# What did Jomon people consume for starchy food? A review of the current studies on archaeological starch grains in Japan

SHIBUTANI Ayako[1]

*ABSTRACT*
*The use of starch residue analysis, an archaeobotanical tool, has become progressively more widespread across the world in the past few decades. Starch grains have been used to support key hypotheses regarding residue analysis as well as in the study of ancient plant utilization and diet. They are important sources of information in contexts where alternative plant remains are poorly preserved. This paper offers an overview of the methodology of starch residue analysis and will examine two key case studies in Japan. Common problems are discussed, and extra caution should be taken in the interpretation of results; notably, taphonomy should be given great consideration. Despite these issues, the technique is being applied more frequently to Japanese archaeological case studies, especially with the integration of other lines of archaeobotanical evidence. Starch residue analysis continues to be an evolving discipline, particularly in Japan, and like all relatively innovative approaches to reconstruct past plant food cultures, its issues will certainly be addressed over time.*

*KEYWORDS:* archaeobotany, grinding stone, Japan, Jomon pottery, plant food, starch grains

## 1. Introduction

Starch is a polymeric glucose carbohydrate (consisting of two glucose polymers), and starch grains, microscopic granules that are semi-crystalline and water-soluble, are developed by plants into energy storage organs in plants (Gott *et al.* 2006; Haslam 2004; Langejans 2006; Reitz & Shackley 2012). Size and frequency vary from plant to plant, but grain size is directly related to starch hydration (Gott *et al.* 2006). All starch grains preponderantly incorporate two polysaccharides: amylose and amylopectin. In addition, starch grains have an electric cell wall and are simple to break down (Gott *et al.* 2006; Hardy *et al.* 2009; Sivak & Preiss 1998).

The principal advantage of starch grains over alternative botanical remains is that their preservation is not affected by burning or getting wet (Gott *et al.* 2006). Mechanical action and high humidity damage starch granules (Barton 2007; Collins & Copeland

[1] *National Museum of Japanese History, 117 Jonai-cho, Sakura, Chiba 285–8502 Japan (shibutani@rekihaku.ac.jp)*
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2011; Copeland *et al.* 2009; Lamb & Loy 2005; Reitz & Shackley 2012; Saul *et al.* 2012; Torrence & Barton 2006; Weston 2009), but they have been found in numerous environments, ranging from extremely dry to wet and in soils and sediments with pH levels of moderate to extreme. Starch is found in (tropical and subtropical) sediments and on artefacts, in temperate and hot climates, and even in coprolites (Langejans 2010; Lentfer *et al.* 2002; Riley 2012; Shibutani 2009b; Torrence & Barton 2006). The analysis of ancient starch residue has developed among archaeological studies throughout the world (Barton & Torrence 2015). The past decade has witnessed a substantial increase in the use of starch residue analysis in archaeological science, and its methodological innovations have enhanced ways to reconstruct past human-environment interactions.

In Japan, Fujimoto's encyclopaedic work (Fujimoto 1994) and numerous botanical and glycoscience works have advanced starch studies. While studies in applied glycoscience have a long history in Japan, within the field of archaeology, Sahara (2000) and Matsui (2005) have primarily mentioned the benefits of starch residue analysis within the field of microbotanical analysis. The study of starch grain assemblages in an archaeological context has become more common as an archaeobotanical tool in the last decade (Matthews & Nishida 2006; Shibutani 2012a, 2012b, 2015). There has been emphasis placed on the utilization of starch grains to determine the functions of stone tools (e.g., Kamijo 2012; Kamijo 2013; Kobayashi & Kamijo 2012; Onishi *et al.* 2012; Sangawa *et al.* 2012; Shibutani 2009b 2011, 2012b, 2014; Shibutani *et al.* 2015; Sugiyama 2014) and wooden ethnographical tools (Kamijo 2014), the utilization of starch morphology as an indicator of plant food cooked in pottery (Shibutani 2007, 2014; Shoda *et al.* 2011), and past plant food consumption reconstructed by human dental calculus (Shimono & Takenaka 2014). In addition, in the current research project, 'Rice Farming and Chinese Civilization: Renovation of Integrated Studies of Rice-based Civilizations,' Japanese analysts conduct residue analyses of grinding stone tools, pottery vessels, and dental calculus from Neolithic sites in the Lower Yangtze River area of China to develop their Japanese studies.

This is often a result of morphological criteria that some researchers see as problematic, a lack of standardised strategies for the identification and quantification in numerous contexts, and a poor understanding of taphonomic processes dealing with starch morphology and assemblages (Shibutani 2012a, 2015). Conflicts with alternative lines of proof resembling macrobotanical remains are another concern (Shibutani 2015; Shoda *et al.* 2011), and in several cases, it appears as if there is no clear understanding of the issues (Shibutani 2015).

Despite these areas of concern, the technique is being more frequently applied to Japanese archaeological case studies. Starch grains extracted from archaeological artefacts show positive leads in terms of the utilization and consumption of bulbs and tubers, even

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though these macrobotanical remains are sometimes poorly preserved in archaeological contexts (Shibutani 2014). This review will indicate the results of two key case studies addressing these common issues in terms of distinction of ‘background noise’ (How can we find contaminated materials from residues?) and comparison of starch morphologies between different artefact types, such as grinding stones and pottery vessels (Can we define tool functions from starch assemblages?), and will provide suggestions for several ways to improve the analysis in future archaeological starch studies.

## 2. Methods of analysis, identification, and quantification in starch residue analysis

Starch residue analysis is split into two broad categories. The first category includes samples from specific archaeological artefacts that are comparable to residues of starchy tissues found on the tool surfaces and ‘food crusts’ adhering to pottery and dental calculus. The second category includes those extracted from bulk sediment and soil samples (Shibutani 2012a, 2015). Starchy plants have always been linked to humans, and in specific instances, the assemblage is often linked to an activity due to the associated discourse data. When small quantities are present, the complete assemblage is recorded, and counts are made on what could be thought of as a ‘representative’ proportion of the assemblage. There are no firm guidelines for quantification, and this varies from study to study, depending on the research goals.

Many studies, specifically Japanese starch studies, have primarily adopted the Fullagar technique (Fullagar 2006). Fullagar has designed a method and theoretical approach to examine starch grains on archaeological artefacts and within sediments. The techniques employed for collecting samples from archaeological sites could be similar to gathering pollen and phytoliths (Reitz & Shackley 2012). Regarding residues on stone artefacts, it is usually recommended that researchers use spot sampling to remove residue from both working and non-working surfaces to compare the quantitative incidence of starch grains. Materials are handled to limit contamination with modern starches, reconcile conservation against studies that will want untreated samples, and be cautious regarding each post-excavation improvement and neglect (Loy & Barton 2006; Shibutani 2009b; Shibutani *et al.* 2015).

A complimentary review of identification strategies in starch residue analysis is given by Coster and Field (2015), who determined that there has always been subjective judgement once the identification involves a distinctive sample of grains. The employment of automated image analysis is stressed by Wilson *et al.* (2010), who mentioned that quantitative variables are used to characterise the granules, and the assignments and probabilities are calculated objectively. Liu and her fellow researchers

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jointly stressed the importance of mixing morphological-size observations and a computer-based discriminant analysis (Liu *et al.* 2014). However, there are difficulties with these typological and morphometric approaches.

Typologically, similar starch types, such as circular or oval-shaped starch grains, occur in an extremely large selection of genera (Shibutani 2010a). Sometimes the diagnostic criteria are based mainly on visual comparisons, which can be susceptible to sound judgement or a small amount of variation between different analysts. This is not only a retardant in starch residue analysis but also in several other areas of systematic studies. Geometric morphometric approaches provide objective techniques for assessing starch form, but until 2017, there was no standardised technique for starch classification in archaeology. Some researchers still use their unique identification systems, generally for usual starch types. Biases created by insufficient count sizes are of major concern and should lead to errors in vegetation inference in palaeoecological studies.

Even though starch studies are conducted by a small number of specialists in Japan (Shibutani 2015), similar methodologies (Shibutani 2009a, 2010a) are used to classify starch morphotypes. All starch grains are divided into classes based on size and form before biological identification is attempted, and basing the starch typology on geometrical form and size makes it possible to analyse morphological variations in the starch assemblage. The qualitative comparison of archaeological starch with modern samples is also conducted. These geometric morphometric approaches supply an objective technique for assessing starch shape, and despite the necessity of a large population size, a degree of random variation should be assessed.

Among the previous studies undertaken in Japan, the main studies of Shibutani and Kamijo adopt similar methods (e.g., Yamamoto *et al.* 2016). All starch samples are essentially recovered from surfaces of archaeological and ethnographic artefacts (Shibutani 2015), and some assemblages are extracted from soil samples as well (Kamijo 2008; Soeda *et al.* 2017). Light microscopy is mainly employed to study starch under brightfield with cross-polarized light. The use of the SEM remains widely used in the food sciences for imaging starch grains and has advantages when using macroscopic food residues (Barton & Fullagar 2006). However, in many Japanese case studies, there are the small residue samples taken from artefacts and soils. Therefore, it is more difficult to use than light microscopy, and the selection of techniques largely depends on the questions asked and environmental conditions.

Typological descriptions of Kamijo and Shibutani are based on size and shape categories by the same measuring method, and the forms of starch extinction crosses and surface conditions are also observed (e.g., Yamamoto *et al.* 2016). Based on these methods, some archaeological starch grains are taxonomically identified to species level, and others are simply to genus level. This paper shows this standard technique in

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determining morphological characteristics (e.g., shape, size, extinction cross, and surface condition) and explores the prehistoric consumption of starchy food by examining the subsequent case studies.

## 3. Distinction of processed plants from contaminated materials in the archaeological context

Extensive data has been accumulated in recent years through the analysis of the starchy tissue residue found on stone artefacts. Starch residue analysis, combined with usewear analysis and alternative scientific residue studies, investigates the function of the stone tools collected. In Japan, starch grains extracted from stone tool assemblages within the Palaeolithic, Jomon, Yayoi, and Kofun periods have been examined (Shibutani 2012a, 2015), and the specific plant species of starch discovered indicates the use of nuts (*Juglans*, *Castanea*) and acorns (*Quercus*, *Lithocarpus*) along with tubers (*Pteridium*, *Pueraria*) and bulbs (Liliaceae) as prehistoric starchy food (Shibutani 2015).

One of the foremost prolific areas of starch analysis has been in the distinction of processed plants from contaminated materials within the archaeological context. Unlike alternative debates reminiscent of prehistoric exploitation of untamed plant resources and the domestication of edible plants, this subject is greatly stressed by Japanese starch analysts. The key argument lies in the morphological similarity between archaeological and modern starch grains. It had been initially mentioned by Loy and Barton (2006) that the post-excavation contaminants are divided into four categories: mobile contaminants within a laboratory, the water used for removing the samples, drinking and ingestion in storage facilities and laboratories, and pulverized gloves (usually vinyl or latex) used for treating artefacts. Supporting this point, refined diagnostic limits of laboratory contamination were delineated by Crowther *et al.* (2014). The presence of contaminated starches on consumables and within the laboratory setting opens the door for such starches to be misidentified as ancient if recovered incidentally throughout the laboratory process. In Japan, the previous survey about treatments of artefacts after excavations showed laboratory contamination is not problematic, because artefacts are washed with tap water, drinking and ingestion are basically prohibited in storage facilities and laboratories, and pulverized gloves are not used for treating artefacts (Shibutani 2009b). However, starches from soil layers at archaeological sites are more problematic.

At several sites, there is an abundance of starch on the surfaces of artefacts but not within the related sediments and soils (Barton *et al.* 1998). In many archaeological surveys, particularly in almost all Japanese excavations, soil samples are not always taken as a means of contamination management, and therefore, the comparison of archaeological and modern starches in those cases is typically vague due to lack of soil

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samples.

Experimental studies examine burial conditions and taphonomic processes of archaeological starches for effective contamination control (Barton 2009; Shibutani 2009b). According to these results, the buried artefacts lay at a shallow depth of 10–20 cm. in what was essentially a loosely packed and recently disturbed soil horizon. This soil depth may be biologically extremely active and contain primarily aerobic microorganisms, such as fungi (Barton 2009; Barton & Matthews 2006). However, Barton's experiment (Barton 2009) confirms that almost all of the starch grains in sediments do not move into deep cavities on the surface of artefacts. In Japanese archaeological surveys, excavated materials are washed clean with tap water to remove adhering soils (Shibutani 2009b), and contaminated residues could be lost during these cleanings. In addition, starch from the working surface of a stone tool is the direct evidence of processing plants (Shibutani 2012b).

These previous studies show that the comparison of starch residues on tools from different soil layers at the same excavation point enables to avoid the contaminated problems. In order to present this simple distinction technique, a case study at the Kitakogane Shell Mound in Hokkaido (Shibutani *et al.* 2015) shows starch residue analysis of grinding stone tools without soil samples.

In Hokkaido, Crawford (Crawford 1983, 1992, 1993; Crawford *et al.* 1976; Crawford & Takamiya, 1990) and D'Andrea (D'Andrea 1995a, 1995b; D'Andrea *et al.* 1995) primarily developed flotation techniques for use in Japanese archaeological surveys, and the amount of archaeobotanical data has been increasing (Takase 2011). There are also numerous reports of acorns and nuts, berries, tubers, burdock, and millet remains from many Jomon sites (e.g., Yamada 1986, 1993; Yamada & Shibauchi 1997; Yamada & Tsubakisaka 2009; Yoshizaki 1997). These macrobotanical remains confirmed the vegetation history in the Jomon period. According to Igarashi *et al.* (1993), in 8,000–10,000 years BP, larch forests remarkably increased in basins under cold climatic conditions, and from 10,000–12,000 years to the Younger Dryas BP, larch disappeared from Hokkaido. Birch-walnut forests flourished for about 8,000 years in the area along rivers of the central basin with increased precipitation.

The Kitakogane Shell Mound is on a tongue-shaped plateau that faces Funka Bay at the southernmost point of Date and was occupied from Early to Middle Jomon (about 5,000–3,500 BC). The site consists of five shell mounds, 14 graves, six pit dwellings, and a watering basin used for disposing stone tools, including grinding and hammer stones. It is an extremely important site to examine environmental changes and human adaptations to such changes, rituals at shell mounds and watering places, and the grave system of the time (Aono *et al.* 2013).

From Kitakogane, numerous faunal remains were found. Botanical remains were

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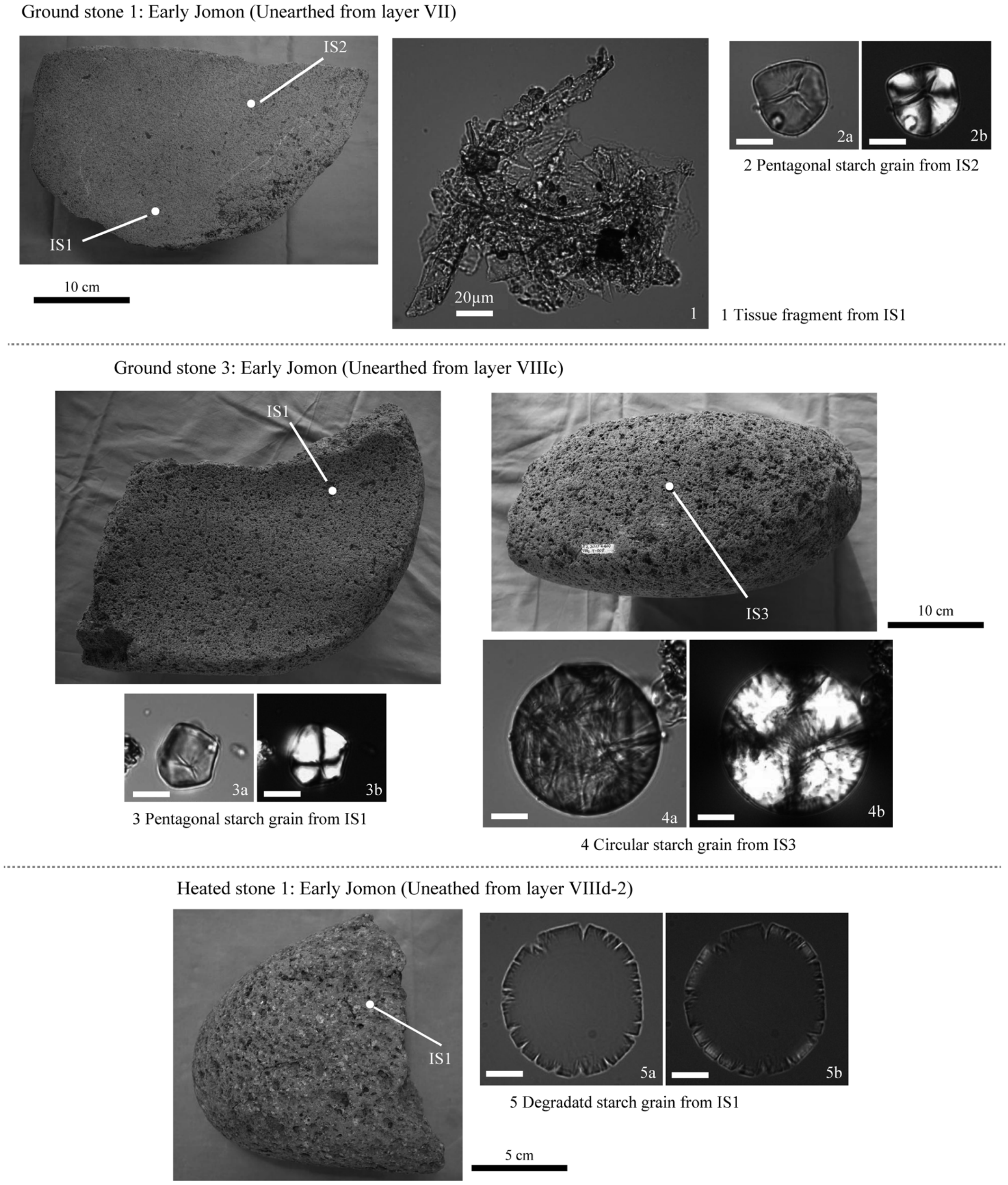


*Figure 1. Examples of sampled stone tools at the Kitakogane Shell Mound and starch grains considered as processed plants (Shibutani et al. 2015). White circle: sampling spot; Bar: 10 μm; Magnification: 1: ×200, 2–4: ×400; a: brightfield, b: brightfield with cross-polarised light.*

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seldom preserved despite the site having over 5,000 grinding stones, presumably used for processing plants. Some criteria, anticipating a 'high proportion' of specific variations between archaeological and modern starches, are not generally found in Japanese starch residue analyses. The concern was determining a technique to assess residues on grinding stones without sediment samples as an example of the presence of starch (Shibutani *et al.* 2015).

Residue analyses of 34 grinding stone tools (19 grinding stones, five querns, one hammer, five heated cobles, and four natural pebbles) were chosen to assess the consistency of starch morphological variations and discover if there have been variations depending on the preservation of sediment profiles. Residue samples were consistently obtained from objects recovered from ancient living surfaces from the higher layer to the lower layer. In total, 17 starch grains were recovered from eight tools, and their morphometric conditions were well-preserved with features that clearly defined the outline of a Maltese cross with few fractures.

Based on the distinction system, using soil layers and the working surfaces of stone tools, proof of processed plants was found through two intact starch grains located on the worn surfaces of two ground stones and one degraded starch on the surface of a heated pebble. Two ground stones were excavated from a depth of 50–60 cm and 70–80 cm from the ground surface, and starch grains were recovered from their usewear parts. Taxonomic identification was supported through 'one-on-one comparisons between ancient starches and modern reference collections' (Yang *et al.* 2013). These two starch grains can thus show plants processed by ground stones, and they are thought to be two walnut grains (*Juglans*).

Regarding heated stones, only this one contains a degraded starch, and residue samples of other stones and a natural pebble stone found from the same excavation spot did not contain any starch grains. It is not assumed that natural and modern contaminated starches attached in the burial process of this site. This starch may be evidence of a processed plant, even though it was an unidentified species.

The botanical identification and distinction of soil profiles resulted in 10 starch grains being extracted from natural pebbles, and non-used surfaces of sampled stones were presumed to be insignificant contaminated materials from sediments. These sampled stones were found from the current ground surface and disturbance soil layers, and these starch grains did not show significant relation to usewears of stone tools. Additionally, the residue samples themselves contained many plant materials, such as tiny fragments of fibres and tissues. The preliminary studies (Holst *et al.* 2007; Shibutani 2010b, 2011, 2012b; Veth *et al.* 1997; Yang *et al.* 2013) mentioned that residue samples sometimes contain other plant materials, such as fibres, tissues, and phytolith, together with starch grains, and they may be used for processing plants with stone tools. However, in this

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case study, these plant materials were presumed to be modern ones by their quality and quantity, and therefore, their starch grains may be contaminated materials.

Four starch grains along with a possible chestnut (*Castanea*) starch were not assumed to be processed plants or contamination. Although residue samples of three natural pebbles from the same excavation spot did not contain any starch grains, their sampled stone tools were found from the disturbance layers. The number of starch grains did not indicate any differences from non-used surfaces, and therefore, we were not able to confirm whether these starches were processed plants or contamination (Shibutani *et al.* 2015).

The exploitation of walnut trees in southern parts of Hokkaido started at the beginning of the Earliest Jomon, and during the latter half of Early Jomon, they had been greatly distributed in Hokkaido (Yamada 1993; Yamada & Shibauchi 1997). The rate of chestnuts grows much faster than that of beech, which took about 5,300 years to arrive at the Kuromatsunai Low Land, which is the northern are of natural growth (Yamada & Shibauchi 1997). Potential *Juglans* starch grains from the Kitakogane Shell Mound can thus show that stone querns were used for processing walnuts in southern Hokkaido during the Early and Middle Jomon. Despite these results and the fact that it is unclear whether walnut starch grains show food use, the results highlight an identification and classification scheme that is primarily qualitative and simply reproducible.

## 4. Plant food processing by grinding stone tools and pottery vessels in the Jomon period in Japan

Food crust remains show a necessary part of the archaeobotanical record for reconstructing past societies, but they are not as often analysed as other macrobotanical remains due to their burial preservation (Pető *et al.* 2013; Zheng *et al.* 2015). Starches from various contexts are vital in collecting information about tool use and processing materials.

Although fewer studies dealing with starchy food remains adhering to the inner surfaces of pottery are conducted than starch studies of stone tools, an outstanding review of this type of analysis is given in Crowther (2012) and Zheng *et al.* (2015). Crowther (2012) argued that earlier studies lack an overarching informative framework for understanding the differential native starch survival affecting the archaeobotanical reconstructions and interpretations of the artefact function. Her experimental study therefore investigated the usually overlooked but vital part of the cooking method, the presence of wetness, to assist in showing the mechanisms underlying the preservation of starch during cooking and form prophetical statements regarding the circumstances under which starches survive. Examining relevant samples of food crust remains, Zheng

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*et al.* (2015) mentioned vital opportunities to interpret the ingredients of food remains and processing technologies thoroughly and showed that their desiccated food remains were made of wheat (*Triticum aestivum*) and barley (*Hordeum*).

Most of the previous studies conduct analyses of food crusts adhering to the inside of pottery combined with multiple analyses, such as carbon and nitrogen stable isotope analysis with starch residue analysis (e.g., Armas *et al.* 2015; Saul *et al.* 2012; Shoda *et al.* 2011). However, the association of analysing starch residues from a variety of materials, such as grinding stones, pottery vessels, and wooden pestles and mortars, has seldom been examined in the archaeology world. This association is vital to understanding past composite use, corresponding to whether edible plants were used as plant food or for different purposes, such as utilizing fibre materials.

In Japanese studies, the comparison of starch residues from varied materials has also developed to reconstruct past plant food and foodways. Such issues are noted for starch assemblages of grinding stones and pottery sherds from the Jomon site of Shimo-yakebe site in Higashi-Murayama city, Tokyo (Shibutani 2014). In this case study, many well-preserved starch grains were recovered from Jomon pottery sherds, but few starches were from grinding stones. Another study by Yamamoto *et al.* (2016) reports that many starch grains were extracted from grinding stone tools, even though rare starch grains were found in the residue inside of pottery. This paper shows whether this difference was caused by tool functions.

The Shimo-yakebe site is one of the foremost vital wetland sites from the Middle to Final Jomon subperiod (ca. 5,300–2,800 cal BP) within the Kanto plain, central Japan. At this site, many well-preserved plant macrofossils, wooden structures for water usage, and piles of *Aesculus*, *Juglans*, and *Quercus* fruits were found (Research Group of Cultural Properties at Higashi-murayama City 2006). Among them, a total of 40 charred plant remains that were attached to inner surfaces of the Jomon potteries were excavated. These charred plant remains are classified into five groups: scaly bulb remains, fibre remains, fruit and seed remains, woven remains, and unidentified macrofossil remains (Kudo & Sasaki 2010; Sasaki 2006). Numerous grinding stones were also excavated from survey areas in this site (Research Group of Cultural Properties at Higashi-murayama City 2006).

Residue samples from 38 charred plant remains on pottery sherds and 20 grinding stone tools (ground stones and pestles) were consistently examined. Pottery residue samples were mainly taken from fragments of charred remains followed by Crowther's procedure (Crowther 2005), and the spot sampling of stone tools was based on Fullagar's method (Fullagar 2006) as well as other Japanese studies.

122 starch grains were recovered from 23 charred plant remains, and 46 starch grains were extracted from 13 stone tools. These conditions were comparatively well-preserved

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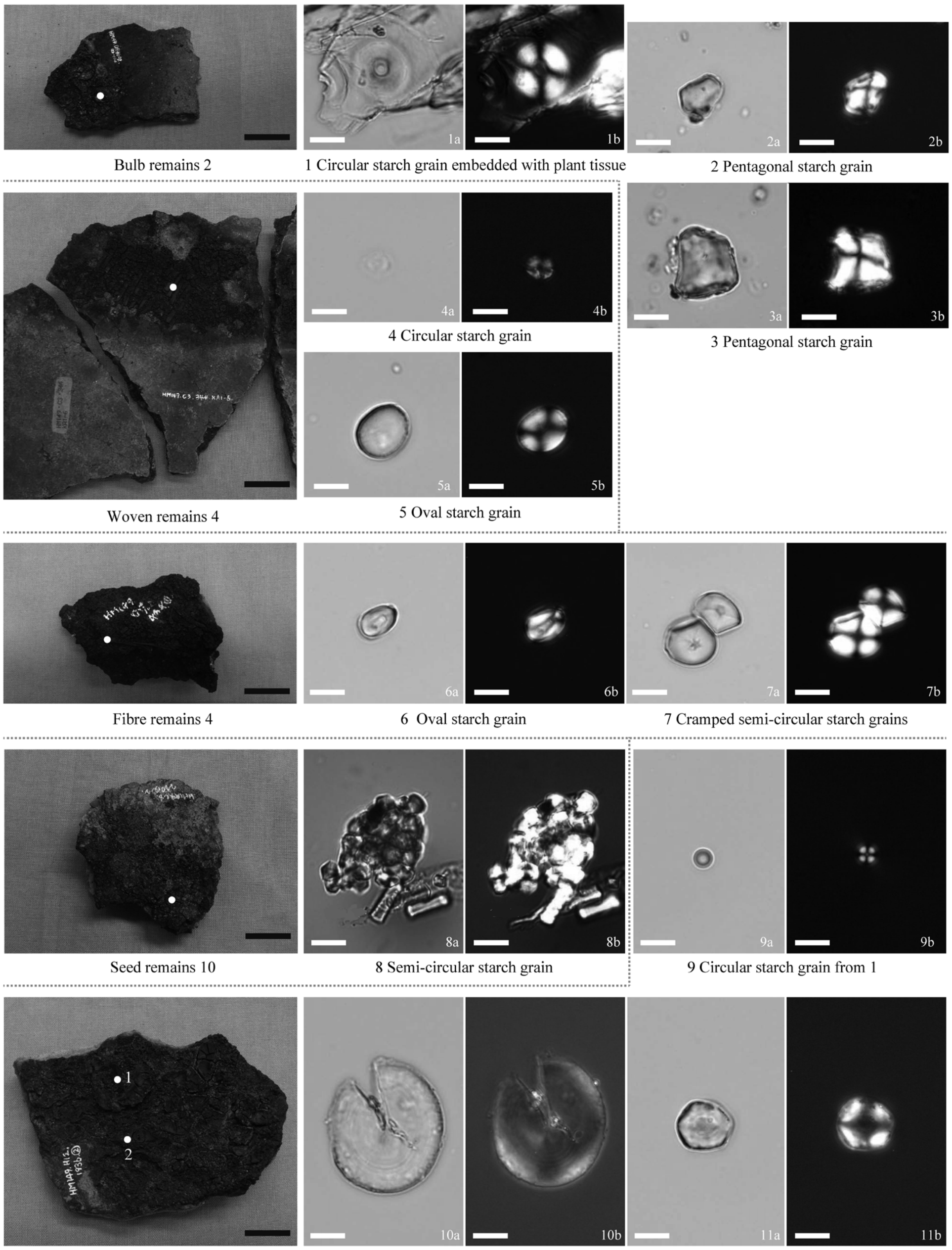


*Figure 2. Examples of sampled pottery vessels at the Shimo-yakebe site and starch grains considered as processed plants (Shibutani 2014). White circle: sampling spot; Bar of pottery photos: 2 cm, bar of starch grain photos: 10 µm; Magnification: ×400; a: brightfield, b: brightfield with cross-polarised light.*

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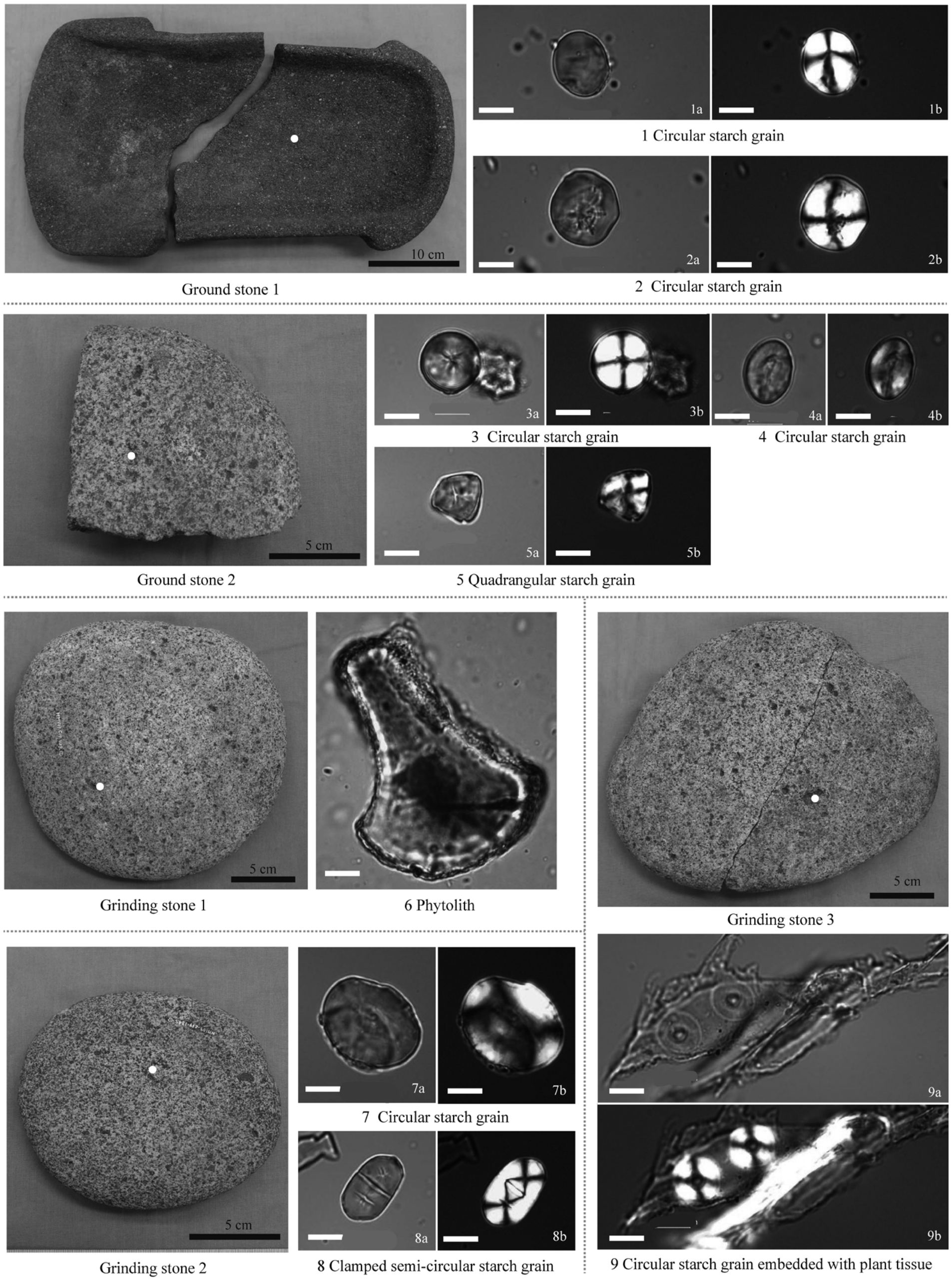


*Figure 3. Examples of sampled stone tools at the Shimo-yakebe site and starch grains considered as processed plants (Shibutani 2014). White circle: sampling spot; Bar: 10 μm; Magnification: ×400; a: brightfield, b: brightfield with cross-polarised light.*

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with features that clearly defined outline and extinction crosses and rare fractures (Shibutani 2014).

Starch grains extracted from the working surfaces of grinding stone tools at the Shimo-yakebe site were known to be *Quercus*, *Castanea*, *Cardiocrinum*, and *Pueraria*. These grain assemblages were proof of food plants processed with stone tools. Cracked and decayed starch grains were conjointly recovered, and these specific plant species can include acorns and nuts, even if they lack diagnostic features comparable to available references. According to an experimental study by Liu *et al.* (2013), the broken forms of starch may vary in plant species, and milling or grinding can cause structure modification in starch grains. The recovery rates of intact starch grains from sampled stone tools at the Shimo-yakebe site were therefore related to the processed components. Supported by these morphological fractures and the botanical investigation, it was concluded that ground stone usages mainly varied in processing acorns, nuts, and bulbs.

Regarding starch grains extracted from pottery sherds, the botanical identification showed the subsequent results: starch grains from bulb remains with potsherds were known to be *Lilium*, *Castanea*, *Quercus*, and *Juglans*; possible *Pueraria* and acorn starch grains were from fibre and woven remain samples; and unidentified macrofossil remain samples contained *Juglans*-type starch (Shibutani 2014). The results coincide with carbon and nitrogen stable isotope analysis and C/N ratio analysis by Kudo and Sasaki (Kudo & Sasaki 2010; Sasaki 2006) and showed that tubers and bulbs were cooked together with acorns and nuts in the sampled Jomon pottery.

Crowther (2012) already mentioned that the utilization of wet (e.g., boiling and steaming) rather than dry (e.g., baking, broiling, parching, and toasting) cooking methods have a substantial adverse impact on the survival of starch. Once totally gelatinised, starch is incredibly difficult to recognise microscopically and classify taxonomically, preventing the identification of cooked starch in archaeological food residues. The recent experimental study of cooking starchy food with Jomon pottery showed that the different preservation of starch grains at species level may be mainly caused by grain sizes (Nishida 2017). In another case of Yayoi pottery residues (Shoda *et al.* 2011), several gelatinised starch grains could possibly have contained unidentified starchy foods, although scanning electron microscopy showed identifiable features of rice on the broken grains that still contained bran.

At the Shimo-yakebe site, 109 well-preserved (mostly without fractures) starch grains were extracted from the inside of pottery. Based on the previous experimental studies (Crowther 2012; Henry *et al.* 2009), when cooking plants in the sampled Jomon pottery, low temperature or high wetness content of starch grain itself caused poor gelatinisation (Shibutani 2014).

Charred plant remains are ideal for investigating past starchy food cooking.

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Experimental and archaeological starch results can provide insight into cooked starch resistance to gelatinisation and degradation, and they will help explain starch taphonomy in archaeological contexts. Additionally, at the Shimo-yakebe site, while grinding stone tools were used for processing nuts, acorns, and bulbs, residue samples of Jomon pottery indicated the cooking method of tubers and bulbs. Consequently, the combination of analysing residues from varied materials is more convincing than one technique to reconstruct the past plant food cultures.

## 5. A summary of the common problems and workable solutions in Japanese archaeological sites

A review of two applications of starch residue analysis in Japan has discovered four common issues that need to be addressed. First, before archaeological samples are even examined, a stronger case must be made that starch types are diagnostic. This requires the objective classification of starch morphometrics for attempting the taxonomic identification and contamination controls. Second, the potential dominant factors on starch presence should be addressed systematically. Third, with archaeological samples, taphonomy is usually poorly understood or passed over, and inappropriately small amounts of starch grains are used to support interpretations. Fourth, the impact of burial settings on starch preservation and assemblage composition needs further investigation.

The scientific discipline dealing with starch should be addressed with urgency. The current morphological analysis, like other areas of the scientific discipline, is a visual examination by a limited type of specialist with the conclusions being supported by the quantity and quality of characteristic types (Shibutani 2015). Despite the criticisms of subjective starch identification by ‘expert analysis,’ visual identification is, and image analysis is not always possible. Extra caution should be applied in the visual examination of starch grains. A major concern with starch evidence in Japanese studies is that current statistical tests offer only a chance that a precise assemblage guarantees processed plants, rather than having the flexibility to show that one starch type is exclusive to at least one species. These methods limit researchers to interpret the possibility of plant use.

Morphological changes could possibly occur before deposition, but considering that starch identification relies on extremely specific, usually refined, morphological diagnostic criteria, the potential of morphological changes might be a necessary area of investigation. For example, gelatinised starches are susceptible to degradation, either from mechanical agitation that may cause gelatinised granules to burst or break up into smaller fragments or through being damaged post-deposition (Barton 2007; Barton & Matthews 2006). Breakage of conjoined forms has already been established (Crowther 2012; Henry *et al.* 2009), and weathering of the surface of starch has occasionally been

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discovered. Once starch variation among and between plant species has been properly addressed, we can examine the depositional and post-depositional morphological changes (i.e., taphonomic process).

Stratigraphic combination and moving might be priorities when attempting to relate starch to archaeological tool uses. Recent studies have investigated (Barton 2007; Barton & Matthews 2006), and potential contamination has been mentioned in earlier studies (Crowther *et al.* 2014; Loy & Barton 2006). Post-depositional processes are also extraordinarily varied depending on the type of soil as well as the size that the analysis is allotted. However, stratigraphic controls for starch residue analysis are rarely conducted in Japan, but it is still possible to scrutinise the associated assemblages from *in situ* decay. We have the distinction here to take residue samples from ancient living surfaces from the upper soil layer to the lower layer. This methodology will offer stratigraphic management that may dispel many arguments against starch interpretations and provide a direct demonstration of the depositional and post-depositional processes. Identifying between multiple depositional pathways may also be achieved by examining associated diagnostic indicators to differentiate vessels and spores from plant structure fragments.

## 6. Conclusions

Starch grains have abundant potential as archaeological tools, and their study offers a massively valuable technique for understanding human use of starchy food resources in prehistory. Starch residue analysis continues to evolve as a discipline, particularly in Japan, and like all comparatively innovative approaches, it has problems that can hopefully be addressed over time. The approach to modern starch reference materials indicates that the assemblages vary in plant species, but the degree and causes of variation, even within an individual plant, need to be fully understood before we can apply this to archaeological samples and make definitive conclusions. The conflict with different lines of proof resembling macrobotanical remains in Japan is a concern.

The problems are often summarised as (1) potential judgement in developing and applying morphological criteria, (2) issues applying criteria from modern assemblages to archaeological assemblages and contamination management, and (3) poorly understood taphonomy. Until these are addressed satisfactorily, caution should be taken when creating a definitive starch residue analysis. Researchers must be realistic about what can and cannot be determined from the information and avoid over-interpretation.

The scientific discipline may also benefit from the publication of images of reference specimens and archaeological assemblages in East Asia as well as numerical tables, and therefore, different datasets can be compared with a great deal of confidence. Many analysts have examined various modern plant species and varieties in their own

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studies (e.g., Field 2006; Lance 2005; Lentfer 2009; Therin *et al.* 1997; Warinner *et al.* 2011), but no communal database permits other researchers access to this information for comparison. Classification algorithms will only assign one of the categories for which training data is available. The more representative the modern training data in Japan or East Asia is, the more reliable the classification will be. The development of morphometric ways and automatic image analysis will improve with large datasets, and this could offer a reliable dataset that will benefit researchers worldwide. As more material is analysed, this data will only be improved.

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