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The importance of wild resources as a reflection of the resilience and changing nature of early agricultural systems in East Asia and Europe

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We examine the changing importance of wild starch rich plant staples, predominantly tree nuts, in early agricultural societies in East Asia and Europe, focusing on Korea, Japan, and Britain. A comparative review highlights variations in the importance of wild plant staples compared to domesticated crops. The Korean Middle to Late Chulmun periods (c. 3,500–1,500 BC) was characterized by a high reliance on nuts alongside millet. This declines with the transition to rice agriculture, but remains significant during the Mumun period (c. 1,500–300 BC). In Japan, the arrival of rice and millets in the Yayoi Period (c. 1,000 BC–250 AD) saw continued evidence for high levels of reliance on wild resources, which declines only in the Kofun and early historical periods. In Early Neolithic Britain (c. 4,000–3,300 BC) cereal agriculture is accompanied by high evidence for wild plant foods. But during the Middle to Late Neolithic (3,300–c. 2,400/2,200 BC) cereals were abandoned on the mainland with hazelnuts becoming a prominent plant staple. Agriculture returned in the second half of the 3rd millennium BC, followed by a strong decline in wild plant food use during the Middle to Late Bronze Age (1,700–700 BC). Such patterns have previously been attributed to the slow adoption of farming by indigenous peoples, with a continued reliance on wild resources. In light of evidence demonstrating that the dispersal of agriculture was largely driven by a mixture of demic-diffusion and introgression of hunter-gatherers into agricultural groups, a reinterpretation of the role of wild foods is needed. It is argued that the relative importance of wild plant staples provides an indicator of the stability and dependability of agricultural and social systems. A heavy reliance on wild foods in early agricultural societies is tied to the slow adaptation of domesticated crops to new environments, where agricultural and social landscapes are yet to be firmly established, and social systems that could mitigate for poor harvests and storage were often absent. The retained lengthy persistence of wild plant staples in East Asian subsistence systems compared to the British Isles likely reflects differences in the ecological and labor demands for rice compared to Western Asiatic cereals.

KEYWORDS

agricultural dispersal, wild foods, subsistence, Neolithic, Bronze Age, Chulmun, Mumun, Yayoi

Introduction

The initial dispersal of agriculture outside the centers of domestication in Europe and East Asia were accompanied by a potentially heavy reliance on starch rich plant foods often viewed as supplementary staples (Moffett et al., 1989; Kreuz, 2007; Lee, G.-A., 2011; Obata, 2011; Ahn, 2012; Antolín and Jacomet, 2015; Bouby et al., 2020; Noshiro et al., 2021). Studies of early agriculturalists have understandably focused on the domesticated rather than the wild element, leading to an underplaying of the role of wild plant foods (Colledge and Conolly, 2014). Considerations of wild edible plants in subsistence systems have therefore tended to be descriptive and the causes behind their changing prominence remains relatively unexplored. Specifically, wild plant foods have generally been viewed as a persistence of pre-existing subsistence practices, tied to narratives that advocate the adoption of agriculture by hunter-gatherers, a position increasingly unsupported by current evidence (cf. Rowley-Conwy, 2014).

This paper begins with a preliminary exploration of the changing prominence of wild plant staples in East Asian early agricultural societies, focusing on Korea and Japan; before turning to Neolithic and Bronze Age Britain in northwest Europe, utilizing various sources of archaeobotanical data. These countries were chosen as providing an interesting comparison of peripheral regions of agricultural dispersal, in which crops were potentially reaching ecologically challenging environments, for which good archaeobotanical data is available.

We then ask what the main driving factors are surrounding the use of wild foods in early agricultural societies. This question is tackled by examining various evidence and models of agricultural dispersal for both Europe and East Asia, and in particular the question of whether crops were ever likely to have been adopted. The role of wild plant staples is then explored in consideration of two factors. The first is the questionable reliability and dependability of domesticated crops as they spread out from their centers of domestication to enter new climatic and environmental zones (Fuller and Lucas, 2017; Liu et al., 2017; Fuller and Stevens, 2018; Gutaker et al., 2020; Ivanova, 2020). The second are the mechanisms available to early agriculturalists, by which they coped with variations in harvests and post-harvest losses during storage, when food supplies fell short of requirements for the coming year. Here we draw on the categories of cultural responses outlined by Halstead and O'Shea (1982). Exploring the question of whether with increasing reliability, as agricultural systems and landscapes became better established and social ties more dependable, subsistence strategies shifted away from reliance on wild foods to buffering systems more dependent on storage and exchange. For example, with the first spread of agriculture, could shortfalls in harvest only be dealt with at a household level? Or were farmers already integrated, through reciprocal exchange of foodstuffs, into expansive networks that supported fluctuations in agricultural harvests?

An examination of the role of wild foods in early agricultural systems in East Asia

Three major cereal crops; rice, foxtail and broomcorn millet, domesticated in China between the 7th and the 4th millennia BC formed the basis of early agricultural societies in Korea and Japan (Figure 1; Stevens and Fuller, 2017). Alongside these were two East Asian legumes, soybean (*Glycine max*) and adzuki bean (*Vigna angularis*), and later Western Asiatic crops, including wheat and barley (Ahn, 2010; Nakayama, 2010; Crawford, 2011; Kim, 2013; Stevens et al., 2016; Lee, 2017).

East Asia experienced a different transition to agriculture to Western Asia, where cereal and pulse crops were domesticated and diffused together into southeast Europe. Rice (*Oryza sativa*) was domesticated in the Lower Yangtze and Upper Huai regions of eastern China (Fuller et al., 2009; Zhao, 2011), whereas foxtail millet (*Setaria italica*) and broomcorn millet (*Panicum miliaceum*) were domesticated in the wider Yellow River Basin stretching into Shandong and northeast China (Liu et al., 2009; Zhao, 2011; Stevens et al., 2016, 2021; Stevens and Fuller, 2017).

Cultivated, but not yet domesticated, broomcorn millet is known from several sites in northeast China in the 6th millennium BC (Figure 2; Zhao, 2011; Shelach-Lavi et al., 2019; Stevens et al., 2021). However, secure records for domesticated foxtail millet at Weijiawopu, Inner Mongolia are somewhat later, dating to the early to middle Hongshan Culture (c. 4,500–3,500 BC) (Sun et al., 2012; He et al., 2022). These millets disperse eastwards, with foxtail and broomcorn millet being present at Wangjiacun (Middle Xiaozhushan III Culture c. 3,500–3,000

BC) on the Liaondong Peninsula (Ma et al., 2015). The spread of rice into northeast China from its core region of domestication in the Lower Yangtze and Upper Huai was much later. Possible cultivated rice is recorded from Houli Culture Shandong (c. 6,500–5,000 BC) (Jin et al., 2014; Crawford et al., 2016). However, morphologically it compares to wild rice from early Yangtze sites, and there is no evidence it was ever domesticated in this region. Rather, after a period of absence, domesticated rice only becomes established in Shandong after 2,600 BC (d'Alpoim Guedes et al., 2015; Stevens and Fuller, 2017), and in Liaoning from around 2,400 BC, associated with the later Upper Xiaozhushan Culture (Ma et al., 2015; Miyamoto, 2019).

Evidence for cereal and wild food use in Korea

From north-eastern China, millet agriculture reached the Primorye region of eastern Siberia by 3,500 BC (Li et al., 2020; Sergusheva et al., 2022) and the Korean Peninsula during the Middle Chulmun period (Lee, G.-A., 2011; Bae et al., 2013; Ahn et al., 2015; Stevens and Fuller, 2017; Kim and Park, 2020; Kim, 2022). Claims have been made for the appearance of millet at the southern tip of the Korean Peninsula between 6,000 and 4,500 BC (Obata and Manabe, 2014; Lee, 2017), but given these are similar to the earliest dates in northeast China they should be regarded with caution.

The spread of rice into the Korean peninsula marks the transition from the Chulmun Neolithic to the Mumun Cultural Period around 1,500 BC (Figure 1; Ahn et al., 2015; Miyamoto, 2019; Leipe et al., 2020). Rice agriculture is seen to have dispersed eastwards into Korea *via* Shandong and the Liaondong Peninsula through the coastal regions of the Bohai Sea and Korea Bay (Figure 2; Miyamoto, 2019). This is largely supported by similarities of stone tools, lithics and some ceramics across these regions (Hudson, 1999, p. 125; Nakayama, 2010; Barnes, 2015; Li et al., 2020), along with current genetic and linguistic analysis (Cooke et al., 2021; Robbeets et al., 2021). However, whether it was primarily driven by demic-diffusion and migration or through adoption and acculturation, and whether incoming rice agriculturalists entirely replaced pre-existing millet agriculturalists still remains a matter of debate (cf. Shoda, 2010).

The earliest directly dated rice grains on the Korean Peninsula are dated between 1,430 and 920 cal. BC (Gyodong, SNU08-305, 3,040 ± 60 uncal. BP; PED-11437, 2,860 ± 20 uncal. BP; Singari, KR06-146, 2,910 ± 60 uncal. BP; Daeheung-ri Keuseonjiang, KR07-045, 2,830 ± 50 uncal. BP) (Shoda, 2010; Ahn, 2012; Ahn et al., 2015). Likewise the earliest paddy-fields in Korea also date to the 13th to 9th Centuries BC (Figure 2; Ahn, 2010, Table 6 in Lee et al., 2014). While earlier dates on rice have been proposed these are regarded as problematic. For example the early date on rice from Oun-1 has a large error margin of 280 years (cf. Crawford and Lee, 2003) and falls outside the range of other dated material from the same house context (Ahn, 2010; Shoda, 2010; Stevens and Fuller, 2017).

Some authors have asked if initial cultivation systems focused on rainfed rice (Ahn, 2010; Barnes, 2015, p. 261), however, isotopic analysis of ancient rice grains shows no difference through time, suggesting the cultivation of paddy-fields from the start of the Early Mumun, c. 1,500–850 BC (Shoda et al., 2021).

Unlike the dispersal of agriculture from Western Asia into Europe, which saw cattle, sheep and goat as constant components of the Neolithic package, in Northeast Asia domesticated animals appear to have played only a minor role. In prehistoric Korea domesticated pig is largely absent outside the northeast (Lee, G.-A., 2011; Lee, 2017), with wild pigs still dominant until the later 1st millennium AD (Lee, 2009). However, a sudden size reduction during the Yayoi period (c. 800 BC—250 AD) in Japan suggests that domestic pig was probably the only animal to have accompanied rice agriculture from Korea to Japan, although even here wild pigs often predominate on many sites (Hongo, 2017).

Methods for examining the changing proportions of acorns/nuts from prehistoric Korea

Archaeobotanical material from 120 Korean prehistoric sites, spanning the Early Chulmun to Late Mumun periods, where flotation or plant analysis of macrofossil remains had been conducted, was compiled from the Archaeobotanical Data in East Asia Project (National Research Institute of Cultural Heritage, 2015). Presence-absence data for acorns, walnuts, hazelnuts, millets, and rice was recorded for each site or site-period. Few sites provided absolute counts, and whilst an exclusive assessment of presence/absence data is far from ideal, we believe this approach can provide a measure of ubiquity and offer cues on the changing importance of wild foods through time. A further complicating factor is the mode of preservation, by waterlogging or charring, which is often not recorded. It is unknown what impact this might have, although waterlogged material is associated both with Mumun paddyfield sites, and Chulmun pits associated with acorn leaching (Lee, 2017).

To assess the contribution of wild plant staples to early agricultural communities, the dataset was filtered to consider only site-phases (i.e., a unique period for each site) where either rice or millets (or both) were recorded. This resulted in a total of 115 site-phases across three periods (Middle Chulmun, Late Chulmun, and Mumun). For each period, the proportion of site-phases that yielded one or more of acorn/nuts was calculated. Figure 3 shows the proportions, with the 90% Jeffreys interval highlighted in color.

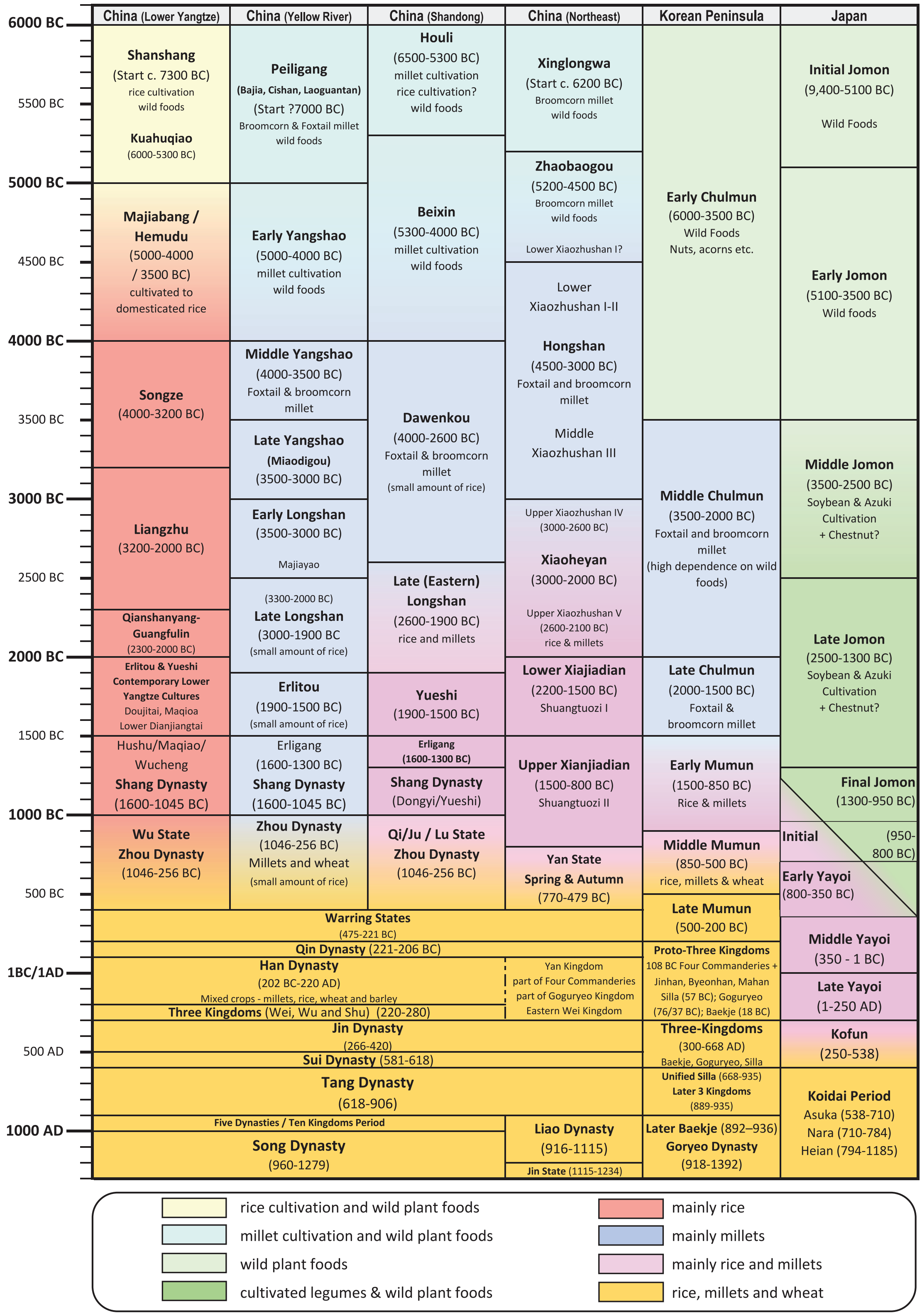

FIGURE 1
Period divisions for Korea, Japan, and in China for Shandong, the Lower Yangtze, North East and Central China (cf. Liu and Chen, 2012; Barnes, 2015; Li et al., 2020). These divisions, especially for earlier periods are only approximate, and may vary geographically for any given region. This is particularly true of Japan where there is a west-east delay.

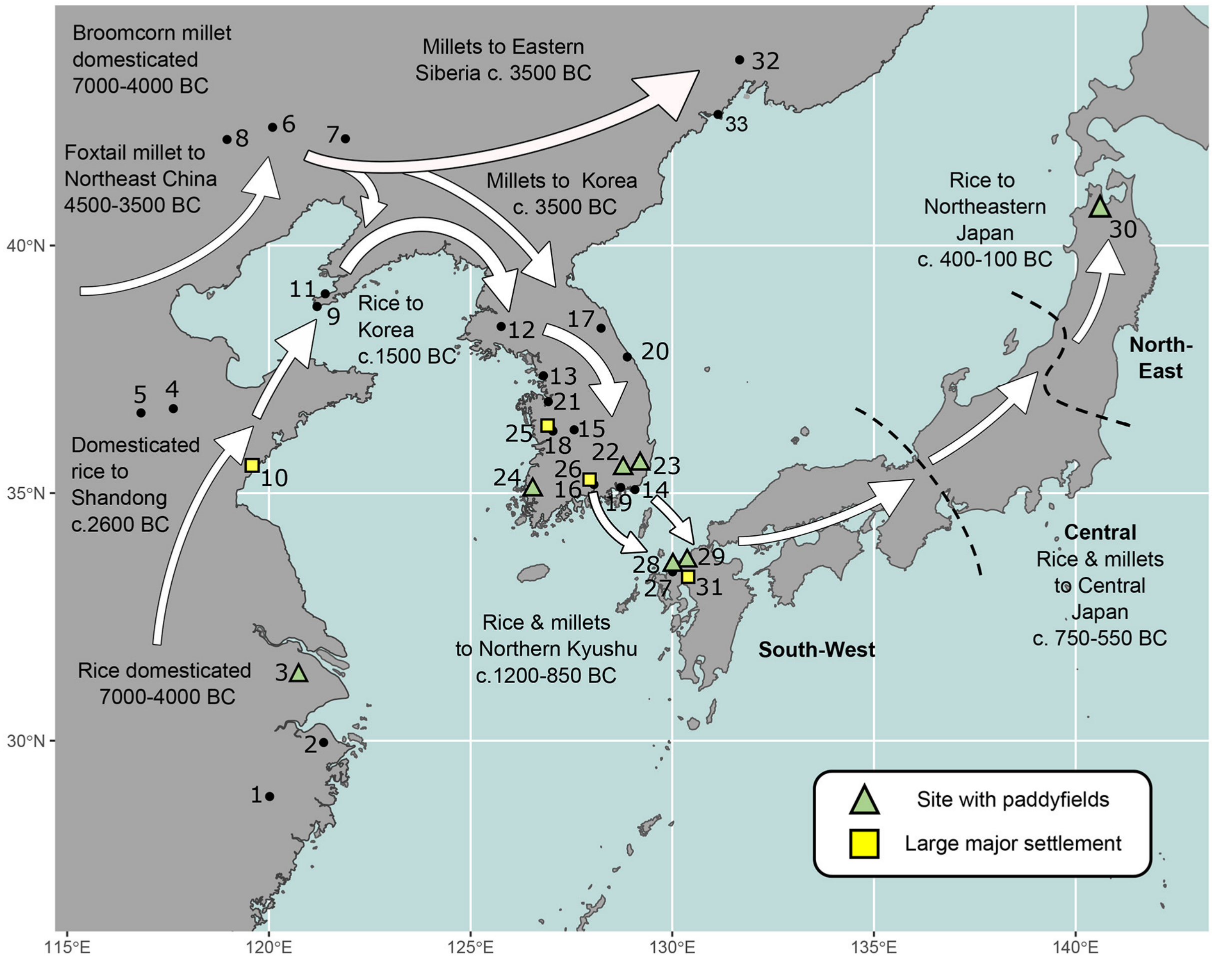

FIGURE 2
Major sites for tracking rice and millet dispersal in East Asia. China (early rice sites): 1. Huxi; 2. Hemudu; 3. Caoxieshan; 4. Xihe; 5. Yuezhuang. China (early millets): 6. Xinglonggou; 7. Jiajiagou/Tachiyingzi; 8. Weijiawopu. China (spread of millet / rice): 9. Wangjiacun; 10. Liangchenzhen; 11. Wenjiadun. Korea (spread of millets): 12. Jitap-Ri; 13. Neunggok; 14. Tongsamdong; 15. Daecheon-ri; 16. Pyeonggeodong. Korea (spread of rice): 17. Sacheon-ri; 18. Singari-Sanjik-ri; 19. Oun-1; 20. Gyodong, Gangreung; 21. Daeheung-ri Keuseonjiang, 22. Geumcheon-ri; 23. Okhyeon and Gulhwa; 24. Shinchangdong. Korea (major settlements): 25. Songguk-ri; 26. Daepyeong. Japan (spread of agriculture Karatsu Plain): 27. Ukikunden shellmound; 28. Nabatake. Japan (Fukuoka Plain): 29. Itazuke. Japan (early "leap-frog" migration): 30. Tareyanagi. Japan (major settlement): 31. Yoshinogari. Russia, Primorye (early millet): 32. Krounovka—1; 33. Gvozdevo—4. (after Miyamoto, 2019).

Results

Most of the Early Mumun sites have remains of acorns and nuts. While two also had remains of millets, there are questions as to the phasing of some sites, or the presence of intrusive material (see below). For example, Jitap-Ri (Jitam-ni) in North Korea had a large find of charred "millet" ascribed to the Early Chulmun (Ahn et al., 2015; National Research Institute of Cultural Heritage, 2015, p. 101). However, an earlier publication on the basis of ceramics and stone agricultural tools, assigned it to the Middle Chulmun (Middle Bissalmuneui) Period (Choe and Bale, 2002; Stevens and Fuller, 2017), which was followed in this study.

Within the Middle to Late Chulmun period (c. 3,500–1,500 BC) millets along with adzuki bean and soybean are well-represented, although neither were recovered from every site. More notable is that the majority of sites have nut and acorn remains, mainly sawtooth oak (*Quercus acutissima*) and Manchurian walnut (*Juglans mandshurica*). Our analysis did show a drop in the number of sites with wild acorns and nuts, but not millets, between the Middle and Late Chulmun. A few Chulmun sites are recorded as having rice, but are regarded as problematic. Rice specimens from Daechon-ri, unlike the millet from the site, were uncharred, hence certainly intrusive (Crawford and Lee, 2003; Ahn, 2010; Stevens and Fuller, 2017). Further, the dating and context of the Late Chulmun sites of Gahyeon-ri, and nearby Islan Localities 1 and 2, have been questioned as the waterlogged rice husks are not associated with archaeological remains (Ahn, 2010; Ahn et al., 2015).

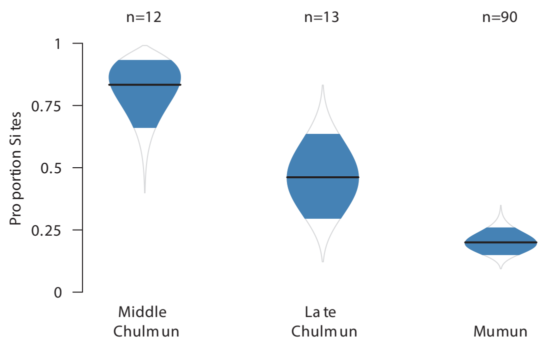

FIGURE 3
Posterior probability distribution of archaeological sites with crop remains (rice and/or millet) yielding wild nuts in prehistoric Korea. Horizontal bars indicate the observed proportion whilst the highlighted regions represent the 90% Jeffreys interval (Data from National Research Institute of Cultural Heritage, 2015).

The majority of Mumun sites (c. 1,500–300 BC), as expected, produced evidence for rice, with millet also better represented. Notably the number of sites yielding remains of wild nuts and acorns dropped substantially compared to the preceding period (Figure 3).

Evidence for cereal and wild food use in Japan

Unlike Korea there is evidence that both adzuki and soybeans were likely cultivated and domesticated during the Jomon period in Japan (Obata et al., 2007; Fujio, 2021), along with barnyard millet (*Echinochloa crus-galli/esculenta*) in northern Honshu and southern Hokkaido (Crawford, 2011) and also possibly cannabis (Kobayashi et al., 2008). From the beginnings of the Jomon period wild nuts and acorns were heavily exploited throughout the Japanese archipelago (Sakaguchi, 2009). Further there is evidence for management and probable cultivation of chestnut in the Jomon period (Minaki, 1994; Matsui and Kanehara, 2006; Yoshikawa, 2011; Noshiro and Sasaki, 2014).

In contrast to Korea, rice and millet agriculture likely dispersed together to Japan, arriving from the Korean Peninsula into northern Kyushu between 1,200 and 800 BC (Miyamoto, 2019; Crema et al., 2022). The Initial Yayoi (965–780 BC), was mainly confined to northern Kyushu, with wet-rice agriculture spreading throughout the archipelago over the course of the 1st millennium BC, although with several episodes of substantial local slow-downs in the dispersal process (Kobayashi, 2009; Crema et al., 2022).

Methods for examining the changing proportions of acorn/nuts from prehistoric to historic Japan

Evidence for changes in wild food resources was made using information extracted from the Database of Plant Macrofossils from Archaeological Sites in Japan (Ishida et al., 2016). The database collates the presence data of over 60,000 macrofossil remains of various species from prehistoric and historic archaeological sites across Japan. The methods employed were broadly similar to those used to analyze the Korean botanical data. Data entries were filtered, using only sites in Honshu, Shikoku and Kyushu that could be assigned to one of four periods; Yayoi (c. 1,000 BC—250 AD), Kofun (250–710 AD) and/or Kodai (710–1,185 AD). Note that the transition between the Final Jomon and the Yayoi is regionally dependent, with the earliest rice appearing broadly around 1,000 cal. BC in Kyushu in Western Japan and as late as cal. 200 BC in parts of Kanto and Tohoku in Eastern Japan (Fujio, 2014, 2021; Barnes, 2019; Crema et al., 2022). As with Korea no differentiation is often available between whether taxa comprise waterlogged or charred remains, although there is no obvious reason why the dominant mode of preservation should vary overtime. We identified a total of 548 site-phases with the presence of rice and/or millets (broomcorn or foxtail). We then calculated the proportion of site-phases with one or more of the following taxa: acorns (*Quercus*/*Lithocarpus*), walnuts (predominately *Juglans mandshurica*), buckeye or horse chestnut (*Aesculus turbinata*), chestnut (*Castanea crenata*) and beechnuts (predominately *Castanopsis cuspidata* and *C. seiboldi*, but also *Fagus* sp.), and specimens that had been broadly identified to two or more of these classifications. Figure 4 shows the proportion of site phases and the associated 90% Jeffreys interval for each of the three period across Southwest Japan (Kyushu, Shikoku, Chugoku, and Kansai regions), Central Japan (Chubu and Kanto regions), and Northeast Japan (Tohoku region).

Results

In line with other authors' observations (Hosoya, 2011; Obata, 2011; Noshiro et al., 2021), collected nuts and acorns are present on a large number of Yayoi sites, but we observe substantial regional variations. In SW Japan, where rice and millet agriculture was introduced first, the proportion of site-phases with nuts/acorns are considerably high in the Yayoi, before a drastic drop to the Kofun and Kodai periods. In contrast, while the same declining trend is observed, the proportion of site-phases in Central Japan with nuts/acorns during the Yayoi period is comparatively low. Finally, in NE Japan the relative proportion of wild resources are comparatively high during the Yayoi period (although with a much higher degree of uncertainty given the smaller sample sizes).

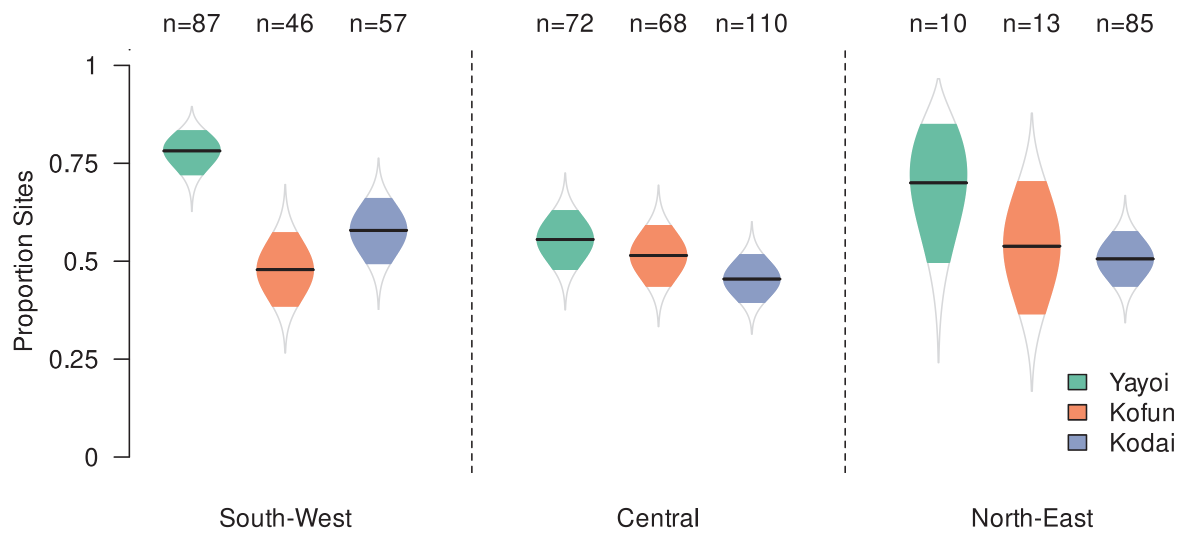

FIGURE 4
Posterior probability distribution of archaeological sites with crop remains (rice and/or millet) yielding wild nuts in different regions of Japan (excluding Hokkaido and Okinawa) in Yayoi, Kofun, and Kodai periods. Horizontal bars indicate the observed proportion whilst the highlighted regions represent the 90% Jeffreys interval. South-West (Kyushu, Chugoku, Shikoku, Kansai); Central (Chubum Kanto); North-East (Tohoku) (Data from Database of Plant Macrofossils from Archaeological Sites in Japan, Ishida et al., 2016).

An examination of the role of wild foods in early agricultural systems in Britain

Cultivated crops in southeast Europe, Greece, Bulgaria and North Macedonia initially comprised emmer (*Triticum turgidum* subsp. *dicoccum*), einkorn (*Triticum monococcum*) and tetraploid free-threshing wheats (probably *Triticum turgidum* subsp. *turgidum*), along with barley (*Hordeum vulgare*), pea (*Pisum sativum*), lentils (*Lens culinaris*), chickpea (*Cicer arietinum*), and flax (*Linum usitatissimum*). However, this package was greatly reduced in size and diversity as it traversed Europe (Colledge et al., 2005; Coward et al., 2008; Fuller and Lucas, 2017; Ivanova, 2020).

Wild plant-foods appear to have played a consistent and significant role during this European dispersal, although a considerable degree of chronological and geographical variation is present. The earliest Neolithic sites in southeast Europe appear largely dependent on cereal agriculture (Halstead and Isaakidou, 2020), but many still produced low amounts of wild plant foods, including acorns, hazelnuts (*Corylus avellana*), and cornelian cherry (*Cornus mas*) (Ivanova et al., 2018). One exception are the aceramic levels at Sesklo which were high in pistachio nuts (*Pistacia* sp.) (Zohary et al., 2012, p. 178). As the Neolithic spread into central Europe, c. 6,000–5,300 BC, wild plant remains, especially cornelian cherry and hazelnut are still frequent in botanical assemblages (Gyulai, 2007; Marinova, 2007). During the dispersal into northern Central Europe in the Linearbandkeramik c. 5,500–4,500 BC, woodland resources, in particular hazelnuts, are seen as an important supplement to early agricultural subsistence (Kreuz, 2007; Lityńska-Zajac, 2007).

Evidence for agriculture and wild food remains from neolithic Britain

The introduction of cereals to the British Isles is placed around 4,000 cal. BC (Whittle et al., 2011; Stevens and Fuller, 2012). However, the crop package that came to form the main agricultural component of British Neolithic farmers was rather meager compared to that which left Anatolia, and comprised only emmer wheat and barley, with some free-threshing wheat, and flax (Jones and Rowley-Conwy, 2007; Supplementary Information in Bevan et al., 2017).

In the late 1980s a number of eminent archaeobotanists noted that in comparison to later periods wild food remains, especially hazelnuts, were more frequent in Neolithic than later samples, sometimes far outnumbering cereals (Moffett et al., 1989). The logical implication drawn was that hazelnuts were of greater importance to Neolithic farmers than in ensuing periods, although cereals were still seen as an integral part of Neolithic subsistence (Robinson, 2000; Stevens, 2007). However, this began a debate regarding the significance of wild foods to Neolithic subsistence, with some arguing hazelnuts in particular, by virtue of their robust shells, were likely over-represented

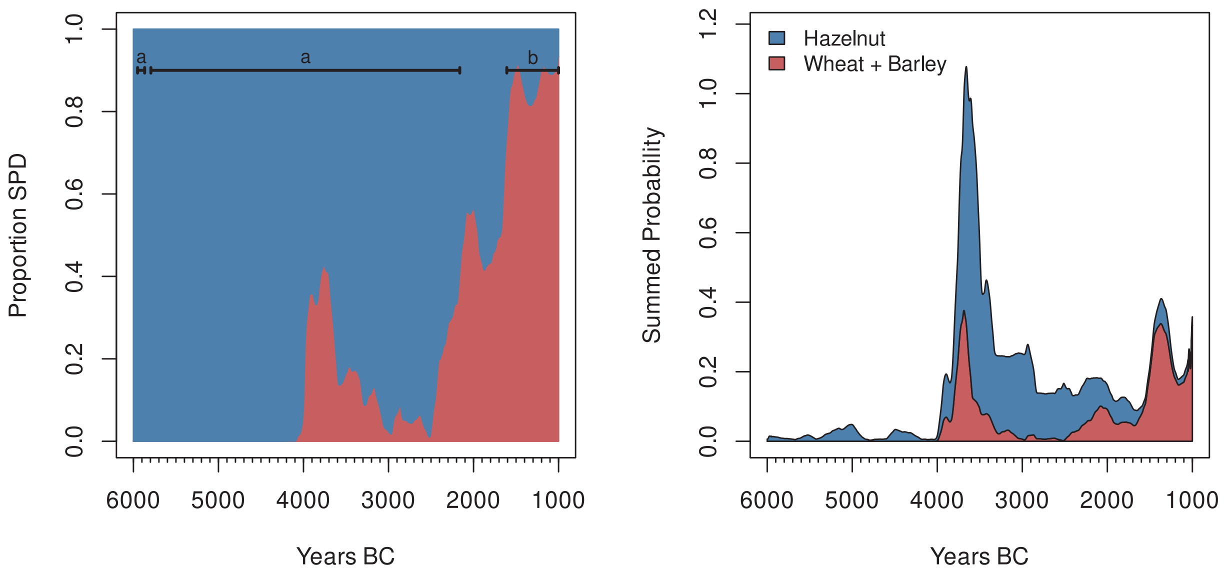

FIGURE 5
Direct radiocarbon dates on hazelnuts and cereal grains from Britain (excluding the Scottish Isles) **(Right panel)** summed probability distribution of radiocarbon dates from hazelnut ($n = 542$) and wheat/barley ($n = 285$). **(Left panel)** relative proportion of dates with time-intervals with significantly higher proportion of hazelnut (a) and wheat/barley (b) obtained from a mark permutation test with 1,000 iterations. Sample size take into account dates with cumulative calibrated probability above 0.5 between 6,000 and 1,000 BC (Data from Bevan et al., 2017).

and hence their importance overstated (Rowley-Conwy, 2000, 2004, 2011; Jones and Legge, 2008; Rowley-Conwy et al., 2020).

A further observation regarding archaeobotanical remains was that evidence for cereal agriculture appeared to decline in the later Neolithic (Piggott, 1954, p. 365; Bradley, 1978; Jones, 1980; Moffett et al., 1989; Robinson, 2000). A study by one of the authors aimed to resolve this issue by using summed probability distributions of wild food remains (predominately hazelnuts) and cereal remains from the British Isles spanning the Mesolithic, Neolithic and Bronze Age (Stevens and Fuller, 2012, 2015; Bevan et al., 2017). The advantage of using direct dates being that it overcame the problems of potentially intrusive material (Pelling et al., 2015).

Methods for analyzing wild food remains in Neolithic Britain

The original analysis by Stevens and Fuller (2012) has been modified and is presented here utilizing direct radiocarbon dates on hazelnuts and cereal remains (wheat and barley) for Britain (taken from Bevan et al., 2017), excluding the Scottish Islands. Figure 5 (left panel) shows the relative proportion of radiocarbon dates for hazelnuts and cereals, with intervals of statistical significant differences obtained from mark permutation tests (Crema et al., 2016; analyzed using the rcarbon R package, Crema and Bevan, 2021) highlighted. Figure 5 (right panel) shows the same data in the form of the summed probability distribution of radiocarbon dates from cereal remains and hazelnut over the Mesolithic, Neolithic and Bronze Age, between 6,000 and 1,000 cal. BC.

Results

The distribution shows that remains of wild plant foods, in particular charred shells of hazelnut, are a conspicuous and ubiquitous part of archaeobotanical assemblages during the Mesolithic and Neolithic. The SPD demonstrates that cereals first appear around 4,000 cal. BC and increase along with hazelnuts during the Early Neolithic, reflecting increasing population levels associated with the arrival of farming seen in similar studies (Collard et al., 2010; Whittle et al., 2011; Shennan et al., 2013; Timpson et al., 2014).

The analysis indicates a shift in subsistence toward wild plant foods and away from cereals in mainland Britain starting from around 3,700 cal. BC. During the Middle Neolithic (c. 3,300 cal. BC) to the end of the Late Neolithic (c. 2,400/2,200 cal. BC) conclusive evidence for cereals is absent from many sites in mainland Britain (Stevens and Fuller, 2012, 2015; Bevan et al., 2017), as also seen in Ireland (Whitehouse et al., 2014). Significantly, sites in England with apparent evidence for cereals during this period generally prove to be intrusive (Stevens and Fuller, 2012; Pelling et al., 2015; Worley et al., 2019). An additional factor seen in the original studies was a high degree of regional variation, with the Scottish Islands continuing with cereal farming during the Middle Neolithic, with little reliance on wild foods compared to the British mainland (Stevens and Fuller, 2012, 2015).

After 2,500 cal. BC a gradual change in subsistence is seen across mainland Britain in which the number of wild foods begins to decline, and cereal cultivation increases, with declining numbers of hazelnut dates from the start of the Middle Bronze Age c. 1,600 cal. BC (Stevens and Fuller, 2015; Bevan et al., 2017). Hazelnuts along with other wild foods are still present in assemblages, and undoubtedly provided some small contribution to the diet, however comparatively to earlier periods they form a minor, relatively insignificant component.

Discussion

Several studies have shown the reliance on wild plant foods declined as cereals became fully domesticated in West Asia and East Asia (Fuller and Qin, 2010; Stevens and Fuller, 2017; Fuller et al., 2018). With the continued use of a wide range of plant foods undoubtedly acting as a buffer against the risk of occasional poor yields (Wallace et al., 2019).

Throughout Europe wild foods have generally been seen as providing an important contribution to Neolithic diets (Kreuz, 2007; Colledge and Conolly, 2014; Antolín and Jacomet, 2015; Bouby et al., 2020). For at least the Middle to Late Chulmun period in Korea acorns and nuts are viewed as important staples, along with other resources such as hunting, shellfish and fishing, perhaps contributing more to the diet than millets (Lee, G.-A., 2011; Ahn, 2012; Lee, 2017; Kim and Park, 2020; Kim, 2022). The question of their continued use after the introduction of rice in Korea is less discussed, but various lines of evidence point to more fully agricultural societies (Ahn, 2010; Lee, G.-A., 2011; Kwak et al., 2017), with a mixture of rice and millet farming (Choy et al., 2021). However, occasional sites, e.g., Shinchangdong, (200–100 BC), have produced high numbers of acorns and wild plant foods suggesting their continued value to subsistence (Liu et al., 2007).

In Japan the sustained use of acorns/nuts have been seen as important dietary resources supporting the transition to rice agriculture within the Yayoi period (Obata, 2011; Noshiro et al., 2021) potentially continuing to the 14th to 15th Century (Hosoya, 2011, 2014).

However, the wider role of wild foods, in particular starchy nuts and acorns, in early agricultural subsistence systems remains largely unexplored. One possible explanation for this neglect is that wild foods, both consciously and unconsciously, have been interpreted as continuity of traditional subsistence practices marking the transition from hunter-gatherer to farmer. This interpretation, and hence the importance of wild foods has as such become intertwined with the mechanisms driving crop dispersal (Rowley-Conwy, 2004, 2011; Rowley-Conwy et al., 2020).

Demic vs. cultural diffusion

The processes by which agriculture spread throughout the globe has a long history of debate which only in the last decade is coming to perhaps what was always a logical conclusion.

Agricultural diffusion through migration or colonization was generally favored before the 1970s (Childe, 1925, 1928, 1942, p. 40; Hawkes and Hawkes, 1943; Clarke, 1952; Piggott, 1954, p. 90; Case, 1969). However, in 1971 the publication of a seminal piece of work by Ammerman and Cavalli-Sforza (1971) provided a fuller, more nuanced, explanation for the spread of agriculture. Within this paper compiled radiocarbon dates for the first appearance of Neolithic sites across Europe demonstrated a slow spread of agriculture in a process that took millennia. They saw this spread as driven by regional and localized expansions of agricultural populations that slowly brought agriculture, at a rate of around 1 km per year (around 25 km per human generation), out from the Near East and eventually across all Europe (Ammerman and Cavalli-Sforza, 1971, 1984, p. 61, 133–135). This population-driven expansion of agriculture was named "demic-diffusion", whereas "cultural-diffusion" referred to the adoption of crops by pre-existing indigenous peoples.

While the paper by Ammerman and Cavalli-Sforza was hugely influential, from the late 1970s into the early 2000s, a shift occurred toward explanations that favored "cultural diffusion" as the main mechanism driving agricultural dispersal (Barker, 1985; Zvelebil and Zvelebil, 1988; Zvelebil, 1994, 1998; Price and Gebauer, 1995; Thorpe, 1996; Robb and Miracle, 2007). In Britain the "continued" importance of wild foods, was seen to support such an argument, to the point that some scholars dismissed cereals as being of little to no significance (Thomas, 1991, p. 4–29; Richards, 1996, 2000; Richmond, 1999, p. 32–34; Pollard and Reynolds, 2002, p. 42; Whittle, 2003, p. 157). This "retreat from migrationism" (Adams et al., 1978) was not only confined to Europe, but was also particularly embraced in Japan (Hudson, 1999, p. 147).

The argument for the importance of wild foods vs. agricultural crops subsequently became tightly bound with the nature of the transition to agriculture in Europe. On the one hand were those who argued for a slow adoption of agriculture by indigenous peoples, still highly reliant on wild resources (Thomas, 1991, 2002), on the other, those who saw a rapidly introduced and fully agricultural Neolithic in which wild foods played little part (Jones, 2000; Rowley-Conwy, 2000, 2004, 2011; Jones and Rowley-Conwy, 2007; Jones and Legge, 2008; Rowley-Conwy et al., 2020). In Japan this argument took a slightly different turn that saw both those engaged in genetics and physical anthropology stressing the importance of immigration (Nakahashi and Iizuka, 1998; Iizuka and Nakahashi, 2002), whilst archaeologists dealing with material culture often argued for a much smaller migration, followed by adoption based on evidence for cultural continuity (Kanaseki and Osaka Yayoi Culture Museum, 1995).

Within the last decade the successful extraction and sequencing of ancient human DNA from individuals spanning Europe and West Asia has lent substantial support to the demic-diffusion model, demonstrating a clear and often dominant West Asian lineage in early European farmers (Haak et al., 2010; Fu et al., 2012; Szécsényi-Nagy et al., 2014; Mathieson et al., 2015; Hofmanová et al., 2016; Silva and Vander Linden, 2017; Ammerman, 2021). Alongside these studies the use of radiocarbon data as a proxy for population levels has demonstrated an initial rapid increase in population that coincide with the earliest evidence for farming (Shennan et al., 2013; Whitehouse et al., 2014; Oh et al., 2017; Crema and Shoda, 2021) which is often seen as supporting the demic-diffusion model (Rowley-Conwy, 2004; Collard et al., 2010; Stevens and Fuller, 2012; Silva and Vander Linden, 2017; Kim and Park, 2020).

Did hunter-gatherers ever adopt agriculture?

As Bellwood (2005, p. 25–26, 37–39) stated, confirmed instances of agricultural adoption by indigenous hunter-gatherers are rare within the ethnographic record. Here we might ask two questions; would hunter-gatherers necessarily want to adopt agriculture? And how easy would it be in a pre-literate, pre-state society for hunter-gatherers to adopt agriculture?

Taking the first question there has long been a subconscious belief amongst Western scholars that farming is "inherently superior" to hunter-gathering, a viewpoint that was popularized during the 19th Century (cf. Rowley-Conwy, 2014). In cases where ethnographic studies have addressed this issue, there is frequently a strong resistance to farming by hunter-gather groups, in part because it is less gratifying in terms of the inevitable delay between sowing, harvest and consumption, but most pertinently because if disrupts social norms built around status and cultural traditions (Stearman, 1999). Further, in comparing hunter-gatherer and agricultural diets, the latter is often more detrimental to general health (Cohen, 1989; Cohen and Crane-Kramer, 2007; Gage and DeWitte, 2009 for discussion). A final point, is that contrary to popular belief, historical records suggest that unlike farmers hunter-gatherers rarely suffer from famine and starvation (Stearman, 1999; Berbesque et al., 2014).

Turning to the question of "how easily a hunter-gatherer might adopt farming", anyone who has farmed will know the cultivation and caring of crops involves a considerable amount of knowledge surrounding soil management, the growing conditions of a particular crop, its storage, processing, food preparation and the construction of tools. Such aspects of life, as much as those equated with hunting and gathering, are highly culturally embedded, through both social structures and ideology. Simply put farming is unlikely to be adopted by non-cultivators without prolonged periods of participation within agricultural communities, which includes considerable social and cultural interaction (Stevens and Fuller, 2012; Rowley-Conwy et al., 2020).

One aspect that genetics has changed concerning the narrative of agricultural diffusion is highlighting that integration and introgression, between hunter-gatherers and incoming farmers in the form of inter-marriage frequently occurred (cf. LeBlanc, 2008). Indeed such interactions are relatively commonly recorded in the ethnographic record (Bellwood, 2005, p. 38). In such situation's intermarriage between incoming agriculturalists and hunter-gatherers might potentially reinforce and bring additional local knowledge of wild resources, including their distribution, harvesting, processing and storage. For example, many species of acorns require leaching in order to render the nuts edible, as do also those of horse chestnut (Hosoya, 2011).

The role of wild foods in subsistence systems

If the high presence of wild foods in early agricultural societies is not related to their continued use by hunter-gathers adopting agriculture then further explanations must be sought.

Fluctuations in food supply are a natural aspect of subsistence for many peoples using traditional, non-mechanized farming techniques. Halstead and O'Shea (1982) identified four main cultural responses or strategies utilized by ethnographic, historical, and prehistoric societies to cope with unpredictable food resources; mobility, diversity, storage, and exchange. Mobility was largely employed by hunter-gatherers and pastoralists, in which groups moved between areas when local resources declined. Diversity, counter-balanced resource failure by exploiting a wider range of resources, such that when one resource declined its impact would be lessened and picked up by other staples. Storage plays a dual role in subsistence, annually it compensates for seasonal fluctuations in the availability of various wild and cultivated resources, however, long-term storage serves to balance years of plenty against those where harvests are poor, for agriculturalists, foragers, hunters and fishers alike. Finally, exchange is used in conjunction with storage to balance out spatial and chronological variation in yields between various communities. Such interactions might involve reciprocal relationships, or the exchange of goods and services, or placed against future obligations. While it was acknowledged that a number of these strategies would be used in unison, it was the degree of dependence on individual strategies that defined various cultural groupings and responses, and that movement between them potentially lead to social change and cultural evolution (Hayden et al., 1981; Halstead and O'Shea, 1982; Testart et al., 1982).

We can then interpret the changing importance of wild foods in early agricultural systems as reflective of two aspects of subsistence. Firstly, the stability of the agricultural system itself. Early agricultural systems were potentially subjected to more uncertainty and dependability of yields relating to the dispersal of crops into new ecological and climatic environments to which they were still adapting (Terasawa, 1986; Obata, 2011; Fuller and Lucas, 2017; Shitara, 2017; Ivanova et al., 2018; Motuzaite-Matuzevičiute, 2018; Gutaker et al., 2020; Ivanova, 2020; de Vareilles et al., 2022). The second aspect relates to what degree technological and social mechanisms had become established within these early agricultural societies to cope with uncertainty of yields. Such that a combination of improved longer-term storage, improved agricultural techniques, a wider range of crops and crop varieties, and secure exchange systems can mediate for fluctuations in harvest. This in turn would diminish the need to exploit a more diverse resource base that utilizes high amounts of wild foods.

The case for the use of wild foods in Britain and East Asia

In this final section we will present some initial interpretations for the changing roles of wild starch rich foods, e.g., nuts, in early agricultural systems in East Asia and Britain, from potential dietary staples to dietary supplements and famine foods. A series of points worth drawing attention to, are firstly in Europe, the importance of demic-diffusion vs. adoption is, in light of extensive ancient genetic studies, now less contested. Whereas, for the initial dispersal of millet agriculture into Korea, and the dispersal of rice agriculture throughout Japan, adoption is still generally perceived as a major contributing factor (see below). Secondly, in keeping with such interpretations, wild foods during the Middle Chulmun in Korea, and in the Yayoi Period in Japan, are regarded as major contributors to subsistence (Hosoya, 2011; Lee, G.-A., 2011), whereas in Britain the role of wild foods has been diminished in those studies that see them in conflict with the idea of agricultural dispersal through demic-diffusion (Rowley-Conwy et al., 2020). It is hoped in the following sections to demonstrate that the role of wild foods and the mechanisms behind dispersal need to be decoupled in order to gain a fuller insight into how the changing use of wild plant staples might be able to shed light on the nature of early agricultural subsistence systems.

Changing subsistence systems in Neolithic to Bronze Age Britain

In the British Isles, a rapid dispersal of agriculture through demic-diffusion is supported by a significant increase in population (Collard et al., 2010; Sheridan, 2010; Rowley-Conwy, 2011; Whittle et al., 2011; Stevens and Fuller, 2012; Whitehouse et al., 2014; Bevan et al., 2017; Rowley-Conwy et al., 2020). This stance is reinforced by genetic studies which demonstrate a Neolithic population derived predominately from continental peoples with a strong Anatolian lineage, and only a minor input from pre-existing Mesolithic hunter-gatherers (Brace et al., 2019).

The status of wild foods in the Early Neolithic is best viewed from the perspective of the later Neolithic when cereal agriculture disappeared over much of mainland Britain (Stevens and Fuller, 2012, 2015; Whitehouse et al., 2014; Bevan et al., 2017; Worley et al., 2019). This interpretation is supported by a significant downturn in population (Shennan et al., 2013; Timpson et al., 2014), the near absence of quern stones (Stevens, 2007; Stevens and Fuller, 2012; Watts, 2012; cf. Peacock, 2013), a decline in grassland and a localized regeneration of woodland (Evans, 1990; Thomas, 2002, p. 32; Robinson, 2014; Supplementary Information in Bevan et al., 2017). Whilst climatic deterioration has been forwarded for this change (Stevens and Fuller, 2015; Bevan et al., 2017), this need not imply a population collapse or a catastrophic event. Rather we propose a readjustment of existing subsistence systems in response to more unpredictable harvests, during which wild plant foods and pastoralism gained prominence to the point that cereal agriculture was eventually temporarily abandoned for almost a millennium. That agriculture continued on the Scottish Islands infers this transition relates to cultural responses to changing resource availability, e.g., how pre-existing subsistence systems adjusted to cope with declining cereal yields, rather than a failure of cereal agriculture *per se* (Stevens and Fuller, 2015). This scenario lends support to theories that advocate for a more integrated subsistence system entering Britain during the Early Neolithic based on a diverse resource base that incorporated pastoralism and the gathering of wild foods, alongside the cultivation of cereals (Moffett et al., 1989; Stevens and Fuller, 2012, 2015; Peacock, 2013, p. 19; Treasure et al., 2019). This early cereal cultivation was established in an environment in which a persistent agricultural landscape had yet to be established, and for which reliable exchange systems and social networks to compensate for shortfalls in agricultural harvests were largely absent. Notably in Neolithic Britain evidence for more complex forms of storage are generally lacking and while bulk storage might have initially occurred in longhouses (Fairweather and Ralston, 1993), that such houses largely disappear after 3,800–3,600 cal. BC (Whittle et al., 2011), when wild foods gain importance comparatively to cereals, might not be entirely coincidental.

It is notable that hazel woodland was in a gradual decline prior to and just following the introduction of agriculture around 4,000 BC, but remained relatively stable for much of the Neolithic, with only a small decline seen in the Early Bronze Age (Supplementary Information in Bevan et al., 2017). For the millennium between 2,200 and 1,200 BC grassland increases with a small slow decline in woodland, including oak, although hazel is relatively unaffected during this period.

Genetic evidence reveals a large influx of peoples to Britain after 2,500–2,400 cal. BC whose descendants originated in the Eastern Steppe (Allentoft et al., 2015; Haak et al., 2015; Patterson et al., 2022). This period marked the beginnings of a slow reintroduction of cereal agriculture into mainland Britain during the Early Bronze Age (Stevens and Fuller, 2012, 2015; Fuller and Stevens, 2018). From around 2,000 cal. BC, we see a marked decline in the importance of wild foods (Figure 5; Bevan et al., 2017). This change eventually accumulated in fully agricultural societies in the Middle to Late Bronze Age (1,600–700 cal. BC) with agricultural fields, permanent settlement, spelt wheat, underground grain silos, shaped saddle querns, and four poster-granaries, all absent previously, but now present (Jones, 1988; Stevens and Fuller, 2012; Peacock, 2013, p. 16; Bradley, 2014, p. 181–193; Supplementary Information in Bevan et al., 2017; Fuller and Stevens, 2018). The fully agricultural landscape that emerged during the Middle-Late Bronze Age was then one in which fluctuations in harvest could be mitigated through a combination of long-term storage and established exchange networks between multi-generational settlements and households, in which wild plant staples were no longer relied on so frequently. However, even this later transition to a fully-agricultural society was likely brought about through a protracted period of migration, with recent genetic studies demonstrating a further gradual incursion of peoples in southern Britain from the Middle to Late Bronze Age from around 1,500 cal. BC, that grew in size and intensity between 1,000 and 750 cal. BC (Bradley, 2022; Patterson et al., 2022).

Changing subsistence systems in Chulmun to Mumun Korea

For Middle Chulmun Korea (c. 3,500–2,000 BC) evidence for the continuation of cultural traits, and settlement patterns (Kim and Park, 2020), has led to the suggestion that millet agriculture was adopted by indigenous peoples (Lee, G.-A., 2011, p. 2; Shin et al., 2012; Bae et al., 2013). Unlike Japan, there is as yet no confirmation for cultivation of indigenous species prior to the arrival of millets. The dispersal of millet agriculture into Korea was accompanied by agricultural stone tools; hoes and harvesting knives, pestles and millets, and ceramic storage-wares, originating in the Middle Xiaozhushan Culture of Liaoning, Northeast China (Choe and Bale, 2002; Miyamoto, 2014). Likewise, this initial dispersal has also been associated with linguistic and genetic expansion from northeast China during the Neolithic (Robbeets et al., 2021).

The complexity of this agricultural package, that encompasses not just millets but a significant cultural component, argues in favor of demic-diffusion rather than adoption. Population levels are generally low during this period (Oh et al., 2017), but a small demographic increase has been correlated with the arrival of millet agriculture (Ahn et al., 2015). However, the possibility of some degree of acculturation between diffusing agriculturalists and pre-existing hunter-gatherer groups in the northwest of the Korean Peninsula, prior to the migration of these groups into the Southern Korean Peninsula, remains plausible (cf. Miyamoto, 2014).

The Middle Chulmun is characterized by a diverse range of regionally localized subsistence systems (Choe and Bale, 2002; Lee, G.-A., 2011). A heavy reliance on acorns and nuts, along with hunted animals, boar and deer, and the exploitation of marine resources is evident, but millets are viewed as providing a small, but persistent contribution (Choy and Richards, 2010; Lee, J.-J., 2011; Ahn et al., 2015; Kim et al., 2015; Lee, 2017; Kim and Park, 2020). The Late Chulmun (2,000–1,500 BC) in our study saw a decline in the proportion of sites with wild acorn and nuts, although those with millets increase (Figure 3). This same period is linked with a decline in population (Oh et al., 2017; Kim and Park, 2020), sometimes attributed to climatic change (Ahn et al., 2015). However, this interpretation has been questioned given the population decline begins prior to the onset of climatic deterioration (Kim et al., 2021).

The arrival of rice agriculture in Korea in the Early Mumun period (1,500–850 BC) has generally been equated with migration/demic-diffusion, given the establishment of new settlement patterns (Kim and Park, 2020), and a substantial corresponding increase in population (Oh et al., 2017). Further it saw the abandonment of all but a few shell midden sites, and coastal regions in general (Norton, 2007). Rice agriculture in the Mumun period was accompanied by other crops, including bread wheat and barley (Kim, 2013), alongside East Asian domesticates; egoma (*Perilla frutescens*), soybean and adzuki bean (Crawford and Lee, 2003; Lee, G.-A., 2011). Further, stable carbon isotope analysis of human bone collagen indicated an intensive contribution from C4 plants, (e.g., millet), in comparison to C3 plants, such as rice or nuts/acorns (Lee, J.-J., 2011; Choy et al., 2021). In our study the transition to rice agriculture is also marked by a clear decline in the number of sites using wild acorn and nut resources (Figure 3).

Villages and settlements in the Mumun period are larger than the preceding Chulmun period (Norton, 2007). Archaeological evidence demonstrates the formation of more complex societies leading to proto-states around 300 BC, started during the Mumun period (Bale and Ko, 2006) with increasing hierarchical and socio-political structures associated with the appearance of rich dolmen burials (Rhee and Choi, 1992; Norton, 2007).

During the Early Mumun period storage pits in houses were thought to be used for general household needs, but in the Middle Mumun (850–500 BC) larger complexes comprising multiple pits outside of houses are interpreted as communal storage at an inter-household or settlement level (Yi, 2014). The contents of these pits has been subjected to some disagreement with some arguing they were used predominately for nuts and tubers (Son, 2004), while others have argued that they are more likely for the storage of cereal grains (Kim, 2008; Yi, 2014).

From the Middle to Late Mumun Period (850–300 BC) many sites produce evidence for pillared-buildings interpreted as stilted-granaries used for storing surplus grain (Bale, 2011, p. 57, 2017). These structures increase in size and number during this period when a transition to more fully agricultural, stratified societies is postulated (Choe and Bale, 2002). The Middle Mumun witnesses the appearance of a few substantial settlements up to 61 hectares in size, comprising some 100–200 houses, such as, Songguk-ri and Daepyeong (Figure 2; Bale and Ko, 2006; Bale, 2011, p. 61–144; Barnes, 2015, p. 267). These settlements provide evidence for significantly larger granaries and likely centralized storage, however most sites still appear to be storing crops at a household level (Bale, 2017).

While it is clear that wild food resources sometimes still played a significant role (cf. Liu et al., 2007), the subsistence system that accompanied rice agriculture into Korea appears resilient enough that the role of wild foods was clearly diminished. This decline can be related to several potential factors, one potentially is the broader and more diverse range of crops, and increased use of millet, that potentially compensated fluctuations in harvests of one to be supplemented by another. However, evidence for improved household storage and more permanent settlement echoes the picture seen for Bronze Age Britain where storage and some level of exchange between more widely spread communities likely negated localized fluctuations in harvests.

Japan

In contrast to Korea the spread of rice agriculture, along with millets, throughout the Japanese archipelago has often been argued by archaeologists to be through a mixture of initial migration followed by later widespread adoption (Kanaseki and Osaka Yayoi Culture Museum, 1995; Imamura, 1996; Mizoguchi, 2013, p. 53, Mizoguchi, 2019; Kaner and Yano, 2015, p. 360; Barnes, 2019; Fujio, 2021). While geneticists have often stressed the role of migration to a greater degree (Nakahashi and Iizuka, 1998; Iizuka and Nakahashi, 2002).

Despite this rice paddy agriculture has often been seen as entering Japan in a fully developed form (Sahara and Kanaseki, 1981, p. 23; Harunari, 1990, p. 127–141; Hirose, 1997, p. 50–51), the nature of Yayoi rice paddies being highly similar to those of Mumun Korea (Rhee et al., 2007).

Following the arguments outlined above the dispersal of rice agriculture through adoption by an indigenous Jomon population is seen as highly problematic. Comparatively to other cereals rice is an extremely challenging crop with high demands on relatively skilled labor (Fuller, 2011). Further, it requires considerable degrees of social organization and integration at a settlement and inter-settlement level, not just in cultivation, but also in the construction and management of water systems (Bray, 1994; Fuller and Qin, 2009; Talhelm and English, 2020). Adoption by an indigenous community even on a small scale would not only present considerable technological challenges, but substantial social reorganization. As an example, the "hunter-gather" Agta of the Philippines cultivate small plots of rain-fed rice, and occasionally small fields of irrigated rice. This knowledge was gained through "paid" work for rice farmers, although often more rice is gained through exchange of foraged and hunted items than through cultivation (Headland, 1986; Minter, 2010). While such activities are well-documented over the last 200 years during the Spanish era, many lines of evidence suggest long-term contact that potentially extends back over a thousand years (Headland and Reid, 1989).

While we consider adoption unlikely without prolonged periods of interaction, skeletal morphology and genetic studies do support complex gene-flows between indigenous Jomon peoples and incoming agriculturalists. The initial theory of Hanihara (1987, 1991), known as the *dual structure hypothesis*, proposed that Yayoi peoples comprised an admixture of Jomon and continental lineages, and later saw backing from genetics and linguistic studies (Hudson et al., 2020). However, a recent study has revealed a significant contribution of continental genes occurred during the Kofun Period, such that the initial contribution of indigenous Jomon into Yayoi (e.g., pre-Kofun) populations was potentially much greater (Cooke et al., 2021). This would support considerable levels of interaction and introgression between existing Jomon communities and diffusing agriculturalists, although as a note of caution genetic signatures can be lost or greatly altered over time, such that sequencing individuals at the advent of agriculture becomes essential to addressing these issues (LeBlanc, 2008).

In Japan during the Yayoi period wild foods appear to retain a greater importance during the transition to rice agriculture (Figure 4; present in over 75% of sites) in comparison to Mumun sites where they declined substantially (Figure 3; present in around 25% of sites). This is in line with arguments that wild plant staples played a very important role in supporting early rice agricultural subsistence during the Yayoi (Hosoya, 2011, 2014; Obata, 2011; Noshiro et al., 2021).

We can forward a number of possible reasons for this continued significance. Based on differences in cultural assemblages, two relatively small migrations of rice agriculturalists are considered by Miyamoto (2019), the earlier from the central coastal regions of the Korean Peninsula to the Karatsu Plain; the later second from the lower Nakdonggang basin to the Fukuoka Plain (Figure 2). These migrations might have created some disjuncture in the stability of agricultural subsistence and social relationships. In which reliance on exchange of grain to compensate for fluctuating harvests through established social ties, as had accompanied rice in its dispersal from China into the Korean Peninsula, were no longer possible.

The migration of rice farmers into northern Kyushu was followed by interactions, and potentially introgression, with local Jomon peoples giving rise to hybrid pottery styles that combined Mumun and Final Jomon traditions (Yane, 1987; Hudson, 1999, p. 121–123; Rhee et al., 2007; Mizoguchi, 2013, p. 67–68; Barnes, 2015, p. 273). This integration of Jomon people into agricultural communities might have increased the resilience of their subsistence systems with the addition of knowledge of local resources, but simultaneously begun to culturally embed reliance on wild foods into these societies.

A notable observation is that comparatively to the South-West, the dispersal of rice to Central Japan is accompanied by fewer sites producing evidence for nuts/acorns (Figure 4). This difference is conceivably related to the possibility that in the generations following the arrival of the first rice farmers in northern Kyushu, agricultural and social systems had developed to a point in which rice agriculture was more reliable and short-falls more easily mitigated against. For example, Fujio (2021) argues that the time difference between the introduction and the full adoption of rice farming took circa 250 years in Northern Kyushu, but only about 20–30 years in the Kanto region. In the transition to North-East Japan, wild starchy foods appear still of some significance, and this can potentially be explained by the lower stability of farming practices in these regions. For example, evidence from early agricultural sites in Amori, such as Tareyanagi, insinuate an abandonment and reversion to a predominantly hunting and gathering economy in the late 1st millennium BC (Takase, 2017; Fujio, 2021; Crema et al., 2022).

Considering the nature of Yayoi subsistence systems there are other factors that we might consider in relation to the continued value placed on acorns/nuts. Comparatively to Mumun Korea, a less diverse array of annual agricultural cereal crops might have been relied on. For example, wheat and barley do not appear to have been an important or prominent part of Yayoi agricultural systems (Shoda et al., 2021).

Turning to other factors that might influence a sustained use of wild plant staples, poor rice harvests likely impacted not just households occupying a single settlement, but across multiple settlements inhabiting the same valley. In these hybrid communities a continued reliance on wild resources would then potentially provide a degree of household autonomy. For example, in 19th Century Gifu acorn gathering was first conducted communally to ensure a balanced distribution of wild resources, additional gathering was then continued by individual households as the needs or size of the household demanded (Matsuyama, 1981). Acorns and nuts were collected in September, following the rice harvest, but then stored and consumed the following summer mixed with other foods (Koyama, 1982). As such the quantity of nuts and acorns harvested could be balanced against the success of the harvest then used to bulk out the previous year's stored harvest if necessary.

In keeping with this interpretation, pits with acorns/nuts, for the leaching of tannins during storage, were a common feature of Jomon sites (Sakaguchi, 2009), and are also found during the Yayoi period, particularly in northern Kyushu (Obata, 2011; Noshiro et al., 2021). These nuts/acorns are sometimes mixed with grain crops (Hosoya, 2002), although possibly such pits might also have been used exclusively to store rice and/or millets (Yi, 2014). While raised floor structures date back to the Jomon period, from the Initial Yayoi they are often more definitively interpreted as possible granaries (Aikens and Higuchi, 1982, p. 226–234; Imamura, 1996, p. 144; Mizoguchi, 2013). As with Mumun raised granaries, those on Yayoi settlements are thought to have been associated with individual households (Hosoya, 2014).

The emergence of early states during the Kofun and early historical periods saw a general drop in the representation of wild foods particularly in Western Japan (Figure 4). This change can potentially be linked to increased exchange, the wider use of communal storage and the gradual formation of more hierarchical social structures. Such changes can be traced back to the later Yayoi period, culminating in the formation of state level societies. Increased evidence for stilted granaries is seen in the Middle to Late Yayoi, from the mid 4th century BC. In parts of Western Japan these granaries are often grouped in what appear to be communal storage areas (Hudson and Barnes, 1991; Hosoya, 2014), with archaeobotanical evidence suggesting mass-dehusking at a level beyond the household (Hosoya, 2002, 2009, 2014). Alongside these changes, the Middle Yayoi also sees the enlargement and subdivision of individual settlements, such as Yoshinogari, along with centralized storage and the emergence of social elite groups (Hudson and Barnes, 1991). The growth of these settlements along with the evidence of communal storage, although later in date, is regarded as broadly analogous with developments in the Middle Mumun of Korea (Bale, 2017). This increased social stratification eventually became institutionalized in the subsequent Kofun period, 3rd to 7th Century AD (Hosoya, 2014), with an established elite symbolized by huge burial mounds.

Conclusions

Within this paper we argue that agricultural dispersal is largely driven by demic-diffusion, but that wild foods form an important part of buffering against innate uncertainty in these early subsistence systems. Such factors identified here, that might be absent within these early subsistence systems, include; an established and wider range of crops and crop varieties; long-term storage, including long-term communal storage; and more complex social ties that bonded more distant communities together when harvests failed. It is proposed that in these early agricultural societies these factors had yet to evolve to a point at which cultivation alone could sustain early agricultural populations. This might further be amplified by a situation in which the environment itself has not yet adjusted to human cultivation (Redman and Foster, 2008; Gron et al., 2020).

In mainland Britain more stable agricultural systems did not arrive until the Early to Middle Bronze Age. Prior to this in the transition from the Early to Middle Neolithic populations began to rely more heavily on pastoralism and wild plant foods than cultivated ones, to the point that cereal agriculture appears to have been largely abandoned.

In Korea, the initial spread of millet farming in the Chulmun Period, while seen as largely driven by small scale migration was likely accompanied by heavy introgression with the local population resulting in subsistence patterns with a heavy reliance on wild resources, as opposed to longer term storage and social exchange networks. The establishment of rice cultivation during the Mumun, driven by larger scale migration and demic-diffusion, saw a higher population growth, denser settlement patterns and a decline in wild plant staples. Mumun subsistence systems appeared more reliant on a wider diversity of crops along with longer term and centralize storage, and exchange, although some evidence for a continued role of acorns and wild foods in subsistence is also seen (Liu et al., 2007).

The advent of rice agriculture in Western Japan in the Yayoi sees some variation in subsistence systems compared to Korea. For example, while granaries are present, along with villages of a relatively large size, wild plant staples continued to play a prominent role. To some extent this likely reflects the nature of rice agriculture in comparison to that of other crops. Failures in rice harvests will impact at the community level rather than that of the individual farmer. As such reliance on agricultural exchange networks to alleviate against poor harvests need to work potentially at a much larger geographical and social scale than potentially for other crops. The reliance on wild staples in the form of wild/managed nuts/acorns then potentially allowed Yayoi rice agriculturalists to mitigate against fluctuating yields at a household level in the absence of alternative exchange networks through which crops were exchanged.

Data availability statement

The datasets presented in this study and the computer code used for analyses can be found in: https://doi.org/10.5281/zenodo.7154422 and https://github.com/ercrema/Stevens_etal_2022.

Author contributions

CS and EC: conceptualization, methodology, and writing—original draft. EC, CS, and SS: writing—review and editing. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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