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Pottery Use and Starchy Foods During the Shuangdun Culture (ca.7.3–6.8 Ka BP) in the Middle Catchment of the Huai River, China

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The use of rice and millet has been uncovered at a few archaeological sites associated with the Shuangdun Culture (ca. 7.3–6.8 ka BP) in the middle catchment of the Huai River, China. Nevertheless, the consumption of rice, millet, and other types of plant foods at other contemporaneous sites in the same region still needs supporting information from more case studies. This article examines pottery sherds (n = 21) excavated from another representative Shuangdun Culture site at Houjiazhai with starch grain analysis. Varied types of pottery vessels contain starch remains from rice (*Oryza sativa*), foxtail millet (*Setaria italica*), broomcorn millet (*Panicum miliaceum*), Job's tears (*Coix lacryma-jobi*), Triticeae, roots of snake gourd (*Trichosanthes kirilowii*), lotus root (*Nelumbo nucifera*), Chinese yam (*Dioscorea panthainca*), lily bulbs (*Lilium* sp.), acorns (*Quercus* sp.), and beans (*Vigna* sp. or/and *Vicia* sp.). Further quantitative analysis of the starch data indicates that cereals, including rice and millet, were predominantly consumed in the pottery vessels. Changes and continuities of culinary practices are also present at Houjiazhai, which are reflected in the different pottery assemblages as well as the utilized plant species in different occupation phases at the site. Combining previous studies, this article also reveals the differences and similarities of the past population in choosing their plant food resources during the period of Shuangdun Culture in the middle catchment of the Huai River, China.

Keywords: starch grain, plant food, Shuangdun Culture, Huai River, Houjiazhai

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INTRODUCTION

China was one of the world's primary centers of independent agricultural development. The most thoroughly studied early agricultural societies in China are located along the Yangtze and Yellow River valleys, which provide some of the oldest solid evidence for formalized rice (*Oryza sativa*) and millet (*Setaria italica* and *Panicum miliaceum*) farming, respectively (Jiang and Liu, 2006; Yunfei and Jiang, 2009; Yang et al., 2012). Even though it is commonly acknowledged that rice and millet farming had spread northward and southward afterward in China, the exact routes regarding the diffusions of these crops over time and space remain an area of active research (Zhang, et al., 2010; Fuller, 2011; Ma, et al., 2016; Yang, et al., 2018; Huan, et al., 2022; Long, et al., 2022).

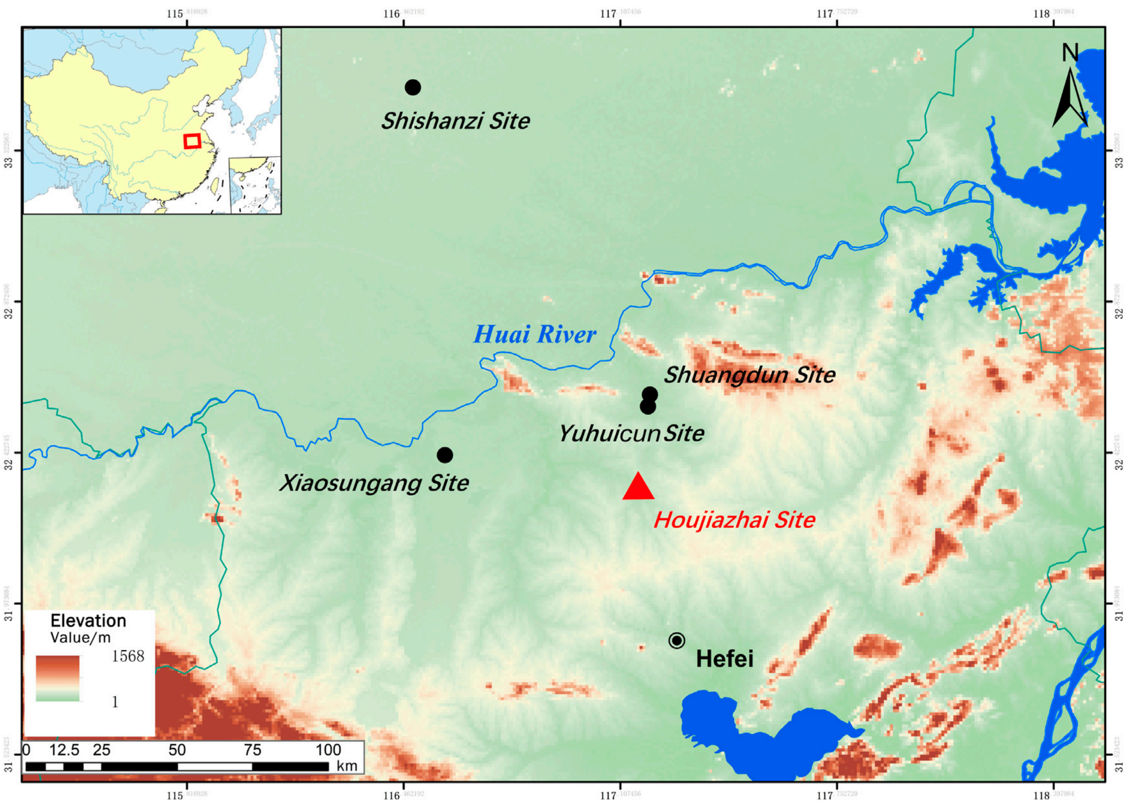

FIGURE 1 | The locations of the site of Houjiazhai and other sites associated with the Shuangdun Culture in the Middle Huai river valley.

The Huai River drains the plain between the Yangtze and Yellow Rivers and has formed a transitional climatic zone between northern and southern China (**Figure 1**). Archaeobotanists have a continuing interest in the catchment of the Huai River (CHR) not only due to its diverse prehistoric cultures but also due to some of the early significant occurrences of rice and millet observed, starting from the early to middle Neolithic period. In the upper CHR, for instance, macrobotanical remains of rice were found at the site of Jiahu (7000–5500 BC) (Zhang and Wang, 1998). In the same region, phytolith and macrobotanical remains from the sites of Tanghu and Zhuzhai revealed that mixed farming of rice and millet had started there during the middle Peiligang Culture period (c. 7,924 ± 41 to 7,640 ± 45 cal. BP) (Zhang, et al., 2012; Bestel, et al., 2018; Wang, et al., 2018). In the middle and lower CHR, several recent studies also yielded remains from either rice or millet (Luo, et al., 2016; Yang, et al., 2016; Luo, et al., 2019; Qiu, et al., 2022). These findings together make the CHR a crucial region for investigating the dispersal of rice and millet in Neolithic central-eastern China.

The present study focuses on the Shuangdun Culture (ca. 7.3–6.8 ka BP) developed in the middle CHR. This culture was named after the site of Shuangdun, which was first excavated in the year 1986 (Kan and Zhou, 2007). In addition to Shuangdun, several other excavated archaeological sites attributed to the same Shuangdun Culture comprise Shishanzi (Jia, 1992), Yuhui (Zhang et al., 2020), and Xiaosungang (Yang et al., 2015). Many of the Shuangdun Culture sites are characterized by their carved symbols on pottery vessels, which are valuable for investigating Neolithic ways of life and the origin of Chinese characters (Huang, 2012; Xu, 2007, 2008).

To understand the prehistoric use of plants during the Shuangdun Culture period, researchers have studied soil samples, stone tools, and potsherds from the site of Shuangdun through phytolith analysis or starch grain analysis (Dong, 2013; Dong, et al., 2014; Cheng, et al., 2016; Luo, et al., 2016; Yao, 2016; Xuan, 2017). The results from these studies indicate that rice and millet had already appeared at some of the Shuangdun Culture sites (**Supplementary Table S1**). Nevertheless, whether rice and millet were commonly cultivated in the entire middle catchment of the Huai River still needs supporting data from more case studies, especially taking into account that some of the previous archaeobotanical work carried out at the Shuangdun Culture sites were either based on a limited number of artefacts or a single analytical method. For instance, only 10 grinding tools were chosen for starch grain analysis at the site of Shishanzi (Dong, et al., 2014). The site of Xiaosungang was studied from the perspective of macrobotanical plant remains (Cheng, et al., 2016). Under such circumstances, potsherds from another Shuangdun Culture site of Houjiazhai were selected in the present study for starch grain analysis. The main objective of the present study is to add more data to enrich the discussion regarding plant foods consumed by the early farming groups associated with the Shuangdun Culture.

TABLE 1 | Carbon-14 dates and dendrochronologically corrected dates of bone samples excavated at Houjiazhai.

Code of laboratory	Sample provenance	Sample material dated	^{14}C date (BP)	Calibrated dates (BC)	
				1σ (68.2%)	2σ (95.4%)
ZK-2185	④	bone	6,350±110	5,467–5,402 (0.26) 5,388–5,225 (0.74)	5,517–5,046 (1)
ZK-2184	③	bone	6,260±90	5,322–5,201 (0.61) 5,175–5,071 (0.39)	5,466–5,434 (0.03) 5,429–5,405 (0.02) 5,385–4,998 (0.95)

The site of Houjiazhai is in the Village of Yuanzhuang, Dingyuan City, Anhui Province, about 60 km south of the Huai River (**Figure 1**). It is a Neolithic platform–shaped site with an area of more than 30,000 square meters. The site was discovered in the spring of 1977 and went through two excavation seasons in the spring of 1985 and the autumn of 1986 (Tang, et al., 2019). An area of 375 square meters has been revealed so far. Based on the material culture and radiocarbon dating of two bone samples unearthed at Houjiazhai (**Table 1**), it has been proposed that the site occupation lasted through two different phases: Phase I (ca. 7.3–6.8 ka BP) and Phase II (ca. 6.2–5.6 ka BP) (Tang, et al., 2019; Luo, et al., 2020).

The pottery assemblage retrieved from the excavations has been carefully classified according to their shapes, sizes, and tempered materials (Tang, et al., 2019). The changes in the pottery assemblages in Phase I and Phase II include the following: 1) cauldron vessels (*fu* in Chinese, a type of cooking vessel with fat bellies and without standing feet), which exclusively appeared in Phase I (n = 28); 2) the number of tripods (*ding* in Chinese, a type of cooking vessel with standing feet) and *dou* vessels (a type of serving vessel with a base) increased dramatically in Phase II, from 7 to 39 and 9 to 45, respectively; 3) the pottery vessels were decorated with simple carved signs in Phase I compared to those elaborately painted with geometric patterns in Phase II; and 4) the technological changes in terms of materials used for pottery tempering. For instance, *ding* vessels from Phase I were shell tempered, while they were shell or sand tempered in Phase II; *dou* vessels were tempered with plants (unidentified) in Phase I but were not tempered in Phase II. Apart from these differences, bowls unearthed from Phase I and Phase II periods were both shell or plant tempered, and their number only shows slight growth in Phase II, from 15 to 18, giving the best example for showing continuity in the pottery assemblages.

Different from the previously studied grinding tools in China and elsewhere that were mainly used for plant processing (Hamon, 2009; Li, et al., 2019; Li et al., 2020a; Chondrou, et al., 2021), different types of pottery vessels hold the unique potential to offer more information regarding the storing, cooking, and serving of plant foods (Craig, et al., 2013; Nieuwenhuyse, et al., 2015; Wang, et al., 2021). Furthermore, our previous research analyzed potsherds from the Phase II of Houjiazhai with starch grain analysis (Luo, et al., 2020). The yielded data, together with the results from the present study, allow a comparison of how different types of pottery vessels were used in different occupation periods at the same site.

MATERIALS AND METHODS

The Pottery Sherds From the Site of Houjiazhai

In the present study, pottery sherds (n = 21) unearthed from the Phase I contexts of the site of Houjiazhai were sampled for starch grain analysis (**Figure 2**). These pottery sherds were chosen because their morphological features still allow us to determine their original typologies. Potsherds that were likely involved in various food-related activities were selected to understand the use of different types of pottery vessels (**Supplementary Table S2**). Two of the samples from jars and two from an urn were selected because they were potentially used for storing foods. To investigate ceramics that were used for cooking, seven *fu* vessels and one *ding* vessel were chosen. Moreover, eight pottery sherds from bowls and one from a spoon were selected because they were likely used to serve food.

All these potsherds were briefly washed after excavation and were kept in the local museum. Although washing may have removed some valuable information on the samples, several studies have successfully extracted starch grains from washed artefacts or those stored in museums (Barton, 2007; Ciofalo, et al., 2020). More importantly, we have presented positive results for the study of the pottery sherds from Phase II of Houjiazhai (Luo, et al., 2020); thus, we believe the sampled pottery sherds retrieved from Phase I of Houjiazhai are promising to provide more valuable information regarding plant use in the earlier stage of the site.

Extraction and Recovery of Starch Grains

The published protocols for extracting starch grains from washed artefacts were consulted and slightly modified for this study (Ciofalo, et al., 2020). First, a wash bottle with ultra-purified water with significant water pressure was used to rinse the artefacts, which removed the majority of additional soil matrix that loosely adhered to and was not a part of the artefacts' use-history (Barton and Torrence, 2015). This type of washing was also intended to remove some possible modern contaminations (Chandler-Ezell and Pearsall, 2003). Second, an ultrasonic toothbrush was used on the internal surfaces of each artefact for 2 min each, followed by rinsing, and the aqueous samples were gathered from different surfaces in different 50-ml plastic tubes for further analysis. Control samples were taken from the soil attached to pottery surfaces, the local museum, and the lab where starch grain analysis was conducted. Then, these samples were processed in the lab for the recovery of starch grains using a

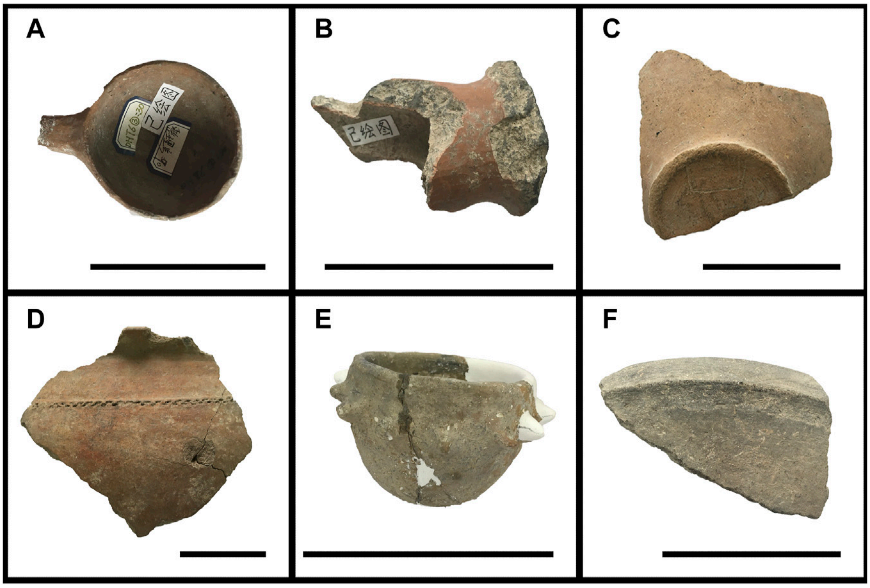

FIGURE 2 | Examples of pottery sherds subjected to starch grain analysis in this study—**(A)** DHT6③:3A, spoon; **(B)** DHT3④:274, a fragment from a bowl (*dou* type); **(C)** DHT6④:99, a bowl fragment; **(D)** DHT3③:53, jar; **(E)** DHT3③: 209, *fu*; and **(F)** DHT3③:183, a *fu* fragment (scale bar: 10 cm).

heavy-liquid solution of CsCl, the steps of which have been adopted and introduced in our previous publications (Yang et al., 2016; Luo et al., 2020).

For comparison of taxonomic ascription, we used an assembled reference collection of starch grains obtained from recent economically useful and edible plants that were collected in the archaeobotany lab at the University of Science and Technology of China (**Figure 3**). We also consulted the published data on modern starch grains (Liu et al., 2014; Wan et al., 2011; Wan et al., 2012).

RESULTS

The starch grains from this study were recovered from all the pottery sherds only, rather than the control samples taken from the museum, the lab, and the soil attached to the surfaces of the pottery sherds (**Supplementary Table S2**). Thus, we postulate the most likely cause for entrapping the discovered starch grains was through intense or prolonged use of the pottery vessels as food-related implements in the past. Overall, the starch grains identified provide insights into the consumption of diverse plant remains at the site of Houjiazhai during Phase I, including cereals, tubers, nuts, and beans (**Supplementary Table S2**).

Cereals

A total of 1,038 recovered starch grains could be identified as cereals. Type A was identified as starch grains from rice, without fissures and lamellae on their surfaces (**Figures 4a, a', b, b'**). The grains were either singular or compound with clear extinction crosses on some larger singular grains. The size range of the singular starch grains was 2.29–9.91 μm.

Starch grains from type B (**Figures 4c, c', d, d', e, e', f, f'**) were identified as Panicoideae from foxtail millet, broomcorn millet, and probably small grains from Job's tears (*Coix lacryma-jobi*). Studies have compared starch grains from these three species and found it is difficult to separate them precisely because of their common morphological features in size and shape (Liu, et al., 2014). Starch grains from type B were singular with centric hilum, and their size range was 8.04–29.25 μm. The shapes of type B starch grains were near-circular or polygonal. Lineal or "Y"-shaped fissures were often present on type B starch grains.

Type C was identified as Job's tears (**Figures 4g, g', h, h'**). Although the shape of starch grains from type C shares some similarities with those from type B, starch grains from type C were characterized by eccentric hilum and extinction cross with zig-zag arms. The size range was 6.93–30.10 μm, and the average size was 19.71 μm. It should be noted that the largest grain sizes of the identified Job's tears, foxtail millet, or broomcorn millet in the present study were slightly bigger than the data reported in a previous study (Liu, et al., 2014), in which the largest grain sizes of the modern starch grains from foxtail millet, broomcorn millet, and Job's tears were 21.17, 12.80, and 29.20 μm, respectively. One of the possible reasons causing a larger size range in the present study could be related to the prehistoric pre-treatments (e.g., cooking and grinding) of the plants because experiments have demonstrated that various processing methods could enlarge the sizes of starch grains (Henry, et al., 2009; Wang, et al., 2017; Li et al., 2020a).

Type D starch grains were identified as Triticeae, with their size ranging from 2.598 to 47.60 μm, and the average size is 18.37 μm. Starch grains from type D were circular or lenticular, with hilum in the center. Fissures were often absent, but lamellae were present occasionally. The extinction cross is "X"-shaped and

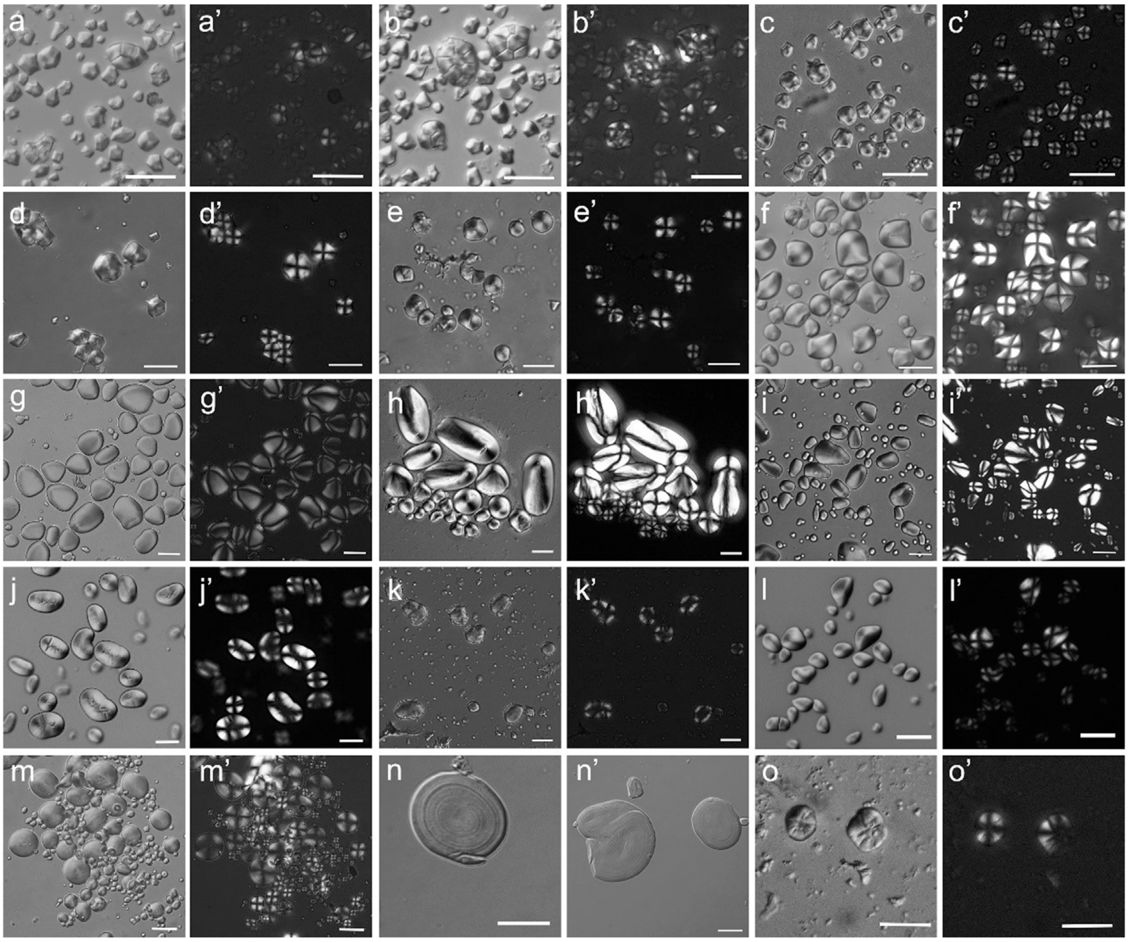

FIGURE 3 | Relevant reference collection of modern starch grains at the University of Science and Technology of China—**(a,a')** rice from Hunan, China; **(b,b')** rice from Fujian, China; **(c,c')** broomcorn millet from Shaanxi, China; **(d,d')** foxtail millet from Shaanxi, China; **(e,e')** Job's tears from Anhui, China; **(f,f')** roots of snake gourd from Anhui, China; **(g,g')** Chinese yam from Henan, China; **(h,h')** lotus root from Henan, China; **(i,i')** lily bulbs from Gansu, China; **(j,j')** mung bean from Henan, China; **(k,k')** sweet pea from Anhui, China; **(l,l')** acorns (*Quercus acutissima*) from Anhui, China; **(m,m')** wheat from Anhui, China; **(n,n')** wheat after boiling; and **(o,o')** Job's tears after grinding (scale bar: 20 μm).

vague in a few cases. Interestingly, a few starch grains from type D were discovered on cooking vessels showing more pronounced lamellae (e.g., **Figures 4q, q'**), a type of damage feature perhaps caused by boiling, according to the previous experimental studies (Henry, et al., 2009; Wang, et al., 2017).

Underground Storage Organs

A total of 129 starch grains could be identified as USOs. These starch grains were characterized by their eccentric hilum and "X"-shaped extinction cross with curved arms.

Among the starch grains from USOs, type E (**Figures 4i, i', j, j'**) were identified as snake gourd (*Trichosanthes kirilowii*), with their size ranging from 16.00 to 30.37 μm, and their average size was 21.26 μm. The forms of starch grains from type E include round, semi-circular, and bell-shaped. This type of plant has been widely discovered in prehistoric China and is traditionally used as a type of famine food (Zhu, 1406).

Starch grains from type F (**Figures 4l, l'**) were identified as lotus root (*Nelumbo nucifera*), with their size ranging from 9.43 to 47.70 μm, and their average size was 17.85 μm. The shapes of starch grains from type F include semi-circular, bell-shaped, and oblong. Different from type E, starch grains from type F often presented clear lamellae, linear fissure, and more extreme eccentric hilum on oblong starch grains.

Starch grains from type G (**Figures 4k, k'**) were identified as Chinese yam (*Dioscorea panthainca*). The starch grains differ from type E and type F in terms of their shapes, which are triangular or quadrilateral ovate. The size range of starch grains from type G was 11.84–35.91 μm, and their average size was 23.01 μm. Type G starch grains also showed extreme eccentric hilum and clear lamellae on their surfaces.

Starch grains from type H (**Figures 4m, m'**) were identified as lily bulbs (*Lilium* sp.) Similar to starch grains from types F and G, starch grains classified into type H also process eccentric hilum

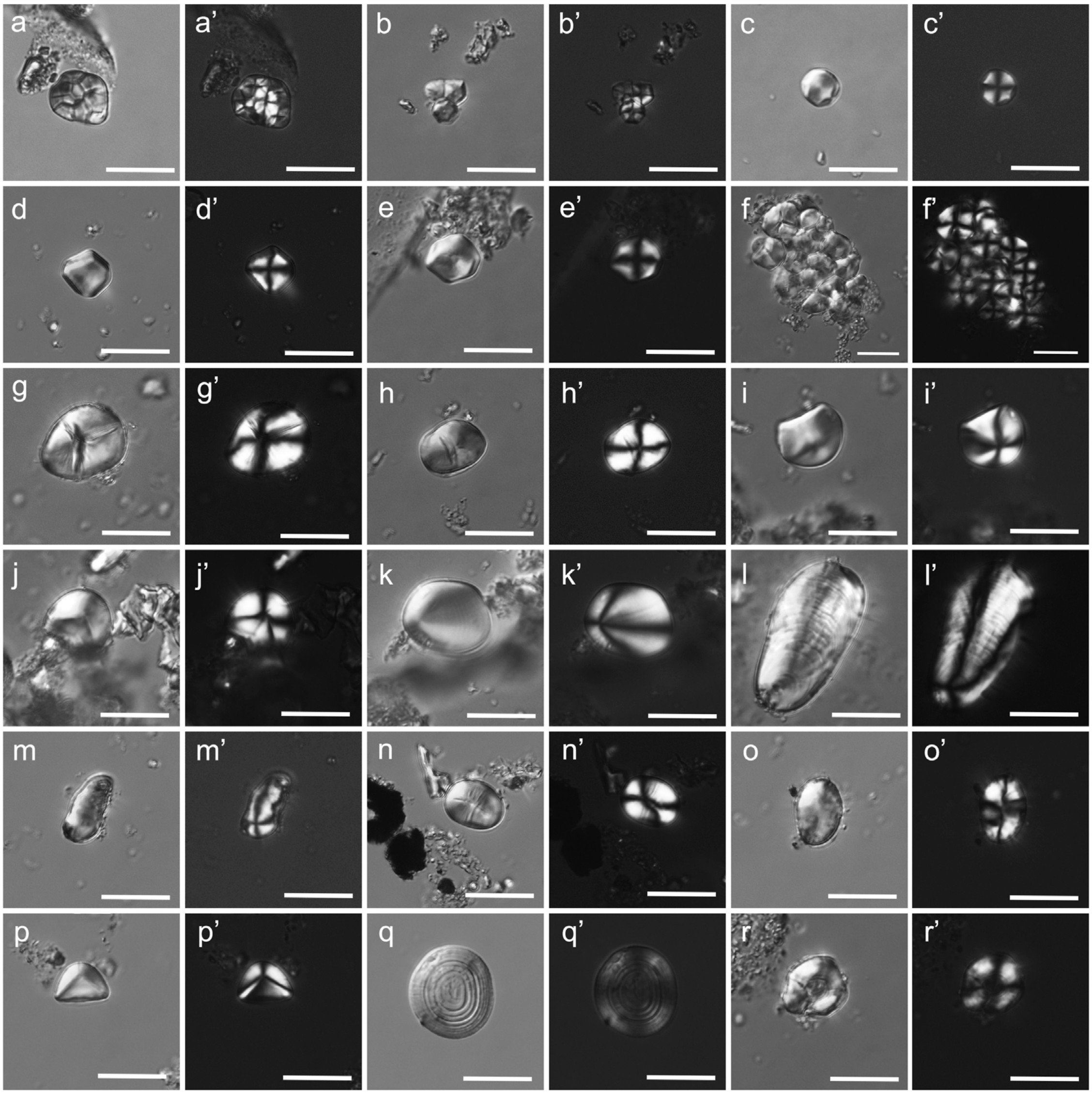

FIGURE 4 | Ancient starch grains identified on potsherds from the site of Houjiazhai—**(a,a',b,b')** rice; **(c,c',d,d',e,e',f,f')** foxtail millet, broomcorn millet, and probably small grains from Job's tears; **(g,g',h,h')** Job's tears; **(i,i',j,j')** root of snake gourd; **(k,k')** Chinese yam; **(l,l')** lotus root; **(m,m')** lily bulbs; **(n,n',o,o')** beans that may include *Vigna* sp. or/and *Vicia* sp.;**(p,p')** acorns; **(q,q')** seeds from Triticeae showing more pronounce lamellae; and **(r,r')** an example of a damaged starch grain (scale bar: 20 μm).

but were thinner in their shapes. The size of type H ranged from 15.79 to 22.39 μm, and their average size was 26.99 μm.

Acorns

A total of 11 starch grains were identified as type I (**Figures 4p, p'**) from acorns (*Quercus* sp.), the size range was 9.91–19.92 μm, and the average size was 17.85 μm. The grains were singular with "X"-shaped extinction crosses. The forms of type I included triangular-ovate and drop-shaped, with centered or slightly eccentric hilum.

Beans

A total number of 14 starch grains were classified into beans (type J) that may include *Vigna* sp. or/and *Vicia* sp. (**Figures 4n, n', o, o'**). The size range of type J was 13.81–34.25 μm, and the average size was 18.78 μm. The grains were singular and oval- or kidney-shaped. The extinction cross of type J resembled two tangent curves. On the surface of starch grains from type J, lineal fissures vertical to the longer axis of the grains were often present near the hilum.

Damaged Starch Grains

Starch grains (n = 117) were classified into the damaged group of type K (**Figures 4r, r'**) based on their incomplete forms and faint extinction cross. These damaged grains were identified only if they possessed typical morphological features that matched our modern reference collections (e.g., **Figures 3n, n', o, o'**). Notably,

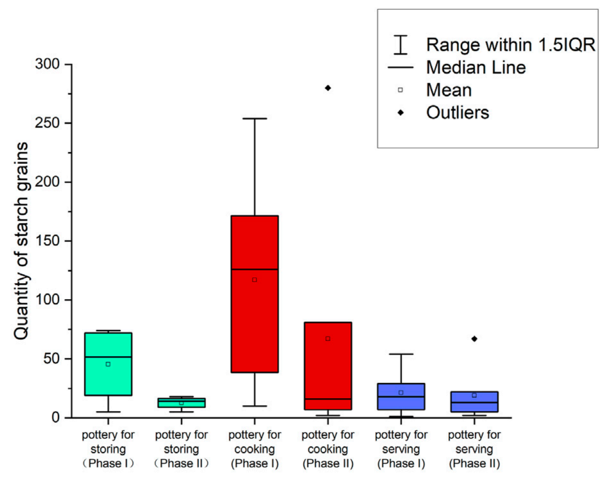

FIGURE 5 | Quantities of starch grains detected on potsherds attributed to Phase I and Phase II of Houjiazhai.

apart from potential prehistoric treatments (e.g., cooking, pounding, grinding, and fermenting) (Henry, et al., 2009; Mickleburgh and Pagán-Jiménez, 2012; Wang, et al., 2017; Li et al., 2020b), the post-depositional process and use of modern chemicals during the stage of starch extraction could have damaged starch grains (García-Granero, 2020). It is thus challenging for us to further interpret what may have caused damage to starch grains on each artefact at the current stage.

DISCUSSION

Preservation of Starch Grains on Different Types of Pottery Vessels

Because starch grains subjected to high temperature would be substantially damaged according to previous experiments (Henry, et al., 2009), it was thus predicted that starch grains, especially the intact ones, would be rare on vessels used for cooking and serving. Interestingly, both intact and damaged starch grains were found on all types of pottery vessels in the present study. Similarly, complete starch grains were also detected on cooking and serving pottery from other archaeological sites in China and elsewhere (Perry, 2004; Yang, et al., 2014). These findings suggest that starch grains would be preserved on multiple types of pottery vessels.

The number of starch grains on pottery vessels used for storing (i.e., urns and jars), cooking (i.e., *fu* and *ding*), and serving (i.e., bowls and *dou*) was also counted: Cooking vessels yielded the maximum starch grains in general (but with a few exceptions, see the sample of TQ2 in **Supplementary Table S2**), followed by vessels used for storing and serving (**Figure 5**). This phenomenon is consistent with the result in our previous study at Houjiazhai (**Figure 5**, Luo et al., 2020), in which the pottery vessels from Phase II were subjected to starch grain analysis (**Figure 5**). These findings tend to suggest that the chance of detecting starch grains can be even higher on pottery vessels used for cooking. However, these propositions still need to be tested in more case studies since the complex life histories of pottery vessels, post-depositional processes of food residues, and different sampling protocols could all potentially affect the chances of discovering food remains (Henry, et al., 2016; Hutschenreuther, et al., 2017; Li et al., 2020b).

Here, we propose two possible factors that might result in the different numbers of starch grains on pottery vessels from Houjiazhai: techniques adopted in pottery making and pottery functions. The cooking vessels from Houjiazhai were all tempered with sand or shell, with rough surfaces (Tang et al., 2019). In contrast, serving vessels (i.e., bowls) from Houjiazhai are compact because they were made without tempering materials. It has been proposed that starch grains can easily become trapped or embedded in areas of an artefact where they are protected from degradation, such as pores, micro-fractures, cracks, holes, and micro-striations on the surface of an artefact (Torrence and Barton, 2006). From this point of view, tempered pottery vessels with relatively loose structures may possess stronger abilities in capturing plant remains and provide more starch grains. Nevertheless, storage vessels from Houjiazhai were also shell-tempered, but these vessels yielded fewer starch grains than cooking pots. Thus, different uses of pottery vessels could also affect the preservation of starch grains considering the contacts of plants with storage vessels were more likely static and superficial, while cooking vessels were probably frequently adopted for boiling plant foods.

Changes and Continuities of Starchy Foods at Houjiazhai

In Phase I, starch grains from beans, Chinese yam, and lily bulbs were discovered, while none of these starch grains appeared in potsherds attributed to Phase II. The other plant species, including rice, millet, seeds from Triticeae, acorns, and lotus root, were utilized in both Phase I and Phase II. The comparison of plant species found on pottery vessels from Phase I and Phase II of Houjiazhai thus infers that people utilized more diverse plant food resources at the earlier stage.

Apart from the quantities, the ubiquities of each identified plant species in both Phase I and Phase II are calculated and compared (**Figures 6A,B**). Ubiquity here refers to the occurrence of identified plant taxa among pottery vessels associated with storing, cooking, and serving. Compared to starch grains from USOs and acorns, the ubiquities of cereals are relatively higher on all types of pottery vessels (**Figures 6A,B**), implying that cereals were mostly consumed with the pottery vessels during the periods of Phase I and Phase II at Houjiazhai. Notably, the ubiquities of certain types of plants vary in different types of pottery containers (**Figure 6**). The striking examples are lily bulbs and wild beans in Phase I, whose starch grains only appear on cooking vessels, but none of their starch grains were found on vessels used for storing and serving. Lily bulbs and wild beans were not likely stored in pots after harvesting; their low ubiquities on cooking vessels also suggest these two types of plants were not the primary food resources at Houjiazhai during the period of Phase I. In Phase II, starch remains from lily bulbs and beans were not even discovered in the pottery assemblages (**Figure 6B**).

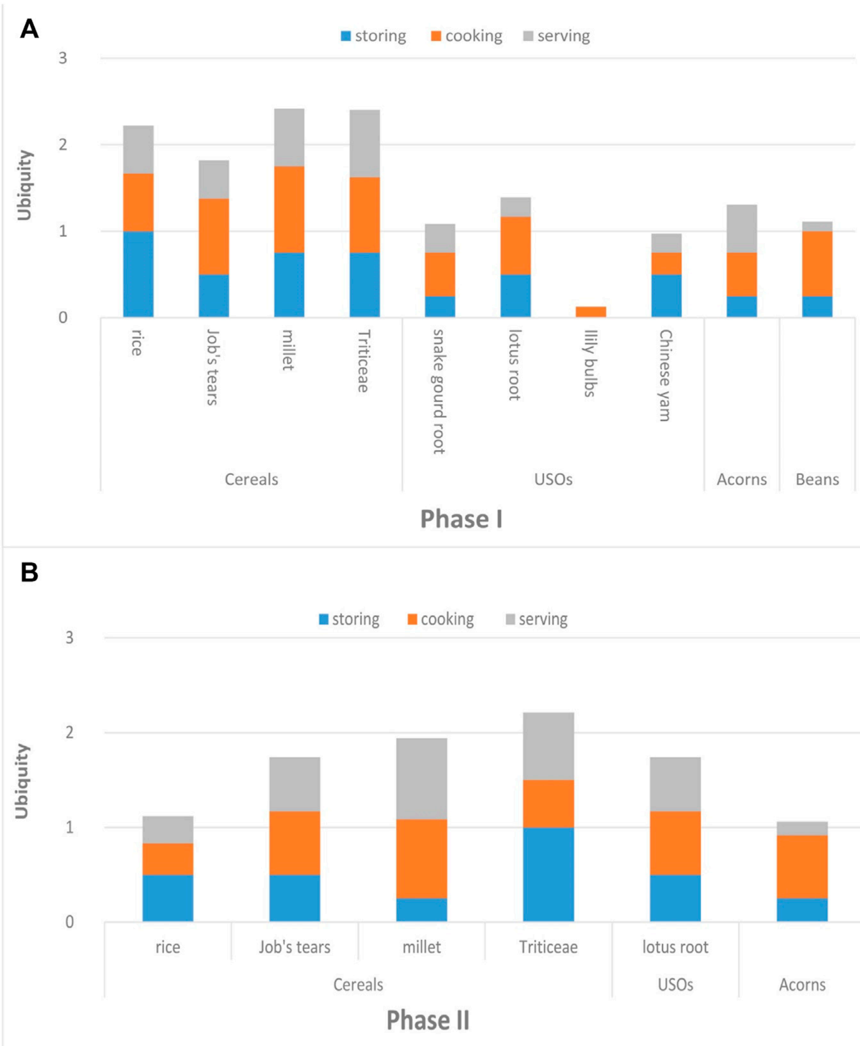

FIGURE 6 | (A) Ubiquities of different types of starch grains on Houjiazhai pottery vessels attributed to Phase I; **(B)** ubiquities of different types of starch grains on Houjiazhai pottery vessels attributed to the Phase II (note: ubiquity refers to the occurrence of identified plant taxa amongst the certain type of pottery vessels: storing, cooking, and serving, see also the **Supplementary Tables S3, S4**.).

The ubiquities of millet, Job's tears, seeds from Triticeae, lotus root, and acorns are relatively the same in Phases I and II (**Figures 6A,B**); only the ubiquity of rice starch grains decreased slightly in Phase II. These results tend to suggest that the past Houjiazhai people probably consumed less rice in Phase II. Yet, limitations of starch grain analysis have been recently discussed by a group of researchers (Langejans, 2012; Mercader, et al., 2018; García-Granero, 2020), and it has been proven that different environments affect the preservation of starch grains on artefacts, with certain starch grains being more resistant than others to amylolysis during their deposition into soils (Haslam, 2004; Hutschenreuther, et al., 2017). Another experimental research study also found a bias in the preservation of the starch grains on ancient grinding tools because starch grains from rice experienced the most morphological changes during dry-grinding processes (Li et al., 2020a). So far, the preservations of starch grains from different plant species on daily-use pottery vessels, which usually have complex life histories, have not been systematically studied. Bearing these factors in mind, we propose to consider whether rice was less intensively used at the site of Houjiazhai with other lines of evidence from macro plant remains or phytolith analysis. Nevertheless, the changes and continuities of foodways at Houjiazhai can still be reflected in the changing pottery assemblage as well as the different types of plant foods consumed in the two different occupation stages.

Diverse Plant Foods at the Shuangdun Culture Sites

Overall, the results in our study are consistent with the previous archaeobotanical work in the research region (**Supplementary Table S1**), suggesting people at the Shuangdun Culture sites utilized various plant species. Starch grains from cereals, USOs, and beans were commonly discovered on artefacts excavated at the sites of Shuangdun, Shishanzi, and Houjiazhai. These findings are supported by the macrobotanical remains identified at the site of Xiaosungang in the same period, where 40 soil samples taken from 6 ash pits and 14 cultural layers were subjected to floatation (Cheng et al., 2016). Acorns, however, were only detected at the sites of Houjiazhai and Xiaosungang (**Supplementary Table S1**).

Among the group of cereals, rice remains appeared at most of the studied Shuangdun Culture sites (3 out of 4), except for the site of Shishanzi. It is worth noting that the reason for not recovering starch grains from rice at the site of Shishanzi could be related to its small sampling size or the difficulties of detecting small starch grains from rice (Yang, et al., 2015). In terms of millet, our study at Houjiazhai and the previous phytolith analysis carried out at Shuangdun indicate millet appeared at both sites (Luo, et al., 2019). Moreover, Zhang et al. (2020) recently found evidence of millet consumption through pollen and lipid analysis of coprolites from another site of Yuhuicun that is associated with the Shuangdun Culture. The multiple lines of evidence thus confirm millet had already reached the sites located in the south of the Huai River during the Shuangdun Culture period.

CONCLUSION

The identification of starch grains discovered on potsherds attributed to the periods of Phase I of Houjiazhai indicates vessels involved in storing, cooking, and serving could provide valuable information regarding plant foods during the Shuangdun Culture period. Further quantitative analysis of the yielded data found that cooking vessels provided the highest quantity of starch grains in both Phases, which is vital for understanding the preservation of plant remains in different tempered pottery vessels. The comparison of results of starch grain analyses on potsherds attributed to Phase I and Phase II at Houjiazhai also demonstrates that prehistoric culinary practices could be studied not only in the pottery assemblages but also in the utilized plant species. Overall, the holistic approach used here, considering the classification of different types of pottery vessels as well as the published data on archaeobotany in the research region, shows a more detailed understanding of which types of starch foods were consumed and then preserved on various Neolithic pottery vessels. The findings of both rice and millet starch grains at the site of Houjiazhai (Phase I) are also valuable clues for mapping the spatiotemporal route for the spread of rice and millets in central-eastern China during the Neolithic age.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**; further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

WAL and WGL designed the research study and wrote the article. HX, WY, WT, DZ, SY, XK, and ZJ conducted the sampling and analysis. All the authors read and edited the paper.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feart.2022.886179/full#supplementary-material

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