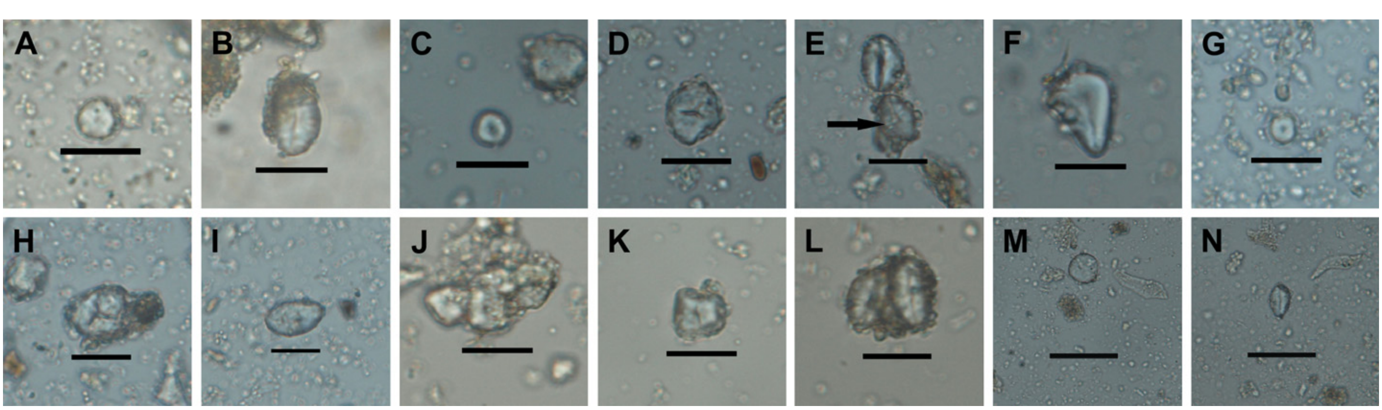

Fig. 4. Starch grains extracted from the used surfaces of archaeological groundstone tools from Baiyinchanghan site: A–B) F64A; C–F) F63A; G–I) F30A; J–L) F61A; M–N) F63A. (Scale bar: 20 μm).

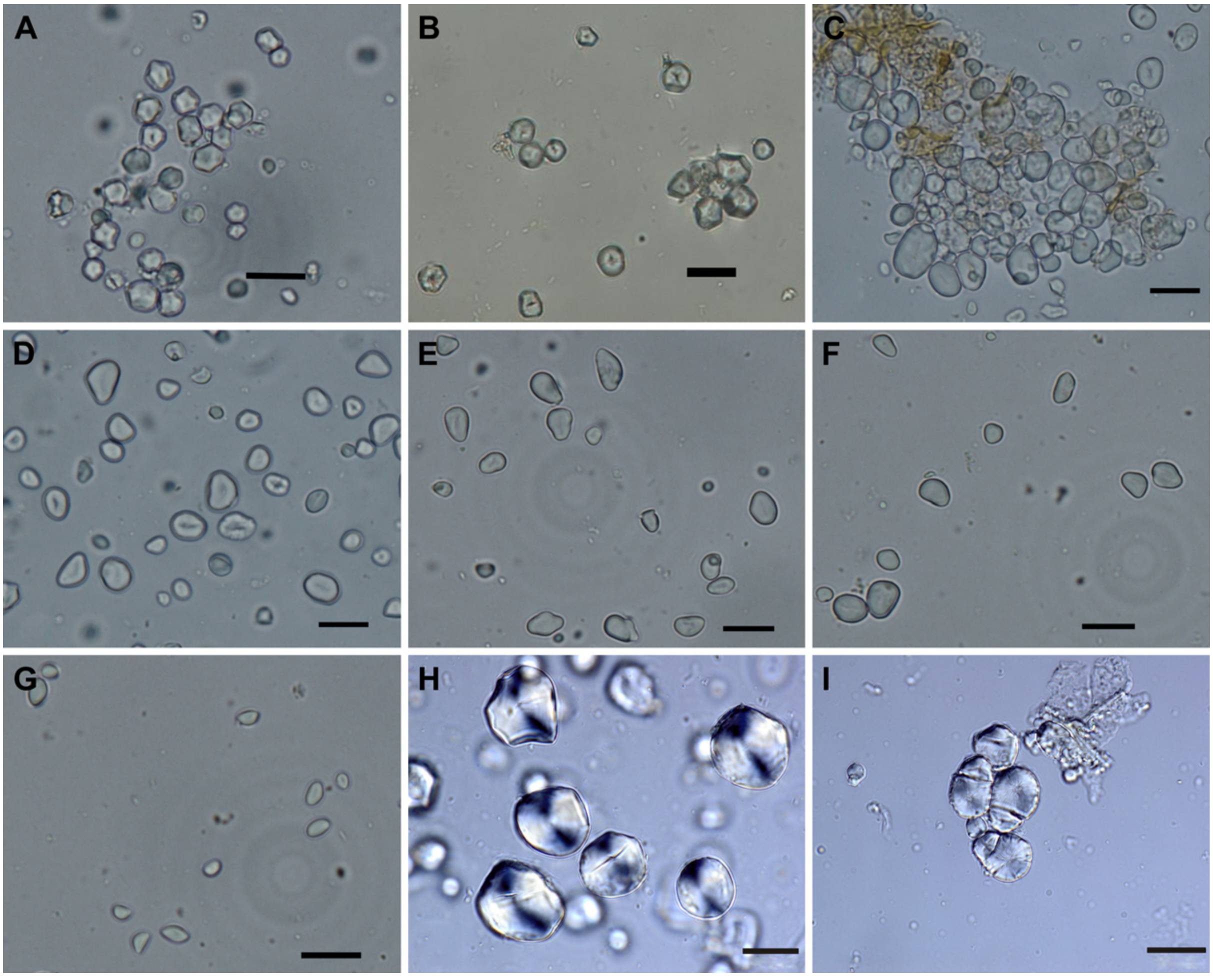

Fig. 5. Starch grains from some modern plants. (A) broomcorn millet (*Panicum miliaseum*); (B) foxtail millet (*Setaria italica*); (C) *Quercus aliena*; (D) *Quercus dentata*; (E) *Quercus acutissima*; (F) *Quercus viriabilis*; (G) *Quercus mongolicus*; (H) *Lithocarpus glaber*; (I) *Cyclobalanopsis glauca* (Scale bar: 20 μm).

sample of these type of starch grains is too small to make a convincing identification. One ovoid starch grain from F64A is 18 μm and has a longitudinal fissure that is characteristic of *Quercus* sp. (Fig. 4B) (compared with Fig. 5C–G, Yang et al., 2009a, 2009b).

2.2. 91LBBF63:8

This grinding stone which had a concave use surface is 34 cm long, 18 cm wide and 3–7.4 cm thick (Fig. 2B). It was uncovered from the house floor of No.63 which belongs to the Xinlongwa Culture, southwest of the hearth (Fig. 3C). Samples F63A and F63B yielded 245 and 9 starch grains respectively (Table 3). Forty-seven of the starch grains extracted from F63A are spherical or polygonal (Fig. 4C). The starch grains range in size between 5 and 11 μm. They have smooth surfaces without fissures. These starch grains are from the grass family Poaceae, and most likely from broomcorn millet (*Panicum miliaceum*) (Yang et al., 2009a, 2010a). We also found twenty-four polygonal starch grains from F63A (Fig. 4D). They have centric and open hilum and deep fissures. Seven grains measured more than 14 μm in length. Yang et al. (2009a, 2010a) indicated that this kind of starch grains is possibly from *Setaria italica*. The size of another ten starch grains are between 11 and 14 μm. *Setaria italica* and *Setaria viridis* have starch grains that fall into this size range (Yang et al., 2010a). The ten grains cannot be identified to species but are probably from *Setaria*. The remaining seven grains had the same morphological features as the other seventeen grains, but range in size between 8 and 11 μm. These grains are also possibly from *Setaria*. Fifteen ovoid starch grains were also found on the use surface of the groundstone. They range in length between 12 and 21 μm and some have longitudinal fissures (Fig. 4E). The

Table 2
Measurement data for modern reference material.

Species	N	Min (μm)	Max (μm)	Mean (μm)
Panicum miliaseum	46	5.96	10.99	8.42
Setaria italica	55	6.23	19.35	9.32
Quercus aliena	47	5.69	17.26	9.43
Quercus dentata	52	5.75	19.76	10.03
Quercus acutissima	62	6.90	20.21	11.13
Quercus viriabilis	88	7.60	19.55	11.34
Quercus mongolicus	54	6.29	12.37	8.72
Lithocarpus glaber	90	8.95	34	17.33
Cyclobalanopsis glauca	47	6.21	25.16	15.66

Table 3
Starch grains recovered from the used surfaces of the groundstone tools from Baiyinchanghan site.

Sample no.	N	Mean (μm) used surface	Identified used surface	Unknown used surface	Range (μm) used surface
F64A/F64B	19/7	13.05	3	16	8–20
F63A/F63B	245/9	14.02	86	159	6–36
F30A/F30B	46/18	13.91	25	21	6–32
F61A/F61B	52/15	11.86	22	30	5–19

measurements and features of this starch assemblage are similar to *Quercus*. One starch grain had eccentric hilum and longitudinal fissure (Fig. 4F). Starch grains with eccentric hila are only found in *Quercus acutissima*. The morphology and size of this starch grain are very close to starch grains from *Quercus acutissima* that were identified previously (Fig. 5E; Yang et al., 2009a, 2009b).

2.3. 91LBBF30:4

This broken grinding stone is rectangular with round corners and measures 20 cm remaining long, 14.6 cm wide and 1.3–3.4 cm thick. It has one beveled use surface with small pits on (Fig. 2C). It was excavated from the floor of No.30 house which also belongs to the Xinglongwa Culture (6200–5400 BC). Forty-six and eighteen starch grains were found from samples F30A and F30B respectively (Table 3). Seventeen polygonal starch grains without fissures were found together from F30A (Fig. 4G). Their size range was 6–10 μm. The morphology and size of this starch assemblage are very close to *Panicum miliaceum*. In addition five starch grains from F30A are polygonal in shape with fissures across the hila (Fig. 4H). Four of the starch grains are 17, 15, 15 and 16 μm respectively. The remaining one is measured 12 μm in size and is possibly from *Setaria*. These five starch grains are possibly from *Setaria italica*.

Three ovoid starch grains were also recovered in Sample F30A (Fig. 4I). They had centric hilum, no lamellae, no fissure. Their length was in range of 17–22 μm. These starch grains are consistent with the acorns (cf. *Lithocarpus* sp., *Quercus* sp. and *Cyclobalanopsis* sp.) in both size and morphology (Table 2; Liu et al., 2010a, 2010b; Yang et al., 2009a, 2009b).

2.4. 91LBBF61:7

This broken sub-rectangular grinding stone had one concave use surface with dimensions of: 15 cm long on the broken edge, 22 cm wide and 1.6–4.2 cm thick (Fig. 2D). The groundstone artifact is from the floor of house No.61 which belongs to the Xinglongwa Culture (6200–5400 BC), southwest of the hearth (Fig. 3D). Samples F61A and F61B yielded fifty-two and fifteen starch grains respectively (Table 3). We found nine starch grains with size range 7–11 μm in Sample F61A (Fig. 4J). The starch grains are spherical or polygonal without fissures. The attributes of this starch assemblage are most similar to samples of *Panicum miliaceum*.

Nine starch grains range in size from F61A is 9–18 μm (Fig. 4K) and are mostly polygonal deeply crossed or Y-shaped fissure. Three of the grains are 16, 18, 16 μm in size. These three grains are likely from *Setaria italica* (Yang et al., 2009a, 2010a). An additional four starch grains from F61A (Fig. 4L) are oval with longitudinal fissures. The sizes and morphologies of these starch grains are most similar to *Quercus* sp.

Although some starch grains can be identified to some extent, there are still many grains which couldn't be identified at the present time (Table 3). Ninety unidentified starch grains observed in samples F63A, F30A and F61A. They had a round form and their size range is 12–36 μm (Fig. 4M). When these grains were rotated, they presented an oval form with a longitudinal fissure (Fig. 4N). These distinctive grains were not found in our reference plants collections and their identification will require more work using additional reference samples.

3. Discussion

Starch grains preserve well in archaeological contexts where other botanical indicators of subsistance may not. Starch grains can be easily extracted in abundance by *in-situ* sampling of the surfaces of artifacts. The numbers of starch grains extracted from use surfaces are much more abundant that unused surfaces of the same tools (Table 3; Barton et al., 1998; Yang et al., 2009a). The frequency of the occurrence of starch on the used surfaces indicates that the groundstone tools were used to process both wild and domesticated plants.

Starch grains from *Quercus* sp, common millet (*Panicum miliaceum*) and foxtail millet (*Setaria italica*) were most likely identified on the four groundstone tools. This result indicates that the four groundstone tools were multifunctional and is consistent with several functional studies of grinding stones dating to the early and middle Neolithic periods in other parts of China (Liu et al., 2010a, 2010b; Wang, 2008; Yang et al., 2009a).

This study of starch grains recovered from groundstone artifacts of the Xinlongwa Culture (6200–5400 BC) provides direct evidence of an economy based on a mix of wild and domesticated plants. Groundstone tools are uncommon in contexts dating to the later Yangshao (7000–5000 BP), Longshan (4500–4000 BP) and other agriculturally-based Chinese archaeological cultures (Ma, 1984; Wang, 2008). Instead, initially groundstone tools were used for the processing of wild plant foods just like other areas of the world (Fullagar et al., 2008; Piperno et al., 2004). This study suggests that there is no direct relationship between the occurrence of groundstone tools and the intensification of agriculture in Chinese archaeological cultures.

It should be noted that groundstone tools could not husk millet as efficiently as mortars and pestles do, but are very good at grinding the cereals into powder (Wang, 2008). The effects of the use of groundstone tools suggesting that the millets and nuts may have both been ground into flour.

Groundstone tools were later used to process the first Chinese domesticates using the same tools as wild plants. But as the processing efficiency of groundstone tools didn't keep up with the increasing dependence on agricultural products, the number of the groundstone tools decreased dramatically during the period of the Yangshao Culture (7000–5000 BP). Groundstone tools were most likely replaced by more efficient bulk processing tools, including wooden mortars and pestles that were not always preserved in the archaeological record (Song, 1997; Wang, 2008).

4. Conclusion

This pilot study of groundstone tools from Baiyinchanghan site in Northeast China greatly improves our understanding of the function of grinding stones and the early Neolithic subsistence economy in the Liaoxi region. Groundstone tools were used for processing a variety of plant foods, including acorns (*Quercus* sp.), millets and others plants. The result of this study is in line with functional studies of groundstone tools (Liu et al., 2010a, 2010b; Wang, 2008; Yang et al., 2009a). This study also illustrates that the recovery of groundstone tools dating to the early and middle Neolithic periods in north China should be used to process both wild and domesticated plants.

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