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The onset, dispersal and crop preferences of early agriculture in the Japanese archipelago as derived from seed impressions in pottery

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ABSTRACT

This paper summarises the results of 225 studies of seed impressions in pottery assemblages from 182 archaeological sites across Kyushu, Shikoku and Honshu islands covering the Late/Final Jomon–Middle Yayoi period (ca. 2000–1 BCE). Focussing on rice, foxtail millet and broomcorn millet impressions, this archaeobotanical dataset was used to reconstruct when and where these crops arrived from the Eurasian mainland on these islands, how they dispersed and whether there were changes in crop preferences over time. While it is generally accepted that crop cultivation started during the Initial Yayoi period (ca. 800/700–500/400 BCE) in northern Kyushu, a limited number of seed impressions in Tottaimon phase 1 pottery suggests that rice and millet were present at different sites on Kyushu and in the Chugoku region even before this period. The earliest impression records also corroborate the hypothesis that rice arrived along with both millet crops, which for a long time have not been considered in research on early agriculture. The earliest crop records from eastern Japan (here Central Highlands to northern Honshu) come from early Fusenmon pottery, which was mainly used in the Central Highlands (central Honshu) and some adjacent areas, dating to the End of Final Jomon period (concurrent with the Initial Yayoi period in northern Kyushu). While the records from western Japan (here Kyushu to Kinki region) associated with Tottaimon pottery suggest mixed rice/millet cultivation during the Initial Yayoi and early part of the Early Yayoi (ca. 800/700–300 BCE) period, Fusenmon groups appear to have preferred millet. In western Japan, related to the spread of Ongagawa pottery, rice became the dominant crop during the late Early Yayoi period. This shift happened later (i.e., during the Middle Yayoi period; ca. 300–1 BCE) in eastern Japan. This 'delay' is manifested in impression records from the Tokai region representing a transitional area between eastern and western Japan. Rice-centred agriculture begun with the arrival of Ongagawa pottery on the Nobi Plain during the Early Yayoi period. In regions east of the plain settled by Jokonmon pottery groups a more rice-oriented agriculture is not evident before the Middle Yayoi period. An exceptional development is indicated for northern Tohoku (northernmost Honshu). Impression records from Sunazawa pottery suggest that local groups adopted only rice during the Early Yayoi period. The rice preference apparently continued into the Middle Yayoi period, but crop cultivation was abandoned by the beginning of the Late Yayoi period.

1. Introduction

When and how agriculture spread from its early centres of origin is one of the major themes in the study of human history (Bellwood, 2005; Anthony, 2007; Fuller et al., 2009; Merrill et al., 2009; Frachetti et al., 2010; Jones et al., 2011; Bocquet-Appel et al., 2012; Spengler et al., 2016; Leipe et al., 2019). Discussions about the onset and spread of an agricultural lifestyle have been ongoing also in Japan since Yamanouchi (1925) discovered the first evidence of rice in form of seed impressions in prehistoric pottery about 100 years ago. Embedded between the long Jomon (ca. 14,000–10th/4th century BCE) and the Kofun (ca. 250–700 CE) periods, the Yayoi period is regarded as the phase during which agriculture was established across most parts of the Japanese archipelago (Kaner and Yano, 2015; Shitara, 2019). Until the 1990s Japanese scholars controversially discussed whether the start of agriculture dominated by the East Asian domesticates rice (*Oryza sativa* L.), foxtail millet (*Setaria italica* (L.) Beauv.) and broomcorn millet (*Panicum miliaceum* L.) dates back to the Jomon period. The main focus was on rice

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cultivation, which was believed to have been the foundation for the establishment of the first ancient state (see discussions in Amino, 1980 and Ando, 2014). Nasu and Momohara (2016) have reviewed earliest evidence for the beginning of cereal cultivation and concluded that the start of agriculture, which most likely happened in northern Kyushu, does not date to the Late Jomon period (ca. 2000–1300/1200 BCE) but to the end of the Final Jomon period, equivalent to the Initial Yayoi period (ca. 800/700–500/400 BCE) exclusively assigned to northern Kyushu. As indirectly suggested by their paper, early agriculture of the Yayoi period was mainly based on the cultivation of rice, foxtail millet and broomcorn millet. In addition, it has been argued that rice cultivation had spread widely and rapidly across western Japan (stretching from Kyushu Island to the Kinki region; Fig. 1B) but was considerably delayed in eastern Japan (Fujio, 2013). Following an earlier hypothesis by Kondo (1962), Nasu and Momohara (2016) speculated that the reason why agriculture spread slower throughout eastern Japan was the broad subsistence strategy of the local Jomon culture populations in response to the richer natural food resources. This is in agreement with Koyama (1978), who suggested that the temperate deciduous forest zone in eastern Japan, which is environmentally more diverse and produces more wild food resources, promoted higher Jomon population numbers and cultural diversity.

In Japan different lines of evidence have been used to reconstruct prehistoric farming, including records of fossil cereal-type pollen and plant opal (phytoliths), remains of paddy fields, specific farming tools (e.g., reaping knifes and hoes) and macrobotanical assemblages based on flotation and impressions in pottery (Nakayama, 2010). Flotation-based archaeobotanical studies have been conducted relatively rarely, thus one of the main sources of evidence available today are records of seed impressions in pottery. While ages of carbonised plant macroremains can be easily obtained by radiocarbon (^{14}C) dating, reliable direct ^{14}C dating of pottery is difficult (Berstan et al., 2008) and records of seed impressions are chronologically mostly tied to the typology assigned to the analysed pottery. The advantage of this is that impression records can be directly placed into the respective chronological framework without further dating efforts. Another benefit of the method in terms of chronology is that the botanical assemblages are not affected by redeposition, which is a common problem in the flotation-based approach (Pearsall, 2015). On the other hand, absolute counts in impression records are normally lower than in macrobotanical records and thus might be regarded as less statistically significant.

Until the beginning of the 1990s the analysis of pot sherds for botanical impressions in Japan was mainly based on naked-eye observations in combination with stereo microscopes or magnifying glasses. The methodological study by Ushino and Tagawa (1991) was a substantial innovation and dramatically changed the analytical opportunities in the field. The method is based on the preparation of silicon casts of the impressions combined with observation using scanning electron microscopy (SEM). This greatly increased the detailedness of the analysed impressions, and thus identification accuracy. With the increased application of this method during the last 30 years, many reliable records of seed impressions became available and substantially contributed to our understanding of early agriculture in Japan and how it dispersed across the archipelago.

This paper presents an up-to-date representative compilation of records of seed impressions in pottery from Late/Final Jomon and Initial–Middle Yayoi cultural context obtained by the refined analytical approach introduced by Ushino and Tagawa (1991). The dataset contains existing and unpublished impression records from archaeological sites in different regions of Kyushu, Shikoku and Honshu islands (Fig. 1). In addition, we outline the regional pottery typologies associated with the presented records and present their temporal framework based on available ^{14}C dates. The results of the seed impression studies are used to discuss the onset of agriculture in Japan, the spread across the study region and preferences in crop cultivation on a spatio-temporal scale.

2. Study of seed impressions in pottery and casting-based approach

According to Hjelmquist (1955), the Danish archaeologist Georg F.L. Sarauw was the first who started to systematically study plant impressions in Danish archaeological pottery collections around the beginning of the 20th century. Since then, this method has been widely applied in Europe and other parts of the world to study prehistoric plant use. In Japan Sugao Yamanouchi pioneered in the study of plant impressions in ancient pottery, which he used to infer the start of rice cultivation (Yamanouchi, 1925). In comparison to the study of charred botanical macroremains, the method has several pros and cons. Compared to charred macroremains, impressions in pottery reflect the state of fresh, uncharred remains and thus tend to exhibit more undisturbed

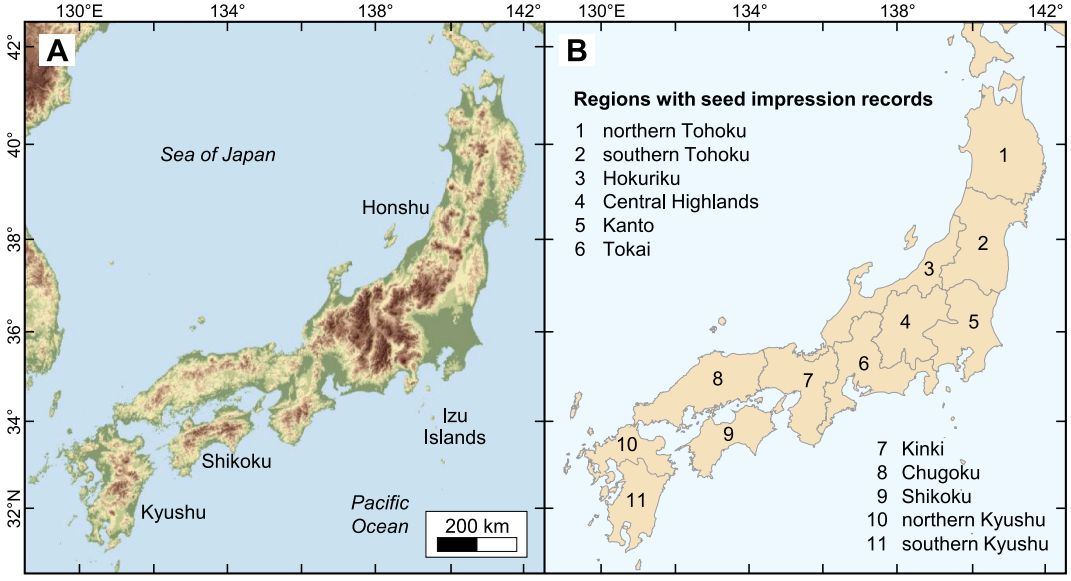

Fig. 1. Overview maps showing (A) the topography of Kyushu, Shikoku and Honshu islands and (B) the location of the eleven regions based on which the compiled seed impression records (Supplementary Table S1) were spatially summarised. Topography is based on the GMTED2010 dataset (Danielson and Gesch, 2011).

morphological details. In addition, seed impression records, and thus information on plant utilisation, can be directly linked with pottery typologies. This allows to directly place such archaeobotanical records into a cultural context. Since pottery is among the most often found archaeological materials from Neolithic contexts in East Asia, the large amounts of archived pottery from archaeological excavations represent a huge stock for non-destructive archaeobotanical investigations on plant use and the development and spread of arable agriculture based on plant impressions.

On the other hand, there is still a lack of understanding how seed impression records are best interpreted in terms of plant use and how suitable they are to infer the economic importance of crops (Fuller et al., 2014; Endo, in press). Previous studies have shown that records of pottery impressions and macroremains from the same archaeological context may not be comparable and that taxa in impression records may be overrepresented, while others are underrepresented or missing (Fuller et al., 2014). This has been mainly explained by a seasonal production of pottery, which leads to an overrepresentation of crops that are harvested during the pottery production season and an underrepresentation or absence of crops harvested outside the production period (Fuller et al., 2014). However, it seems unlikely that all impression records are affected by this condition. The relationship between pottery

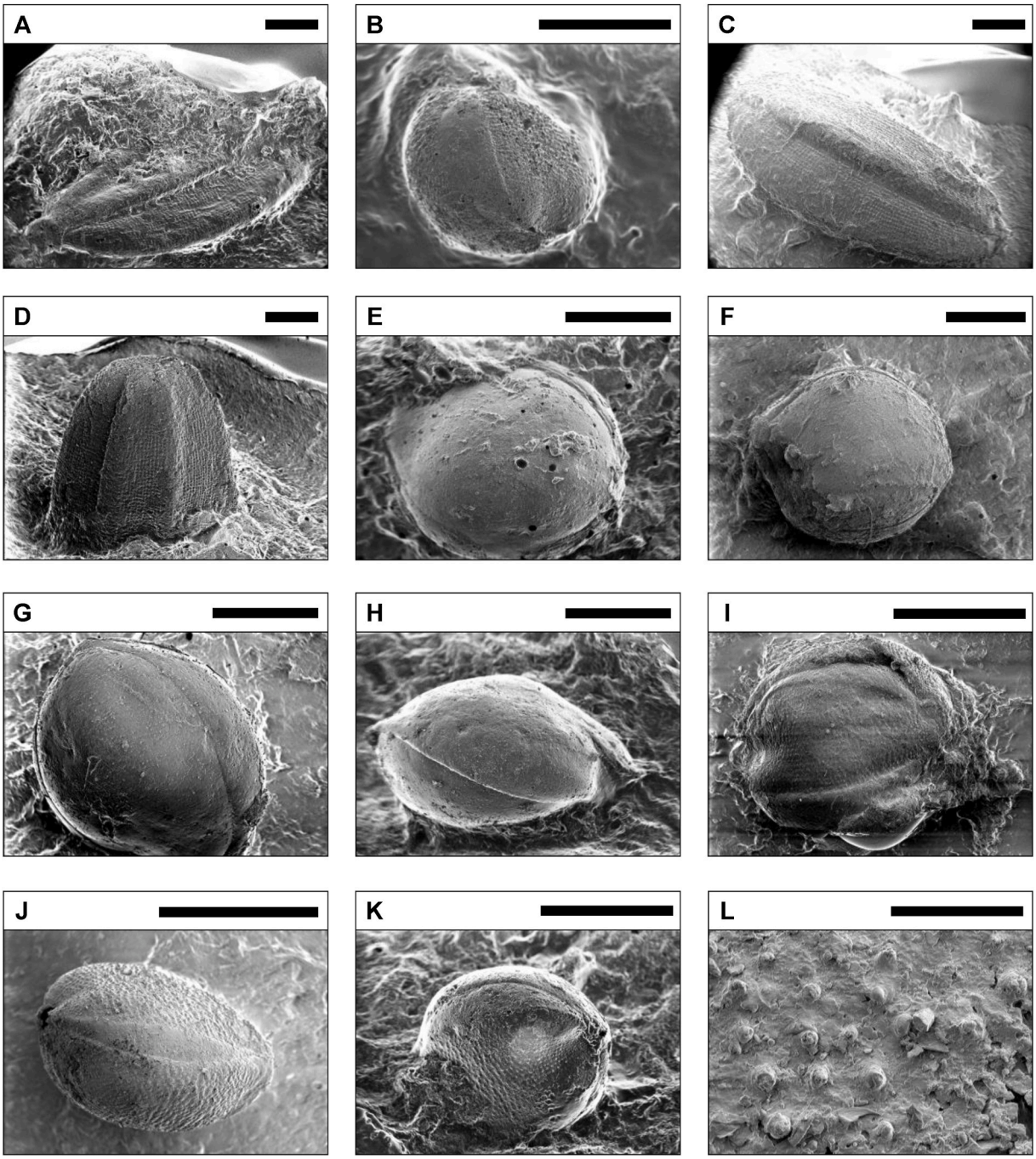

Fig. 2. Photo plate illustrating representative SEM images of silicon casts of plant remain impressions in prehistoric pottery from Japan obtained by the method described in Hisa and Katada (2005), including seeds of (A) – *Oryza sativa*, (B) – *Setaria italica*, (C) – *Oryza sativa*, (D) – *Oryza sativa*, (E) – *Panicum miliaceum*, (F) – *Panicum miliaceum*, (G) – *Panicum miliaceum*, (H) – *Panicum miliaceum*, (I) – *Setaria italica*, (J) – *Setaria italica*, (K) – *Setaria italica* and (L) – papillae of upper lemma of *Setaria italica* seed; scale bars = 1 mm, except (L) where scale bar = 100 μm.

production and activities around crop harvesting, processing, storage and consumption is rather divers depending on different factors, such as social organisation, available natural food resources and climate conditions, which should be taken into account when interpreting seed impression records. In order to gain information about the time and place of impression formation, the taxonomic spectrum and type of plants remains should be also considered.

Three decades ago, a new method to analyse seed impressions in pottery was introduced by Ushino and Tagawa (1991), which was later further improved by Hisa and Katada (2005) to reduce work time and to allow processing larger quantities of pot sherds. Casts are made from impressions by means of silicone and are then analysed using SEM. Thanks to the high-resolution transcription of soft clay and the SEM technology, morphological details of the original plant remains are well preserved and can be observed even at ×500 magnification or higher (Fig. 2). The application of SEM to investigate silicon casts of plant impressions facilitates inspection not only of the shape and size of whole imprints but also their surface morphological features and therefore allows for secure identification of the original objects (Grikpedis, 2019).

While this method has been proven a solid means for studying seed impressions in pottery, a new approach based on microCT scanning has been introduced and successfully applied to address different research questions (Barron et al., 2017, 2020). This technique is capable to provide high-resolution images of botanical impressions and even inclusions within pot sherds at low time investment and is thus a promising tool for future studies.

3. Pottery typology

In Japan, archaeological pottery has been systematically studied for the last ca. 150 years and, as a result, a complex pottery typology/chronology has been established (Morimoto and Kobayashi, 1938–1939, Kobayashi and Ogawa, 1989). However, there is ongoing debate among scholars regarding the periodisation, chronology and relationships among the different potteries. Especially for the pottery types linked to the transition from the Jomon to the Yayoi period (i.e., from a complex hunter-fisher-gatherer to an agricultural lifestyle) the number of available ^{14}C dates is still small. An additional problem for dating the Jomon/Yayoi cultural transition is the plateau in the calibration curve between ca. 700 and 400 BCE (Reimer et al., 2020). Therefore, it is not yet possible to assign a robust absolute chronology to the pottery types and cultural periods (Fig. 3), which was used to subdivide the current archaeobotanical dataset.

The earliest evidence for the use of cereals in Japan is related to the appearance of Tottaimon pottery in northern Kyushu Island and in the Chugoku region (Fig. 1B) during the Final Jomon period. To summarise the different types, in this article the Tottaimon complex was organised into five phases (Fig. 3). Similarities of Tottaimon pottery in shape and production technique with Mumun culture plain pottery suggest influence from the Korean Peninsula (Hudson, 1999 and references therein; Hyungwon, 2014). Impressions of cereals (rice/millet), identified as the oldest in Japan, appear on Tottaimon phase 1 pottery (Fig. 3) from archaeological sites in northern Kyushu and the Chugoku region. However, there is yet no reliable chronology for the appearance of Tottaimon pottery, nor for the oldest cereal impressions. Regarding the chronology of the later Tottaimon types (phases 2–5) used in this study, we refer to Miyaji (2009) and Miyamoto (2018). The ages of the Yusu I (Tottaimon phase 2) and Yusu II (Tottaimon phase 3) types are based on ^{14}C dates of four samples of carbonised rice and carbon residue attached to pot sherds recovered from the Uki-kunden archaeological site on the Karatsu Plain in northern Kyushu (Miyamoto, 2018). Based on the calibrated ages of these dates, Miyamoto (2018) estimated the age range of Yusu I to the 9th–8th century BCE and Yusu II to the 7th–6th century BCE. The pottery typology of the Chugoku region (Fig. 1B) refers to Hamada (2019). The chronology of Ongagawa and Jokonmon types from the Tokai region (Fig. 1B) is given according to Ishiguro (2011). Chronological information in Nakazawa and Matsumoto (2012) was used for Fusenmon type pottery, which, for simplicity, was subdivided

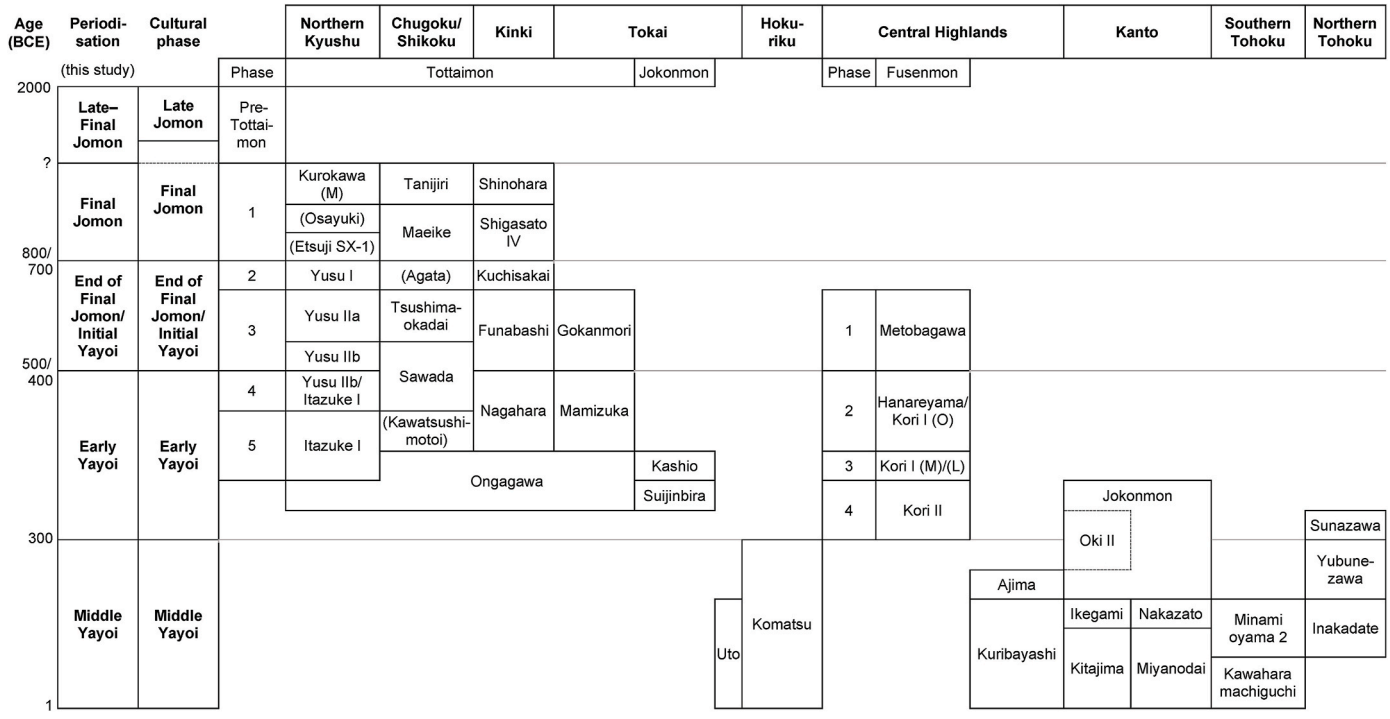

Fig. 3. Overview of the pottery by region from which seed impression records are contained in the compiled dataset (Supplementary Table S1) and their chronological relationship. Absolute chronology is based on Miyamoto (2018). The question mark indicates that no reliable age is available for the beginning of Tottaimon phase 1 during the Final Jomon period. For simplicity, Tottaimon and Fusenmon pottery is summarised into phases. The periodisation used to group the seed impression dataset (Fig. 4) is shown in the column on the left. Native spelling (Kanji and Hiragana) of the pottery types is provided in Supplementary Table S2.

into phases 1–4 in this study (Fig. 3). The relative chronological relationship of the pottery types from nine different regions (Fig. 3) was adopted from Shitara (2008). Regarding the Yayoi periodisation, the Initial Yayoi subdivision is limited to northern Kyushu in the current study (Mizoguchi, 2013). This subdivision was added to the existing chronology in the 1970s in response to the discovery of paddy fields dating to the Yusu period at the Itazuke site (Sahara, 1983). Consequently, sites outside northern Kyushu where cereal remains but no typical features of rice cultivation (e.g., paddy fields, irrigation systems) were found are not assigned to the Initial Yayoi period.

4. Seed impression data and methods

The compiled dataset contains 225 pottery assemblages, which were analysed for seed impressions, including 222 collected from available publications and three unpublished study results (Supplementary Table S1). To maximise the reliability of the compiled dataset, only impression records based on silicon replicas and identification using SEM are included. Records based on investigation by naked eye or aided by a magnifying glass tend to be less reliable and are excluded. Where possible, identifications were verified using the descriptions and photographs provided in the original publications. Particular attention was paid to the identity of spatiotemporally isolated impressions. Ambiguous identifications are outlined in the Discussion section. The analysed assemblages come from 182 different archaeological sites from eleven regions (Fig. 1B) on Kyushu, Shikoku and Honshu islands (Fig. 1A). Although in recent years archaeobotanical records based on replica methods for seed impressions have been also conducted on Hokkaido and the Ryukyu Islands, which reflect the unique nature of early agriculture in both regions, they are not subject of the current paper. For discussing spatial differences in the compiled impression data, we refer to the defined eleven regions (Fig. 1B) and to 'western' and 'eastern' Japan. The extent of the latter two regions is not formally defined in terms of the distribution of archaeological cultures. Although cultural differences have been identified during the Yayoi periods, no sharp boundary between both regions can be specified due to overlaps in the cultural records from Tokai and south-western Hokuriku. In this study western Japan, which is often regarded as the Yayoi cultural core zone (Barnes, 2015; Mizoguchi, 2013), refers to Kyushu, Chugoku, Shikoku and Kinki and eastern Japan to the Central Highlands, Kanto, north-eastern Hokuriku and northern and southern Tohoku.

Since impression data from the Late Yayoi period (ca. 1–250 CE) is still scarce, it is not considered in this study. A similar situation exists regarding the Middle Yayoi period (ca. 300–1 BCE) in the regions of western Japan and the Early–Middle Yayoi period in Kyushu. From these contexts only few impression records are available (Supplementary Table S1) and thus were not consider for analysis. This study exclusively focuses on recorded impressions of rice, broomcorn millet and foxtail millet. Although a few barley (*Hordeum vulgare* L.) and wheat (*Triticum aestivum* L.) impressions have been associated with the End of Final Jomon–Yayoi period, the typological identity of the pot sherds remains ambiguous (see section 6.3. for further discussion) and were therefore excluded from analysis. In 23 analysed assemblages, no impressions of cereal remains were detected. Each record is assigned to one or more pottery types (Fig. 3).

For visual inspection and numerical analysis of the spatio-temporal distribution of the impression records, the dataset was classified into five cultural periods; Late–Final Jomon (pre-Tottaimon pottery), Final Jomon (Tottaimon phase 1), End of Final Jomon/Initial Yayoi (Tottaimon phases 2, 3 and Fusenmon phase 1), Early Yayoi (Tottaimon phases 4 and 5, Ongagawa pottery and Fusenmon phases 2–4) and Middle Yayoi (Fig. 3). To account for records with typologies that cover more than one of these periods, we defined two additional categories; Initial–Early Yayoi and Early–Middle Yayoi. If no pottery type was attributed to an analysed pottery assemblage in the original publication, the cultural period (e.g., Early Yayoi) assigned to the assemblage was used to place it into the chronological classification. Accepted age ranges for the defined periods were adopted from Miyamoto (2018) (Fig. 3). An exception is the Late–Final Jomon/Final Jomon boundary for which no age was assigned due to ongoing debate concerning the representativity of the available ^{14}C dates related to this context.

To infer trends in cereal preferences, the impression records were grouped into three different categories; records with only rice seed impressions, with only broomcorn and/or foxtail millet impressions and records that have impressions of rice and of one or both millets. In addition to this cereal ubiquity measure, frequencies for each of the three cereals were calculated from their absolute counts for selected pottery types, regions and periods. Only securely identified cereal impressions were considered for analysis. Records that only report the presence or absence of impressions ($n = 3$) were not considered in the calculation of cereal frequencies. Omitted from both analyses were also five records (nos. 62, 69–72 in Supplementary Table S1) from pottery that was assigned only to 'Tottaimon', as these records may represent the defined Final Jomon, End of Final Jomon/Initial Yayoi and Early Yayoi periods (Fig. 3). In addition, 19 impression records from pottery assemblages that fall into two different periods (Initial–Early Yayoi and Early–Middle Yayoi) were visualised but not considered for analysis.

For discussion, some published ^{14}C dates have been used and converted to calendar ages. For calibration of the dates, we used the OxCal v4.4 software (Bronk Ramsey, 1995) and the calibration curve IntCal20 (Reimer et al., 2020).

5. Results

The results of the analysis of seed impression from 220 pottery assemblages were grouped into seven periods for spatio-temporal investigation (Fig. 4). In pottery assemblages securely identified as pre-Tottaimon types dating to the Late–Final Jomon period ($n = 15$) no rice, broomcorn millet or foxtail millet impressions were found (Fig. 4A). Although millet impressions were found in Late–Final Jomon pot sherds from the Central Highlands and southern Kyushu, their typological identify remains controversial. In two pottery assemblages assigned to Tottaimon phase 1 type from the late Final Jomon period in northern Kyushu millet seed impressions were detected (Fig. 4B). Another study on Tottaimon phase 1 type pottery from Chugoku revealed one rice grain impression. In three other analysed Tottaimon phase 1 pot sherd assemblages from Kyushu and Shikoku no impressions were found (Fig. 4B).

Twenty-two pottery assemblages from Kyushu, Shikoku, Chugoku, Kinki, Tokai and the Central Highlands dating to the End of Final Jomon/Initial Yayoi period revealed cereal impressions (Fig. 4C). Eight, ten and three records have impressions of only rice, only millet or both cereals, respectively. One record did not reveal impressions of cereals. There are eight pottery assemblages from Chugoku and Shikoku, which either date to the Initial or Early Yayoi period (Fig. 4D). The highest number of impression records ($n = 85$) is available from Early Yayoi assemblages (Fig. 4E). There are two records from Kyushu. The regions Shikoku, Chugoku and Kinki are dominated by records with both rice and millet ($n = 13$) and only rice ($n = 11$). Five records show only millet impressions. A contrary distribution is obtained for the datasets from Hokuriku, the Central Highlands and Kanto ($n = 36$), where 27 records list only millet and three only rice impressions. In the northernmost region (northern Tohoku) all five available records contain only rice grains. Four studies did not reveal any cereal impression in the investigated materials.

A total of 13 records cannot be unambiguously assigned to either the Early or Middle Yayoi period (Fig. 4F) and are not considered for interpretation. Of the 69 records assigned to the Middle Yayoi period (Fig. 4G), three are located in western Japan, three in Tokai, one in western Hokuriku and 62 in regions of eastern Japan. Most records in eastern Japan are located in the Central Highlands ($n = 22$) and Kanto ($n = 21$), followed by northern ($n = 11$) and southern ($n = 8$) Tohoku. In

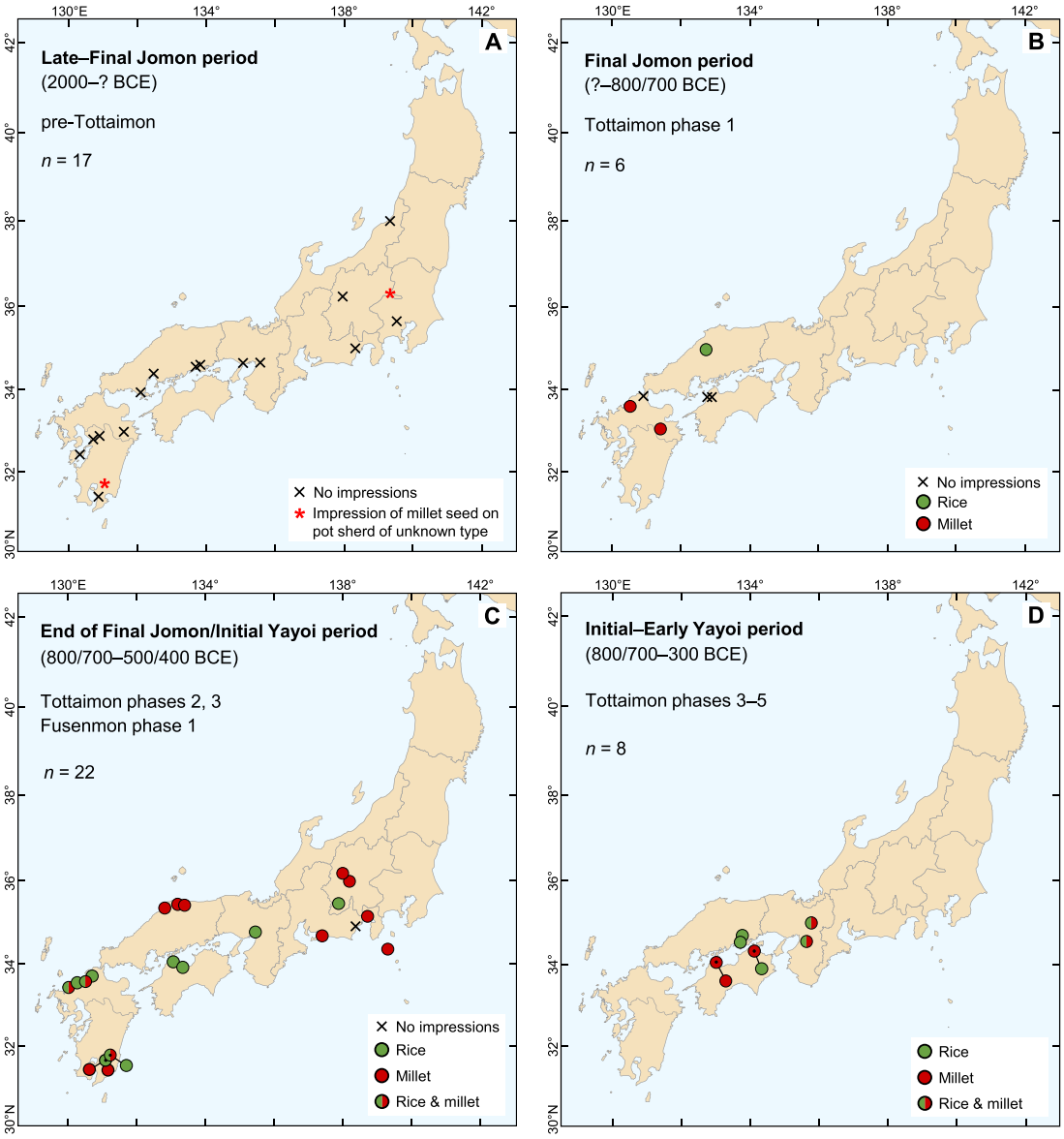

Fig. 4. Map compilation illustrating the spatial distribution of the compiled seed impression records (Supplementary Table S1) with identified cereals organised by cultural period or pottery typology (see Fig. 3 and Material and methods section for details) including (A) the Late–Final Jomon period (i.e., the pre-Tottaimon pottery period), (B) the Final Jomon period (i.e., the Tottaimon pottery phase 1), (C) the End of Final Jomon/Initial Yayoi period, (D) the Initial–Early Yayoi period, (E) the Early Yayoi period, (F) the Early–Middle Yayoi period and (G) the Middle Yayoi period. Subfigures (D) and (F) show impression records from pottery that represent more than one cultural period. Absolute age ranges, representative pottery types and absolute numbers (*n*) of shown records are given for each period. The question mark indicates that no reliable age is available for the beginning of Tottaimon phase 1 (Final Jomon period). Since only few, non-representative numbers of impression records are available from Early Yayoi pottery from Kyushu Island and Middle Yayoi pottery from the western regions of Kyushu, Shikoku, Chugoku and Kinki, these regions are highlighted in white in the respective maps. For illustration purposes, all records per time period that would otherwise overlap are placed next to their location and connected by black lines. The black dots mark the actual location of the shifted symbols (records).

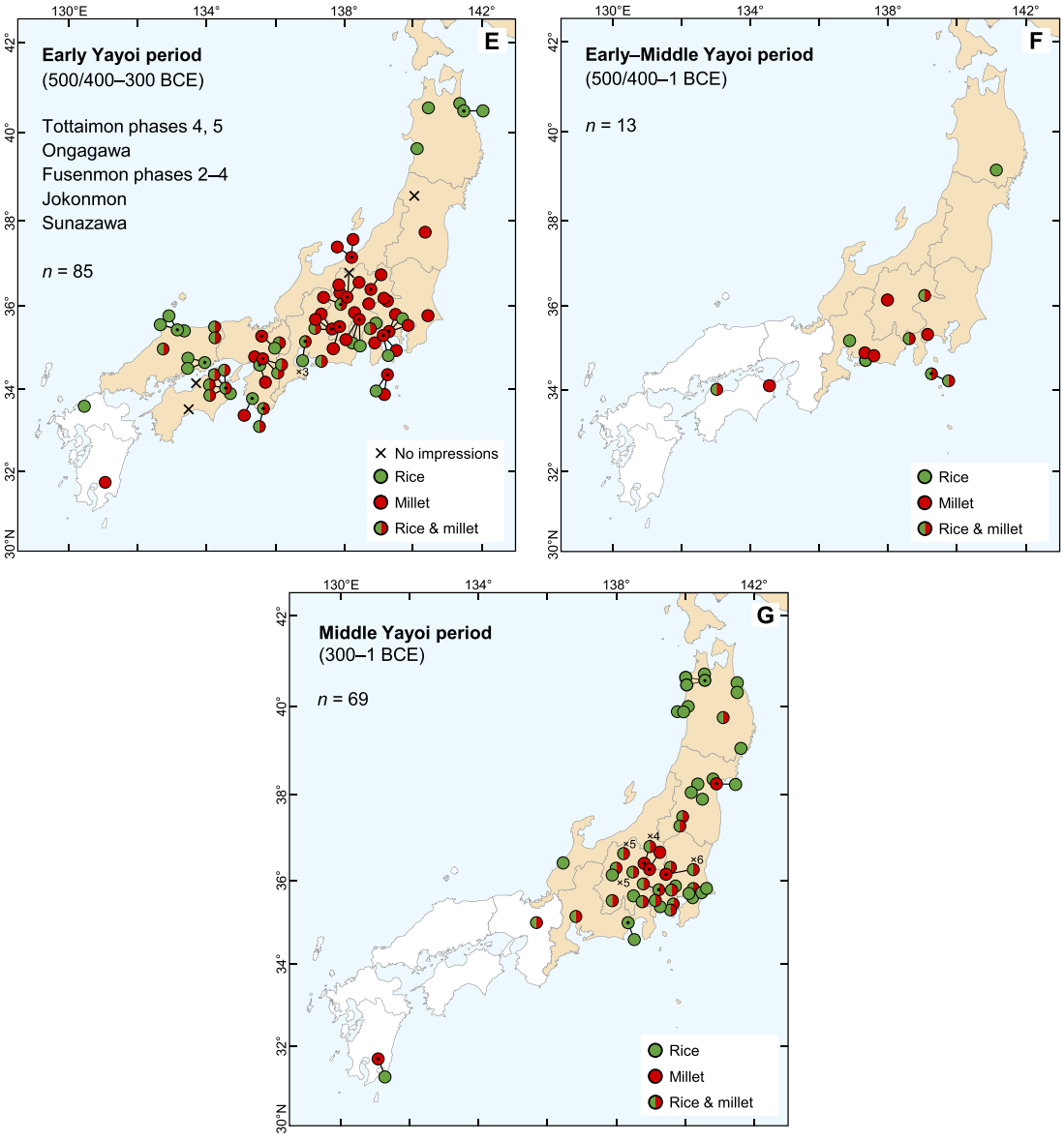

Fig. 4. (*continued*).

most records from the Central Highlands ($n = 17$) millet appears together with rice. Records with only rice or millet account for two and three, respectively. A similar distribution is documented for Kanto; 14 records contain millet and rice, six only rice and one only millet. By contrast, the northern and southern Tohoku data show a different picture. In southern Tohoku most ($n = 5$) of the nine records contain only rice impressions. In northern Tohoku this trend is even more distinct with ten out of eleven records containing only rice.

To identify differences in cereal distribution between the pottery types represented in the compiled dataset, percentages for each cereal (rice, broomcorn millet, foxtail millet) were calculated based on the sum of absolute counts per pottery type (Fig. 5). This was supplemented by the cereals' ubiquities for rice, millets and rice and millets in impression records per pottery type (Fig. 5). The same measures were calculated for impression records from Tokai, Hokuriku, the Central Highlands, Kanto and northern and southern Tohoku assigned to the Early and Middle Yayoi periods (Fig. 6) for discussion of trends in cereal choice in eastern Japan.

6. Interpretation and discussion

6.1. The arrival of rice and millet to the Japanese archipelago

In the past, the beginning of agriculture was dated to the Late Jomon period based on rice impressions (Hirai and Watabe, 1995; Takahashi, 1992) and charred millet and rice macroremains (D'Andrea et al., 1995). As for the impression data, not only the typology of the analysed pottery but also the identity of the impressions have been questioned in recent studies (Nakazawa, 2009). Directly ^{14}C-dated charred remains of rice, broomcorn millet and foxtail millet from deposits of a Late Jomon pithouse at the Kazahari site in northern Tohoku have long been regarded as some of the oldest evidence for the cultivation of these crops in northern Japan (D'Andrea et al., 1995). However, additional dating of the seed assemblage revealed a much younger date (TERRA-578#10, 173 ± 35 ^{14}C BP) (Takase, 2011), suggesting contamination of the initially obtained dates. No impressions of rice, broomcorn millet or foxtail millet have been reported from pottery pre-dating the Late Jomon period (Nakayama, 2014; Obata, 2016). Impressions of these cereals are also absent from records dating to the Late–Final Jomon period (pre-Tottaimon phase) (Fig. 4A). One broomcorn millet impression reported from the Chiamigaito site at the northern end of the Kanto Plain and one foxtail millet impression from the Hoshihara site in southern Kyushu are associated with pot sherds that cannot be unequivocally dated to the Late–Final Jomon period.

According to the generally accepted definition, the beginning of agriculture corresponds with the beginning of the Yayoi period (Sahara, 1975). Many archaeologists have suggested that agriculture spread from the southern part of the Korean Peninsula to northern Kyushu during the Initial Yayoi period based on remains of paddy rice fields and ^{14}C-dated carbonised rice grains (e.g., Shitara, 2000; Ishikawa, 2010; Miyamoto, 2018). In response to new, earlier evidence for the existence of cereals or cereal cultivation from northern Kyushu, the Initial Yayoi subdivision was added to the classic Yayoi periodisation after the discovery of paddy fields dating to the Yusu period at the Itazuke site (Sahara, 1983). To date, the Initial Yayoi period is limited to northern Kyushu and the contemporaneous interval in the remaining parts of Japan is associated with the late Final Jomon period. However, the earliest securely identified impressions of rice and millet come from Tottaimon phase 1 type pottery (Fig. 4B), which is believed to pre-date the Initial Yayoi period (Fig. 3). This includes one rice grain impression from the Itaya III site in Chugoku (Nakazawa and Ushino, 2009), located about 200 km northeast of northern Kyushu, and respectively one foxtail millet grain from the Etsuji (Nakazawa, 2015) and Ishiiiriguchi (Obata, 2016) sites in northern Kyushu. The currently available seed impression records confirm the hypothesis by Nakazawa (2009) that cereals did not appear in Japan before the advent of Tottaimon pottery during the second half of the Final Jomon period. At the same time, the data suggest that the cereals existed in Japan already before the Initial Yayoi period, which is associated with Tottaimon phase 2 and 3 type pottery (Fig. 3), as proposed by Nakazawa (2017). However, the few available impression data from Tottaimon phase 1 type pottery call for additional investigations. In addition, future studies should also aim to provide an absolute chronology for Tottaimon phase 1 pottery. Nevertheless, it would not be appropriate to include Tottaimon phase 1 to the Initial Yayoi period based exclusively on the existence of cereals. The Initial Yayoi period is a subdivision that was added to the Yayoi period due to the discovery of paddy fields, irrigation systems and moats at the Itazuke settlement site. None of these features have been identified at Tottaimon phase 1 sites at which cereal remains were found.

6.2. The spread of rice and millet across the Japanese archipelago

The impression dataset indicates that rice and millet spread eastwards across western Japan and to Tokai and the Central Highlands during the End of the Final Jomon/Initial Yayoi period (Fig. 4C). Research on early agriculture was for a long time dominated by a focus on rice and rice cultivation, which was believed to be one of the main drivers of early state formation. More recently, this view has begun to change under the influence of new seed impression records, which indicate that both rice and millet were cultivated since the beginning of agricultural practices. A key archaeological site in the discussion about the arrival of agriculture has been Nabatake located in northern Kyushu. Flotation carried out on deposits of a cultural layer dated to the Yusu I pottery phase (Tottaimon phase 2; Fig. 3) in 1980/81 (Karatsu City Board of Education, 1982) revealed 78 charred rice spikelets (Kasahara, 1982). A single grain of foxtail millet was also recovered, although Ando (2009) pointed out the possibility that the grain is not related to the rice spikelets because it was recovered from an intruded layer. The first evidence that the earliest rice appeared together with millet came from an impression study on Yusu I pot sherds from Nabatake (Endo, 2015). This study revealed that both rice and foxtail millet were present at the site. More recently, the findings of Obata (2018), who found impressions of rice and foxtail and broomcorn millet in Yusu I pottery from the Hashimoto-Ichoda archaeological site in northern Kyushu, confirmed this initial evidence. In addition, combined presence of rice and millet was also confirmed at the Kurotsuchi site in southern Kyushu, but the pottery was assigned to Tottaimon phase 2/3 (Nakamura et al., 2013). However, the remaining six impression records, which date to Tottaimon phase 2 and are located in northern and southern Kyushu, Shikoku and Kinki, contain only rice. More records with millet from sites in western Japan (Santatani I, Nishikawatsu, Aoki, Kaminakadan and Onishi) are reported from the following Tottaimon phase 3.

Based on pottery typology and a set of directly dated charred rice grains from the Uki-kunden site in northern Kyushu, Miyamoto (2018) suggested that cereal cultivation spread across western Japan during 800/700–500/400 BCE. This long-distance spread was probably not gradual and influenced by environmental and/or cultural factors. Since almost all of the early cereal impressions are from Tottaimon pottery, it seems likely that this spread was carried by populations of the Tottaimon pottery group.

Apart from western Japan, cereal impressions dated to the End of Final Jomon/Initial Yayoi period have been also reported from archaeological sites in eastern Japan. These impressions are found in Fusenmon pottery, which was mainly distributed in the Central Highlands from the end of the Final Jomon to the Early Yayoi period but is also found at sites in Tokai, Hokuriku, Kanto and southern Tohoku. This comparatively early appearance of cereals in the core domain of the Fusenmon pottery is supported by ^{14}C dating of charred rice grains from the Chikaraishijori site in the Central Highlands (Nagano Prefecture Buried Cultural Heritage Center, 2011). Disregarding the oldest date (IAAA-83092, 2889 ± 29 ^{14}C BP) of a rice grain from this site, whose identity cannot be definitely verified, the second oldest, securely

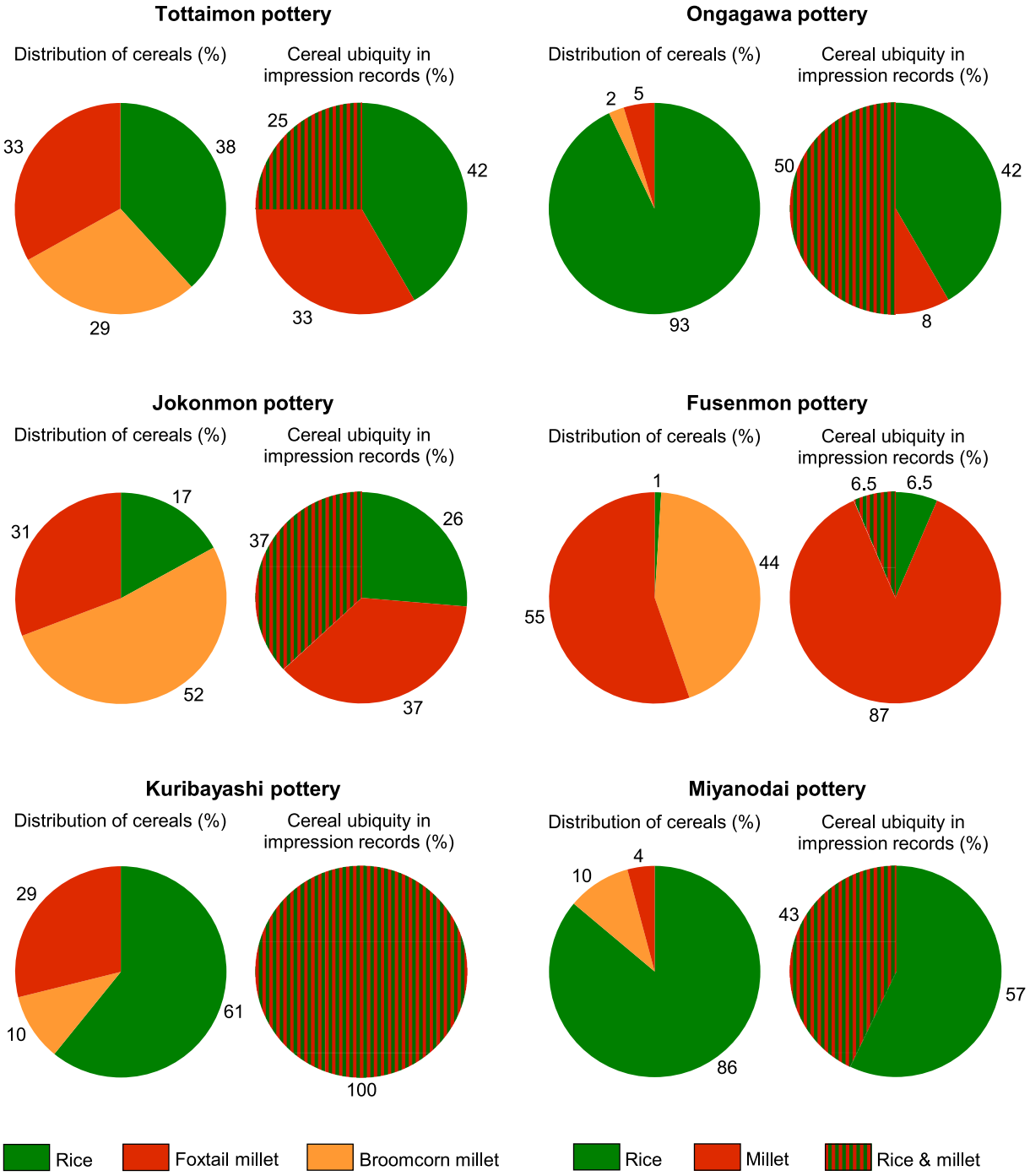

Fig. 5. Chart compilation showing the percentage distribution of cereal seed (rice, foxtail and broomcorn millet) impressions (left pane) and the percentage distribution of records, which contain either only rice or millet or both rice and millet impressions (right pane) for six pottery types from different regions. Numbers show the percentage values for each category.

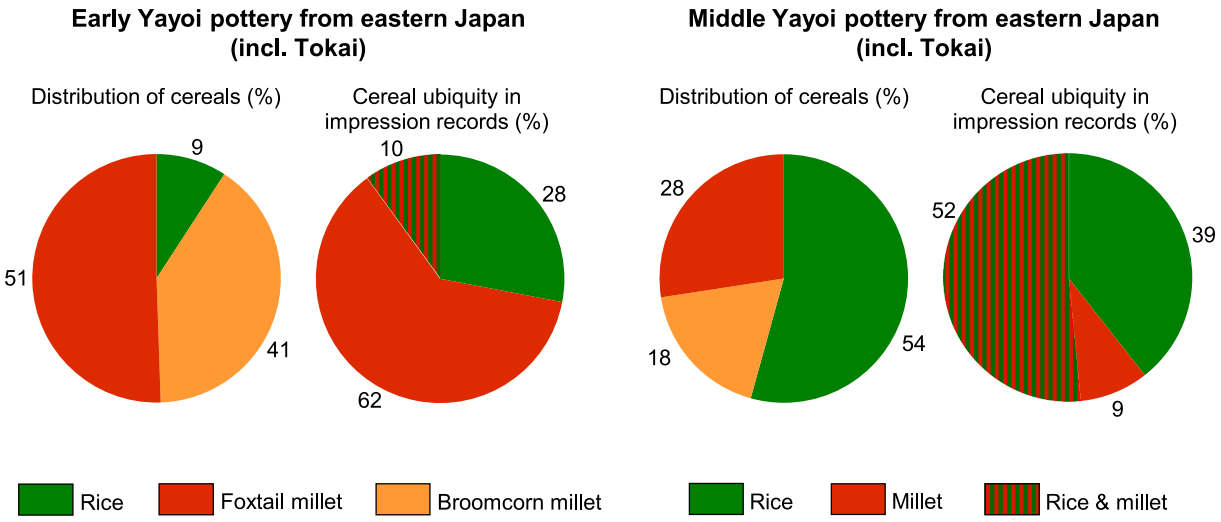

Fig. 6. Chart compilation showing the percentage distribution of cereal seed (rice, foxtail and broomcorn millet) impressions (left pane) and the percentage distribution of records that contain either only rice or millet or both rice and millet impressions (right pane) for the Early and Middle Yayoi periods in the regions Tokai, Hokuriku, Central Highlands, Kanto and northern and southern Tohoku. Numbers show the percentage values for each category.

identified specimen (IAAA-83082, 2494 ± 29 ^{14}C BP) demonstrates that the crop has appeared at Chikaraishijori at around 760–550 BCE (68.3% confidence interval of calibrated age) (Leipe et al., 2020b).

Of four Fusenmon phase 1 pottery assemblages from different archaeological sites in the Central Highlands and Tokai (including the Izu Islands; Fig. 1A) three contain exclusively millet and one only rice. However, it is still unclear whether the latter assemblage with the single rice impression from the Ishigyo site in the south-western part of the Central Highlands represents Fusenmon or Tottaimon pottery (Nakazawa, 2012; Endo and Takase, 2011). Another controversial issue that has been discussed is whether these cereal records indicate the start of agriculture in each area. For example, regarding the find from Niijima Island (Izu Islands) in eastern Tokai, Sugiyama (2014) discussed the possibility that the analysed pottery was obtained by exchange and cereals were not cultivated by local groups.

The dataset suggests that cereals spread further northeastwards arriving in southern and northern Tohoku during the early Yayoi period (Fig. 4E). Rice had already arrived at the Sunazawa site on the Tsugaru Plain, the northernmost part of Honshu Island, during the 5th–4th centuries BCE (Sasaki et al., 2018), and paddy rice fields have also been detected at this site. Another four records from different archaeological sites in northern Tohoku are also associated with Sunazawa type pottery and exclusively contain impressions of rice grains. On the other hand, few data are available from the relatively large region of southern Tohoku. In one out of two analysed pottery assemblages one foxtail millet seed impression was identified. This is surprising as one would expect that cereals were transmitted to northern Tohoku via southern Tohoku. Based on pottery typological analyses Sahara (1986) hypothesised several decades ago that most of southern Tohoku was bypassed by the spread of cereals. He found that pottery similar to Ongagawa pottery, which was also recorded at early rice farming site in northern Tohoku, is distributed only at sites along the Sea of Japan coast. He concluded that cereals must have arrived to northern Tohoku via this narrow route. In terms of crop preferences, the current dataset is in agreement with Sahara's hypothesis. Like at the sites of the Ongagawa pottery communities in western Japan, there was a clear focus on rice cultivation in northern Tohoku.

In sum, the dataset indicates that rice, millet or rice together with millet spread from the western part of western Japan across Honshu Island up to the northern Tohoku region between the Tottaimon phase 1 and the Early Yayoi period.

6.3. Crop preferences

As suggested by recent seed impression studies at the Nabatake (Endo, 2015) and Hashimoto-Ichoda (Obata, 2018) sites, rice, broomcorn millet and foxtail millet arrived to Japan as a package at the latest during the Initial Yayoi period (800/700–500/400 BCE), but likely earlier. This is supported by records of rice and millet impressions in Tottaimon phase 1 pottery. The arrival of these three cereals as a package seems plausible, since they were also cultivated on the Korean Peninsula (Son et al., 2010; Nakayama, 2014) during the Early Bronze age (1300–800 BCE), which has been identified as the origin of the crops and the immigrants who introduced agriculture to Japan (Miyamoto, 2019). However, there are obvious differences between the cereal impression records representing the different pottery types distributed across different regions and periods (Fig. 5). In Tottaimon pottery distributed across western Japan, the three crops are equally represented regarding the total number of impressions and cereal ubiquities. On the other hand, in Fusenmon pottery, more or less coincident with Tottaimon pottery, there is a pronounced dominance of foxtail and broomcorn millet with only a share of rice of 1%, which is corroborated by the ubiquity of millet assemblages of 87%. This suggests that only, or at least mostly, millet was selected by groups in the Central Highlands and some adjacent regions of Kanto. The mountainous environment less suitable for rice cultivation in paddy fields appears to be the main reason for this choice. An additional reason may have been the complex subsistence of the regional Jomon hunter-gatherer communities, which consisted of a plant cultivation and management component. A long tradition of cultivation of plants, such as azuki (*Vigna angularis* Willd.), soy bean (*Glycine max* L.) and perilla (*Perilla frutescens* L.) as well as management of chestnut and acorn has been identified in previous archaeobotanical studies (Noshiro and Sasaki, 2014). Since these Jomon groups were already familiar with plant cultivation and management, they were likely more open to adopt new crops (Nasu and Momohara, 2016). The preference of millet may have been likely due to their experience with other dry field crops (i.e., azuki and soy bean). By contrast, paddy field rice cultivation requires more labour and a higher degree of labour organisation, for example for building, operating and maintaining irrigation facilities, and thus requires substantial changes in societal organisation (Endo, 2016; Leipe et al., 2021).

It is widely accepted that the Yayoi is a hybrid culture that evolved from the admixture of indigenous Jomon with immigrants from the Asian mainland (Shitara, 2000; Mizoguchi, 2013). Evidence for this is

found in human genomics (e.g., Watanabe et al., 2019) and the record of Yayoi cultural objects (e.g., Hudson, 1999), including pottery. Fusenmon pottery from Early Yayoi sites in western Japan with evidence for rice-focused cropping systems (e.g., Karasumazaki in Kinki) demonstrate that indigenous groups were connected with the newcomers via communication and exchange. It seems that Jomon people in eastern Japan did not ignore the newly arrived agricultural lifestyle and crops, but rather were interested in them. This not only applies to Fusenmon pottery communities but also to groups settling in Tohoku. Pottery assemblages document communication between northern Tohoku Jomon and populations in northern Kyushu, which were already more agriculture-oriented (Shitara, 2014a). This is documented by Kamegaoka pottery associated with Tohoku Jomon groups found at sites in northern Kyushu with some of the earliest evidence of paddy field rice cultivation (Shitara, 2014a). Despite this evidence that Kamegaoka groups must have known about the agricultural practices in northern Kyushu, there is, however, no evidence that they adopted crop cultivation. This did not happen, as Shitara (2014a) suggests, until 200 years later (ca. 5th century BCE) when Sunazawa pottery groups started rice cultivation (see section 6.2. for details). Regarding the Jomon people in the Central Highlands, we assume that they actively obtained sufficient information about the new crop cultivation system and have for strategic reasons adopted only millet, as it better fitted their traditional subsistence economy. Shitara (2014b) evaluated the early agricultural groups in the Central Highlands and the Kanto region, which focused on millet cultivation, as a culture that maintained elements of the Jomon culture and created an 'alternative agricultural system'.

While the currently available archaeological evidence shows that millet cultivation was adopted relatively early in the Central Highlands, as reflected by seed impressions in Fusenmon pottery, the spread of cereals further northeastwards appears to have been interrupted. Although the Fusenmon type pottery domain reached into southern Tohoku, no evidence for the use of the newcomer crops has been found in this region. The currently northernmost site with evidence for millet cultivation dating to the early Early Yayoi period is Izumi A in northeastern Hokuriku (Nakazawa, 2017) (Fig. 4E). An investigation at the Odaira-goseki site in the central part of southern Tohoku has revealed one impression of foxtail millet, although the pottery typology is less precise and the analysed material may only date back to the Early Yayoi period. Clear evidence for cereal cultivation is available from pottery assemblages dating to the Middle Yayoi period (Fig. 4G). The data suggests that millet adoption was limited to the Central Highlands and that Fusenmon groups settling in regions further northeast did not adopt these crops during the Initial–Early Yayoi period. Additional archaeobotanical studies will help to verify this comparatively late shift to agriculture in southern Tohoku.

Worth to note is that also barley and wheat are regarded as part of the Yayoi crop package in different previous works (Kanaseki and Sahara, 1976; Crawford, 2011; Kaner and Yano, 2015). It seems plausible that both West Asian domesticates arrived as part of the crop package introduced from the Korean Peninsula. It has been suggested that on the Korean Peninsula wheat arrived during the Early Mumun (i.e., Early Bronze Age) period (ca. 1500/1300–850 BCE) (Ahn, 2010; Kim, 2013) or the Middle Mumun period (ca. 850–550 BCE) (Crawford and Lee, 2003), and charred wheat, rice and broomcorn and foxtail millet often appear as a package in archaeobotanical assemblages from cultural layers of many sites that were dated to the Bronze Age (Shoda, 2009; Shoda et al., 2021). The calibrated age (805–772 BCE) of the oldest published direct date of wheat (UCI67222, 2585 ± 20 ^{14}C BP) from the Pyeonggeodong site in the southern part of the Korean Peninsula shows that the crop was present in the region at least since the early Middle Mumun period (Lee, 2016). However, in Japan unambiguous evidence for the use barley or wheat during the Yayoi period is scarce and it is still contentious when the crops became part of the cropping system (Shoda et al., 2021). Among the few finds associated with the Yayoi period are charred barley and wheat grains from the Ishi-no-tsubo site in the Central Highlands (Yamanashi Prefecture), which have been recovered by a flotation study (Yoshikawa, 2000) and were discussed by Nakayama (2010). Three barley and one wheat grains were found across three pits that Yoshikawa (2000) typologically dated to the Middle Yayoi period. Based on the presence of Ongagawa type pottery, Nakayama (2010) associated one of these pits to the late Early Yayoi period. Ishi-no-tsubo is a multi-layer site covering the Early Jomon–modern age period and barley and wheat grains were also found in deposits/features typologically dated to the Heian (794–1185 CE) and Kamakura (1185–1333 CE) periods. Therefore, it cannot be excluded that the seeds assigned to the Yayoi period represent contamination. Another example is a barley impression in a pot sherd from a Final Jomon context at the Nakamichi site (Yamanashi Prefecture) (Nakayama, 2010). In this case too, it remains unclear whether this small sherd represents Fusenmon pottery or a later period (Nakayama, 2014). A directly dated charred wheat grain (PLD-11631, 1860 ± 20 ^{14}C BP) from the Karakami site located on Iki Island (Nagasaki Prefecture) in the Tsushima Strait about 20 km off the north-western coast of Kyushu Island listed in the online Rekihaku Database of Radiocarbon Dates (https://www.rekihaku.ac.jp) provides the most robust evidence for the use of this crop in the Japanese archipelago during the Yayoi period. Its calibrated age (131–222 CE, 95.4% confidence interval) falls into the second half of the Late Yayoi period and is in agreement with wheat dated to ca. 200–400 CE found at the Harunotsuji site located on the same island (Takamiya, 2004). The archaeological records of both sites demonstrate close connections of their inhabitants to the Korean Peninsula and China during the Early Yayoi–Early Kofun period (Nagasaki Prefectural Board of Education, 1995; Oksbjerg, 2007).

One possible explanation for the absence of barley and wheat impressions in Yayoi pottery is that pottery production was a seasonal activity (Fuller et al., 2014). In this case pottery was most likely produced around the harvest season of rice and millet in early autumn when conditions are more favourable (i.e., less wet) for pottery production. The winter crops barley and wheat, on the other hand, would have been sown in autumn and harvested in late spring/early summer, a season that is much wetter and thus less suitable for pottery production. However, whether pottery production during the Yayoi period was a seasonal activity, which coincided or overlapped with the rice and millet harvesting season, remains unclear. The recorded crop remains suggest that they were incorporated into the pottery mainly outside the rice and millet harvest season. Impressions of spikelets are rarely found. On the other hand, impressions of chaff are commonly found, which is an indicator for dehusking as final crop processing for food preparation. This links the impression records, at least partly, to 'daily' activities, rather than a specific season. Insect remains provide additional evidence that impression records also represent stored economic plants. Imprints of weevils, well-known as grain pests, are part of the Yayoi period impression records (Obata, 2016) and show that seeds of crops became at least partly incorporated into pottery after storage. Impressions of pest insects have been also related to the storage of acorn or chestnut during the Jomon period (Obata et al., 2020). In addition to pest impressions, the number of wild plant remains in the compiled records is very low, which not only indicates that the impressions partly represent stored economic plants but also suggests that part of the pottery production was conducted indoor. Therefore, it seems unlikely that pottery production during the Yayoi period was exclusively a seasonal endeavour, which would explain the absence of barley and wheat in the existing impression records. Instead, together with missing unequivocal evidence from macroremain records, this suggests that both crops were not part of the arable agriculture at least until the end of the Middle Yayoi period.

An alternative scenario is that barley and wheat were known, but not adopted by farmers during the Initial–Middle Yayoi period. Mizoguchi (2019) argues that rice and millet were easier to adopt by non-agricultural populations because during the time slot between sowing in summer and harvesting in autumn people were less occupied

with food procurement. By contrast, barley and wheat would have fit less well into the well-structured spatio-temporal organisation of food procurement and processing, including collection of wild plant food and hunting. Possibly barley and wheat became incorporated into the crop package after agriculture became more consolidated and intensive and the importance of wild food resources further declined, perhaps during the Late Yayoi–Kofun period. For this period few secure archaeobotanical records are yet available, but existing evidence shows that wheat was widely cultivated by the 7th century CE (Shoda et al., 2021). It is the task of future research to uncover the spread of barley and wheat across Kyushu, Shikoku and Honshu before they reached Hokkaido via this southern route likely during the Satsumon period (7th–13th century CE) (Crawford et al., 2011; Leipe et al., 2017; Lister et al., 2018).

6.4. The Tokai region: buffer zone or nodal point?

Tokai is regarded as a transitional region, which divides the elongated Japanese archipelago into an eastern and western part in terms of the distribution of the Yayoi culture populations. Thus, it is an important area for studying the diffusion of agriculture. According to the seed impression data, cereal crops arrived in the central part of the Tokai region along with Tottaimon type pottery (phase 3; Fig. 3) from western Japan at the end of the Final Jomon period (Fig. 4C). However, unequivocal evidence for this is limited to a single foxtail millet impression. It seems that the arrival of millet (and perhaps also rice) was carried by the spread of people related to the Tottaimon pottery tradition. Given the available pottery records, this eastward spread did not go beyond central Tokai. Only a limited number of Tottaimon pot sherds, probably indicating exchange, is documented from sites located further east.

The appearance of Ongagawa pottery in central Tokai during the Early Yayoi period (Fig. 3) marks a second phase of influence from western Japan. This phase is marked by a shift towards agricultural practices more focused on rice cultivation, as indicated by the two available seed impression records of Ongagawa pottery (Supplementary Table S1). The record from the Nishishiga site (Nagoya City) contains 15 rice impressions and one of broomcorn millet. At the Asahi site (Nagoya City) all ten impressions belong to rice. Thus, it was hypothesised that rice-focused agriculture arrived with Ongagawa type pottery to this area (Endo and Takase, 2012). Similar to the earlier spread of the Tottaimon pottery, the Ongagawa pottery, and thus rice-centred agriculture, did not spread further east than to central Tokai during the Early Yayoi period. This limitation in the eastward spread of rice-centred agriculture was explained by the stance of Jomon communities from eastern Japan regions, which did not have a motivation to adopt the more labour-intensive paddy field rice cultivation, similar to Fusenmon people in the Central Highlands. However, the easternmost regions of the Ongagawa pottery overlap with the domain of Jokonmon pottery communities. Since Jokonmon pottery is associated with communities of Jomon descent, this suggests interaction between the two cultural groups. An example for this interaction is the Nishishiga site, from where both pottery types have been reported. In addition, the impression dataset suggests that rice was newly added to the crop package at sites that are represented by Jokonmon pottery, including the Onishi, Gokanmori (both Toyohashi City) and Shibusawa (Fujinomiya City) sites (Supplementary Table S1). On the other hand, records that exclusively contain rice are only available from two Middle Yayoi sites (Uto and Harazoe, both Shizuoka City) in the eastern part of Tokai. It appears that rice-focused agriculture spread continuously across western Japan, but the spread temporarily stagnated in the Tokai region due to the existence of Jokonmon populations. This phenomenon is probably due to a higher number of Jomon populations in eastern Japan in response to a higher diversity and availability of wild food resources in the region's productive temperate deciduous forest environments (Kondo, 1962; Koyama, 1978; Leipe et al., 2020b). To describe the temporary stagnation in the spread of agriculture, the term 'Jomon Wall' was coined (Kobayashi, 2007). By contrast, Shitara (2000) has a more nuanced view on the agricultural system of Jokonmon groups and calls it an agriculture of 'Jomon descent', as it appears to have been less focused on rice cultivation. An alternative explanation for the discontinuous spread of more rice-focused cropping practices is that it was not related to more numerous and affluent Jomon populations in eastern Japan, but to cultural factors (e.g., social transformations and internal conflict) within the groups that carried this cropping system eastwards.

The sum of available evidence suggests that from the second half of the Early Yayoi period Tokai was a nodal point and a hub for the spread of agriculture towards the east. This spread can be divided into two main flows; a mixed rice-millet agriculture spread to the Central Highlands and further on to northern Kanto and a rice-focused agriculture spread along the Pacific coast to southern Kanto (Fig. 4E).

6.5. Development of cereal cultivation from the Early to Middle Yayoi period

Examination of the development of cereal cultivation over different cultural periods is limited by the uneven spatio-temporal distribution of the available impression records (Fig. 4). The available records from the End of Final Jomon/Initial Yayoi period are relatively few (Fig. 4C), which limits identification of changes towards the Early Yayoi period (Fig. 4E) for which much more data is available. In addition, comparison of the data from the Early Yayoi with that of the Middle Yayoi (Fig. 4G) period from western Japan is hampered, due to the very few records available for the latter period. A comparison seems only reasonable between the Early and Middle Yayoi periods in eastern Japan and Tokai from where more data, respectively 52 and 66 impression records, are available. Percentage comparison reveals substantial differences between both periods (Fig. 6). While in Early Yayoi period records millet (91%) clearly dominates over rice (9%), rice (54.5%) slightly exceeds the frequencies of millet (45.5%) during the Middle Yayoi period. This shift from a millet-dominated agriculture towards rice cultivation is also reflected by the cereals' ubiquities. In the records from the Early Yayoi period 62% contain only millet impressions and 28% only rice. In the Middle Yayoi period records with exclusively millet account for only 9%, while the remaining ones contain either only rice or both rice and millet. This suggests that more communities, which before mainly relied on millet cultivation, incorporated rice into their cropping systems during the Middle Yayoi period, showing that rice became generally more important. However, millet continued to be an important part of Middle Yayoi agriculture. The charts for this period (Fig. 6) suggest that mixed millet-rice cultivation was practiced at most sites. With 51% in Early Yayoi records and 27% in Middle Yayoi records foxtail millet slightly dominate over broomcorn millet, which respectively accounts for 41% and 18.5%. This suggests that foxtail millet was preferred over broomcorn millet. However, even if this general preference existed, it is difficult to estimate the ratio of both crops in terms of caloric return rates.

This shows that the shift towards rice in eastern Japan happened later than in western Japan, where the crop probably already dominated during the Early Yayoi period, as indicated by the sum of impressions in Ongagawa pottery (Fig. 5). About 93% of all Ongagawa impressions account for rice. The data organised by pottery types (Fig. 5) also indicate that the preference for millet was even more pronounced in the Fusenmon than in the Jokonmon domain, with only 1% and 17% of all cereal impressions accounting for rice, respectively. Spatial differences in cereal distributions in eastern Japan are also indicated during the Middle Yayoi period. The shift towards rice cultivation was more pronounced in Miyanodai pottery communities (Fig. 5), which occupied mainly southern Kanto, compared to Kuribayashi pottery communities, which mainly settled in the Central Highlands and at sites in northern Kanto, where the proportion of documented Kuribayashi type pottery makes up the highest share (Ishikawa and Matsuda, 2014). Fujio (2013) argued that Kanto was the region on Honshu Island where rice

cultivation began the latest (i.e., during the Middle Yayoi period). On the other hand, the arrival of millet at the eastern end of Kanto (Hanawadai site) during the early Early Yayoi period (around 400 BCE) is suggested by a single foxtail millet grain impression (Fig. 2K) in a Fusenmon phase 2 pot sherd. However, it is possible that this pottery was brought to the site from the Central Highlands, reflecting regional exchange.

In addition, at the Nakayashiki site, located in south-western Kanto dating to the late Early to early Middle Yayoi period, not only 21 broomcorn millet and 15 foxtail millet impressions were identified (Sasaki et al., 2010) but also large numbers of charred seeds of rice and both millet crops have been recovered (Nakayashiki Site Excavation Project Team, 2008; 2010). The oldest directly dated (2395 ± 30 ^{14}C BP) cereal grain (rice) has a calibrated age of 510–400 BCE (68.3% confidence interval) (Yamamoto and Koizumi, 2005), which unambiguously proves the Early Yayoi age of these cereal records. It can be said that this Early Yayoi record of mixed rice-millet agricultural practices has changed the image of the Yayoi period in the Kanto region.

While the impression dataset reveals changes in crop preference in the southern parts of eastern Japan, this is not the case at the northern end of this region. The records from sites in northern Tohoku dating to the Early Yayoi period (Fig. 4E) exclusively contain rice. This is also the case for the eleven records dating to the Middle Yayoi period with only one exception at the Yubunezawa site in central northern Tohoku where one rice impression is accompanied by one foxtail and one broomcorn millet impression. This suggests that a preference for rice cultivation has persisted during the Early and Middle Yayoi periods in northern Tohoku. However, the early rice-oriented agriculture in northern Tohoku did not persist and the subsistence returned to mainly hunting and gathering linked with the development of the Zoku-Jomon culture (continuation of the Jomon culture). Therefore, Takase (2004) called the early phase of agriculture in northern Tohoku an 'experiment of Yayoization'.

7. Conclusions

The compiled dataset of seed impressions from different cultural periods and regions in Kyushu, Shikoku and Honshu islands provides detailed insights into the arrival and spread of rice, foxtail and broomcorn millet in Japan and the development of early agricultural practices during the Final Jomon–Middle Yayoi period. The data show that rice and millet had arrived on northern Kyushu Island by the Initial Yayoi period, which paralleled the end of the Final Jomon period on the other islands. This period has been dated to 900–800 BCE and is regarded as the time during which crop cultivation started in Japan. However, there is evidence that cereals appeared before this period. There are a few rice and millet impressions in Tottaimon phase 1 pottery from sites in northern Kyushu and Chugoku, which predates the Initial Yayoi period (associated with Tottaimon phases 2 and 3 pottery). Further archaeobotanical studies are needed to verify these few data.

There is sufficient evidence to argue that the three newcomer crops arrived as a package most probably from the Korean Peninsula. Although also barley and wheat appear to have been part of the crop repertoire of Mumun farmers on the Korean Peninsula by the time arable agriculture spread to Japan, no reliable evidence that the crops were part of the new cereal package exists from impression and charred macroremain records. While archaeobotanical records show that both crops were part of the cropping system by the end of the Kofun period, it is the task of future investigations to uncover when they arrived to and spread across the Kyushu, Shikoku and Honshu islands.

After their arrival in northern Kyushu, the crops spread eastwards along with Tottaimon pottery until the central Tokai region by the end of the Initial Yayoi period. There is also evidence for the arrival of crops during the Initial Yayoi period in the Central Highlands, but it seems that only millet was adopted by groups that probably mainly consisted of indigenous Jomon populations. In a second spread, rice-centred agriculture dispersed across the western part of the archipelago until central Tokai accompanied by Ongagawa type pottery during the Early Yayoi period. It then continued to spread along the Pacific coast and apparently arrived in southern Kanto by the middle Middle Yayoi period. The rice-centred agriculture in Hokuriku is also suggested to have appeared during the Middle Yayoi period. Influenced by the millet-centred agriculture in the Central Highlands, a mixed rice-millet cultivation system spread to northern Kanto during the Middle Yayoi period. There are clear indications that agricultural practices focused on rice appeared in northern Tohoku during the Early Yayoi period. People who made pottery similar to Ongagawa pottery might have been involved in this appearance of rice cultivation. Thus, our dataset supports the connection between the rice cultivation in northern Tohoku and the rice-oriented agriculture of Ongagawa communities in western Japan.

Except northern Tohoku, where rice cultivation started during the Early Yayoi period and probably ceased by the Late Yayoi period, cereal cultivation spread across Kyushu, Shikoku and Honshu islands during the Yayoi period and continued during the following cultural periods. With some time lags in eastern Japan the spread was not entirely continuous throughout the archipelago. The impression data suggest that the island region was marked by a long-term shift in cereal cultivation with rice becoming generally more important by the Middle Yayoi period, except northern Tohoku where hunting, fishing and gathering appear to have revived by the end of the Middle Yayoi period.

Although Late Yayoi and Kofun archaeobotanical records are relatively few, they suggest that the importance of rice as a cultivar continued to increase during these periods (Ando, 2002; Kakinuma and Endo, 2021). On the other hand, it remains unclear whether this development reflects an increasing importance of rice as food for commoners. Alternatively, in response to increasing social stratification from the Yayoi to the Kofun period, the 'value' of rice may have (further) increased, so that it was preferably used for specific purposes and/or by groups of elevated social status (Leipe et al., 2020a). By the beginning of early state formation (end of 7th century CE), rice became an important tax value, which, in combination with the limited availability of land suitable for paddy rice cultivation, suggests that at this time rice was not the staple food for common people, but that their diet was mainly based on a variety of cereals, including wheat, barley and different millets available at this time.

Author contributions

Conceptualisation, E.E.; Material and data collection, E.E.; Methodology, E.E., C.L.; Analysis, E.E., C.L.; Writing (original draft), E.E.; Writing (review and editing), E.E., C.L.; Visualisation, E.E., C.L.

Data availability

All data needed to evaluate the conclusions in the paper are present in the paper and/or the Supplementary Data.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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