Title

古代日本における物質文化専門化の進展：先史時代土器標準化の定量的研究

Name

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抄録

先史時代の社会において、土器生産は社会や文化の変化を反映し、生産体制や専門化の進展は遺物の形状に表れることが広く知られている。近年、計算・デジタル技術の進歩により、形状変化を定量的に分析することができ、先史社会における生産組織に関する新たな知見を得ることが可能となった。本研究では、幾何学的形態計測法を用いて、弥生時代初期から前期（紀元前 900/800 年～紀元前 300 年）の調理用土器（甕形土器）の生産変化を検討した。この時期は、農耕社会への移行、水田耕作の拡大、人口増加、社会階層の形成といった大規模な社会的変化が特徴的である。分析の結果、甕形土器の形状のばらつきが減少する傾向が確認され、生産が家庭レベルから、より専門化された小規模グループによる体系的な生産体制へと移行した可能性が示唆された。また、甕形土器と壺型土器の標準化の度合いの違いは、用途や生産率が物質文化専門化に与えた影響を明らかにしている。本研究の成果は、古代日本における人口動態や社会構造の変化が生産体制に与えた影響を明らかにするとともに、各時代や地域の生産活動を比較分析するための重要な基盤を提供するものである。

キーワード：日本考古学、土器生産技法、計算・デジタル的考古学、幾何学的形態測定学的分析、弥生時代

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Title

The Rise of Craft Specialization in Ancient Japan: Quantitative Insights into Prehistoric Pottery Standardization

Name

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Abstract

In prehistoric societies, pottery production often mirrored changes in sociocultural landscapes, with shifts in production organization and specialization reflected in the shapes of artifacts. Modern computational and digital methods in archaeology allow us to analyze these shape variations quantitatively, providing insights into production organization in prehistoric contexts. This study utilizes geometric morphometric analysis to investigate changes in pottery production of cooking pots during the Initial ~ Early Yayoi period (~900/800 BC–300 BC) in Japan, a pivotal era marking the transition toward an agricultural society. As wet-rice farming spread across the Hakata Bay region, population growth led to significant social transformations, including the development of social hierarchies. Results show a clear trend toward reduced variability in vessel shapes, suggesting a shift to more structured production practices and heightened standardization. Differences in standardization between cooking jars and mortuary vessels highlight the impact of function and rate of production on craft specialization. These findings contribute to our understanding of how demographic and social changes influenced production organization in prehistoric Japan, providing a model for analyzing production organization across different contexts and periods.

Keyword: Japanese Archaeology, Pottery Production Techniques, Computational & Digital Archaeology, Geometric Morphometric Analysis, Yayoi Period

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1 Introduction

In order for material cultural lineages to be successfully passed down, there must be a learning process where individuals acquire the skills needed to replicate the general shape or adhere to the basic ‘rules’ for each object within the bounds of cultural norms. Thus, the act of creating material culture functions as both a direct and indirect method of transmitting cultural norms to individuals (González-Ruibal, 2012, p. 21). This was particularly true of pottery, an essential part of daily life, which required certain necessary skills to produce. With expanding agriculture and increasingly complex social structures, it is hypothesized that pottery production methods likely transitioned from small household-based activities to more organized forms of production that could supply a growing population. In doing so, the variability of the shape of pottery likely fell, with production units favoring (consciously or unconsciously) more standardized shapes.

This study focuses on quantifying these changes in pottery production through geometric morphometric analysis (GMM), investigating how potential shifts in production methods are reflected in the shape and standardization of pottery from the Initial ~ Early Yayoi period in the Hakata Bay region, Japan. By examining changes in variability and standardization, this study aims to clarify how production methods evolved in response to demographic and societal changes during this early agricultural era in Japan.

2 Material Culture Production Organization

The organization of pottery production operates on multiple levels, where ‘social learning strategies’ combine with production structures, ranging from household-based workshops to specialized, small-group settings and large-scale industry. Hansen (1979) emphasizes that knowledge transmission is essential to the perpetuation of every culture and the structure of all human societies. In this sense, learning serves as a cornerstone of societal organization, with shifts in learning approaches impacting social structures, both past and present. In pottery production, social learning generally involves three key participants: instructors, models, and learners. Instructors guide learners using specific pedagogical tools to direct their attention toward set goals, while learners employ various methods to acquire and apply new skills (Loftus, 2022b). These combined tools and learning methods form what we term “social learning strategies.” Each strategy varies in the time and effort required; in general, more intensive approaches result in products that more closely replicate those made by the instructor, leading to lower variability among artisans (see Fig. 1, ‘A’). As a result, production environments that require high standardization often favor structured transmission methods to maintain consistency.

In this context, pottery production ‘organization’ reflects the degree of specialization and standardization expected within a community. Household-based production, for instance, may exhibit greater variability due to the informal, flexible nature of learning, whereas specialized workshops tend to adopt more formalized learning strategies to achieve uniformity in output (Fig. 1, ‘B’). This relationship between production structure and learning strategy suggests that as pottery production transitions from individual households to specialized groups, the social learning mechanisms adapt accordingly to support consistency and specialization.

In the context of pottery production, variability in shape often reflects both conscious and unconscious decisions made within a socio-cultural framework that emphasizes the preservation of a particular “style” to uphold social identity. Variability can therefore serve as an indicator of the underlying learning strategies, as well as the production organization. While high variability might indicate a looser, household-based learning structure, low variability is often associated with structured, specialized production. Recently developed quantitative methods now enable us to measure and analyze this variability, providing insights into the production and organization of prehistoric pottery.

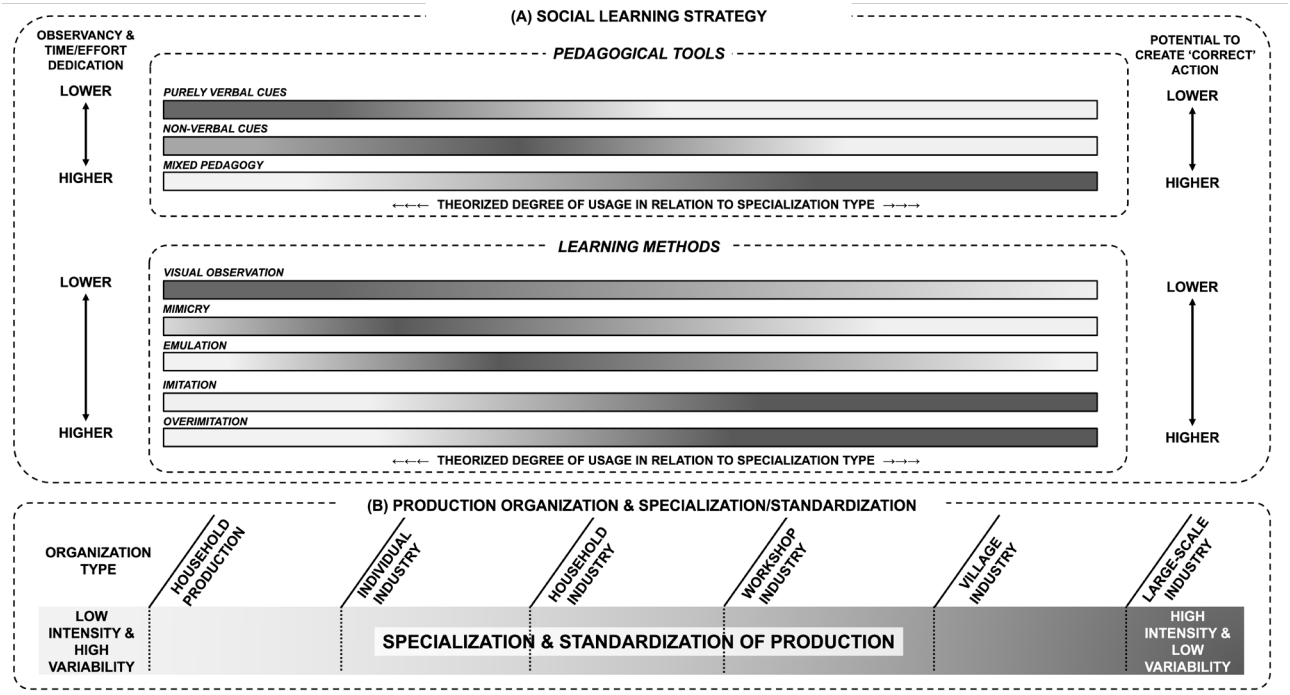

Figure 1. *Theoretical framework outlining the complex relationships between differential social learning strategies, organization type and standardization of material culture (Revised from Loftus, 2022b)*

3 Quantifying Production Organization through Material Culture

“Specialization”, or the ratio of producers to consumers, refers to the spectrum of production contexts within which material culture is crafted. This spectrum ranges from individual production for personal use to large-scale regional production (Fig. 1). In essence, specialization measures the ratio between the producers of a craft and its consumers (Loftus, 2022a). “Standardization” in ceramic studies quantifies this specialization by assessing the uniformity of the produced items, typically reflecting a production process that uses limited materials and follows a formalized routine (Arnold & Nieves, 1992, p. 93). In other words, more formalized means of teaching/learning will likely produce material cultural artifacts which are more similar to one another, despite being produced by different individuals.

Ethnoarchaeological research indicates that individuals within a particular socio-cultural context tend to produce material culture that mirrors that context due to learned behaviors (Ingold, 2001). This phenomenon is highlighted by Terashima & Hewlett (2016), who explain that craftspeople often create goods resembling those

of their instructors. Costin (1991) notes that “degrees of material cultural stability can result in recognizable patterns of past societies”. Pottery serves as an exemplary case of this, given its complex cognitive processes and extended learning period, which, when guided, results in fewer errors and clearly delineates social styles through form (Gandon et al., 2020; Roux, 2019). By integrating ethnographic and archaeological evidence of standardization, it is hypothesized that different specialization types employ distinct social learning strategies, evident in the material culture, particularly pottery shapes.

The analysis of ceramic shapes, independent of size (considering size yields ‘form’), is foundational in archaeology. Detailed quantitative shape analysis can reveal changes in production organization, levels of elite control, and individual variability in shape creation. Degrees of “standardization”, or the relative consistency in shapes (Bai, 2022), helps quantify variability, reducing personal bias (Longacre et al., 1988; Arnold, 2000). This study uses Geometric Morphometrics (GMM) to measure differential standardization to extrapolate relative degrees of specialization in production organization. Cooke and Terhune describe GMM as a toolkit for multivariate analysis and visualization of Cartesian coordinate data (Cooke & Terhune, 2015). Modern GMM studies fall into three categories: traditional GMM, landmark-based GMM, and outline-based GMM. Many studies on pottery complexity favor 2D outline-based GMM, processing pottery drawings into usable data through Elliptical Fourier (EFA) and Principal Component Analysis (PCA) scores. These scores facilitate significance testing, dimensionality reduction, distribution analysis, and relative rate of production (ROP) extraction, thereby gauging relative standardization.

4 Prehistoric Case Study – The Initial ~ Early Yayoi Period (BC 900/800~300), Hakata Bay Region, Island of Kyushu, Japan

The onset of the Initial ~ Early Yayoi period (弥生時代早期・前期) (around 900/800 BC to 300 BC) signifies the roots of an increasingly intensive wet-rice agricultural society in Japan. This era is notable for the gradual spread of wet-rice agriculture, which dramatically altered Japan’s social, economic, and cultural framework. The transition from a hunter-gatherer existence during the Jomon period (縄文時代) to an agrarian lifestyle prompted the formation of more stable communities (Mizoguchi, 2013, p. 53), improvements in farming techniques, the rise of social hierarchies, and most relevant to this study, shifts in material culture production methods, as seen through evident changes in the organization of labor activities (Mizoguchi, 2013, p. 54). During the Yayoi period, new technologies, such as metal tools and distinct pottery styles, were introduced, enabling more effective farming and food storage solutions. These innovations paved the way for the complex societies that would develop in later periods of Japanese history. Previous studies on social learning and production organization tell us that modern hunter gatherers often learn through “observation and imitation” with “little or no instruction from teachers” (Terashima & Hewlett, 2018, p. 314). Contrast this to agricultural societies where social learning seems to take on more rigid and clearly defined steps. As such, the early Yayoi, as a transitional period, is a potentially fruitful case study of changes in production organization in prehistoric humans.

The period features a variety of pottery shapes, each serving different purposes in the society and the daily lives of the people living in the Hakata Bay region (博多湾) on the island of Kyushu in the south of Japan. For example, some vessels are used primarily for cooking, others for serving, and others in mortuary contexts, with many scholars of the Yayoi period dedicating years to studying the morphological differences between these and their relationship with agricultural society (such as Misaka, 2022). The Hakata Bay region is widely recognized as one of the initial contact zones between the native hunter-gatherers and incoming migrant populations (Misaka, 2014). The “Yayoi” culture took root in the Hakata Bay region during this period and subsequently spread throughout western Japan (Miyamoto, 2016, 2017) – meaning that a recognizable cultural tradition should have been established in the material culture of the time. This cultural consolidation should be evident in the standardization of pottery vessels, a topic not yet thoroughly examined in previous literature. Therefore, this study focuses on this critical Hakata Bay region to explore potential changes in pottery standardization and associated production organization. This study employs a morphological stage system, dividing the period into three major phases: (Stage 1 = Yuusu style (BC 900/800-500), Stage 2 = Itazuke 1 style (BC 500-400), Stage 3 = Itazuke 2 style (BC 400-300)).

5 Materials & Methods

5.1 Materials: Hakata Bay region ‘Kame’ Cooking Jars

In earlier investigations, Loftus (2021, 2022a) observed a significant trend towards the standardization of mortuary pottery during the early Yayoi period in this region, suggesting potential shifts in social learning strategies. However, ‘tsubo’ mortuary vessels (壺型土器) were not the predominant ceramic types of this era, as they primarily served as storage and funerary containers. Consequently, standardization of these pots might have lagged behind that of more commonly used vessels, with increased production likely emerging later in the period.

To examine differences in pottery standardization practices between two shape types, this study focuses on the most prevalent pottery form from this period and region: the “kame” cooking jar (甕 型 土 器). The kame was handcrafted using clay slabs, without the aid of pottery wheels, and fired at low temperatures in open flames, without kilns (Misaka, 2022). Its production was seemingly predominantly a household activity, with no evidence of specialized “workshops” at this time (Mizoguchi, 2013). The kame displays complexity in its evolving shape over time, influenced by concurrent indigenous and Korean Peninsula ‘Mumun’ (in Japanese, ‘Mumon’ 無文土器) tradition production methods (Hashino, 2018). Additionally, there were at least two stages of hybridization in form during this period (Loftus, 2022b). Nonetheless, the kame can be generally categorized into two major types: carinated/cordoned and smoothly rounded (Fig. 2). This study employs a subset of samples openly available from Loftus (2022b), analyzing 200 complete vessels from the Hakata Bay region.

Figure 2. *Carinated/cordoned (left) and smoothly rounded 'Kame'cooking jars from the Hakata Bay region. 3D photos taken by the author, with permission from the housing institute, the Fukuoka City Archaeological Research Center (* 福岡市埋蔵文化財センター *).*

5.2 Statistical Methods: Geometric Morphometrics (GMM)

This study utilizes the aforementioned '2D outline-based geometric morphometrics' as the base of data presented. GMM is a toolkit of different computational analysis in the extrapolation and visualization of differential shape in archaeological artifacts. Specifically, this study utilizes the following workflow:

1) Data Collection: High-fidelity photocopy of site report line drawings (600 DPI); conversion to binary (black and white) pallet.

2) Contour Extraction: Elliptical Fourier Analysis ('R' package 'MOMOCS') (Bonhomme, Picq, Gaucherel, & Claude, 2014; R Core Team, 2020, v3.6.3); Size factors removed from counterclockwise traced contour data.

3) Dimensionality Reduction: Contour data fed into PCA; PC scores extracted for further quantitative statistical testing (first three PCs).

4) Significance Testing: PC scores utilized to test statistical significance using MOMOCS; Significance tested between temporal stages (the main goal of this study).

5.3 Data Availability Statement

The minimal data set (PC scores) which supports the findings presented in this study will be made available upon reasonable request to the corresponding author.

5.4 Ethics Statement

This study primarily utilizes 2D outline data of archaeological artifacts published in openly accessible archaeological site reports from the Northern Kyushu region of Japan. No unpublished data was utilized in this study. Furthermore, no destructive analysis was conducted in this study. No living descendant groups have any ongoing claims to the data or original artifacts presented in this study. All data is securely stored by the corresponding author, and no data is linked to any specific individual, living or otherwise.

5.5 Funding Information

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6 Results

6.1 Significance Testing

Following the extraction of elliptical Fourier coefficients and analysis through principal component analysis (PCA), multivariate statistical significance testing was conducted to confirm that observed changes in pottery shape across temporal stages were not due to random variation. Both Wilks' Lambda and Pillai's trace showed p-values of < 0.05, demonstrating significant temporal changes in vessel morphology (Tabachnick & Fidell, 2007). *Wilks' Lamba: df1: 6, df2: 390, F:2.144, p:0.0477; Pillai Trace: df1: 6, df2: 392, F:2.144, p:0.04771.*

Furthermore, in order to accurately assess where the above statistical significance lies between each morphological stage, pairwise comparisons of each stage are also provided. Pairwise comparisons revealed that although the morphology between stages 1 and 2 showed no statistical significance, there was clear significance between stages 2 and 3, suggesting that more major shifts in production standardization likely occurred in the latter part of the period. *Pairwise Comparisons: Stage 1-2:p=0.30977, Stage 1-3:p=0.023982 , Stage 2-3:0.047914.*

6.2 Kame Variability (Fig. 3)

Fig. 3: A: Variability in Kame shape falls within the upper half of vessels, with PC1 (51.8% of total variance)

directly representing the general openness of the mouths of vessels, and degree of curvature of the vessel necks. PC2 (18.7%) represents more clearly the lips of kame vessels, especially the degree of outward curvature of lips relative to the neck. PC3 (9.09%) is represented primarily by the width of the base of vessels. PC1-3 represent 79.59% of the total shape variability in all examined kame vessels, with remaining PCs showing less than 7% of total variance displayed. The latter are not included in this study as they fall below the often-utilized threshold of ~10% variability of each PC.

Fig. 3: B: When considering the first two PCs which are above the ~10% threshold, there is a clear trend towards a gradual process of shape standardization (at least within the upper halves of vessels which hold the largest amount of variability). PC1 over the three examined temporal stages shows a relatively compact spread of variability, with stage 3, despite a general lack of samples during this period, showing both a morphological shift (as expressed by the average line moving) and the peak of distribution becoming more pronounced. PC2 on the other hand, shows a marked change in morphological distribution between stage 1 and 2, with a clear central grouping of samples into a higher peak, but flattens out again into a more varied shape in stage 3. It is possible that some variability became apparent again in this latter period, or that the lack of samples in this period is skewing the results slightly. Regardless, the general trend seems to be a gradual reduction of morphological variability.

Fig. 3: C: PCA morphospace tells a similar story to that of PC distribution, with 95% confidence ellipses slowly shrinking in their breadth over the three periods, and with stage 1 vessels showing a relatively wide range of variability in the morphospace among all four quadrants. On the other hand, stage 3 vessels seem to group in the left two quadrants primarily, and are represented by less angular, and more “curvy” vessels – this would align well with previous results of typo-chronologies presented by Loftus (2022b).

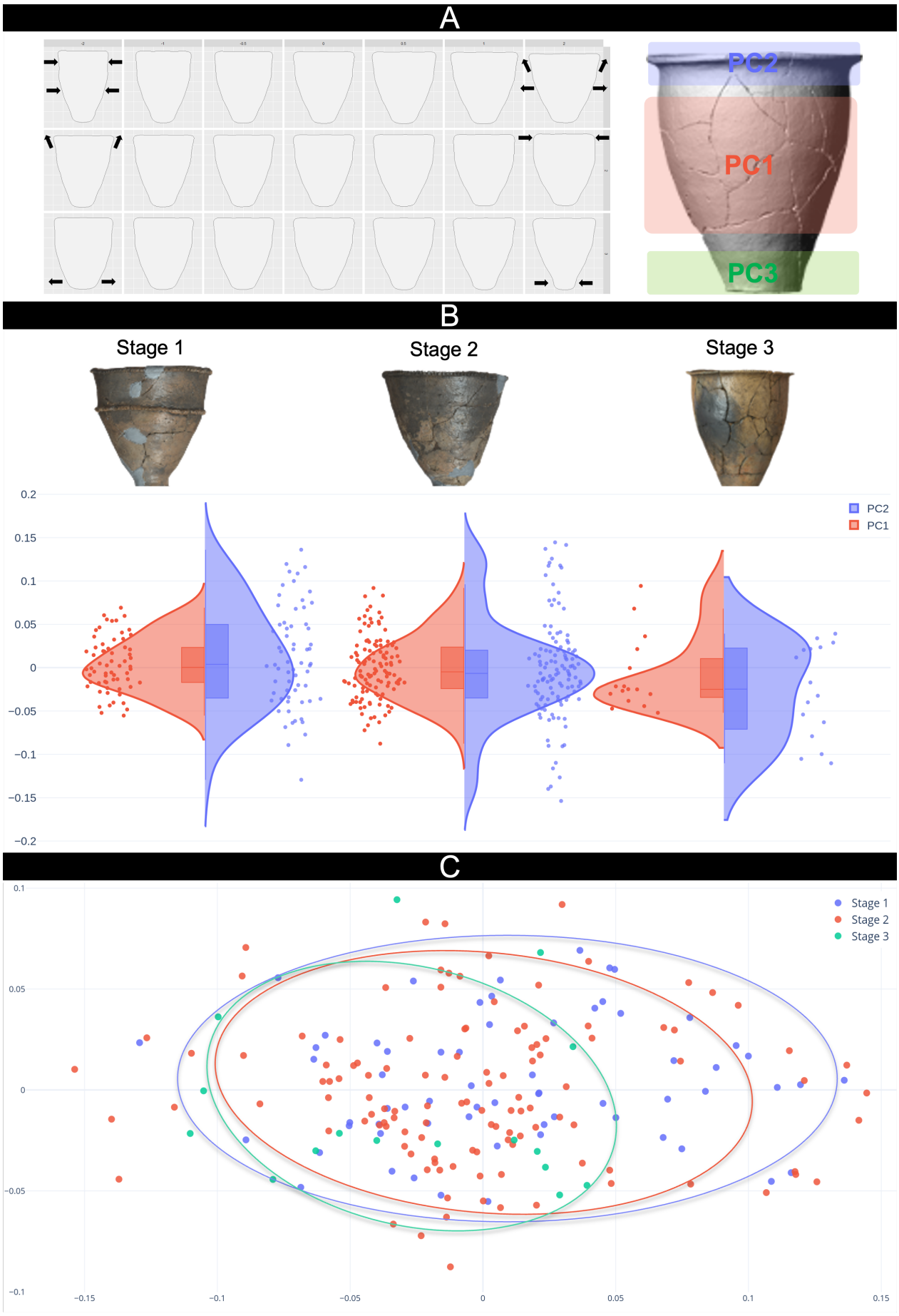

Figure 3. *Results of Geometric Morphometric analysis on 'kame' cooking pots. A: Summary of shape variation along PC axes (PC1–3) of kame outlines, utilizing the 'PCcontrib' function; B: Box plot distribution with overlaid violin plots of PCA scores (PC1, 2) over the three temporal periods; C: Principal component morphospace plot of PC1 (x axis) and PC2 (y axis) between the three temporal periods (stages 1, 2, 3).*

7 Discussion

During the early Yayoi period, significant population growth and migration in the Hakata Bay region introduced diverse groups with distinct pottery traditions and techniques (Usami, 2020). While this diversity might initially suggest an increase in pottery shape variability due to the integration of various styles, the evidence instead reveals a trend toward standardization (lessening of variation). This trend suggests that as population demands grew, communities adopted new strategies to ensure consistent production. The increased need for reliable pottery likely prompted a shift from household-based production to small-group units where experienced potters trained others, leading to uniformity.

The observed standardization despite population growth and migration suggests that potters and their communities implemented intentional strategies to control variability and maintain consistency in pottery production. Centralizing production and formalized learning allowed communities to scale up pottery production efficiently, meeting the demands of a growing population without sacrificing quality. Typically, when specialization of production is achieved and a set number of potters are able to focus on production alone, a larger number of more specialized pots are able to be created in a comparatively short amount of time. Standardized pottery shapes could have reinforced cultural identity and cohesion within communities, especially in the context of integrating diverse migrant groups. When focusing on the Hakata Bay region in particular, a clearer picture of differential standardization emerges, contrasting with the broader Northern Kyushu region (北部九州地方) as previously analyzed by Loftus (2022b). The cooking jars from the Hakata Bay region exhibited a much quicker standardization process than those from other regions, aligning with the understanding that the majority of population increase occurred in the Hakata Bay region (Miyamoto, 2016). This demographic shift played a critical role in shaping the pottery production landscape, significantly impacting social learning strategies and related production organization.

A contrast exists between the standardization of cooking jars and mortuary vessels (Loftus 2022a) within the Hakata Bay region. Cooking jars demonstrated a relatively consistent shape from the beginning of the period, gradually becoming more standardized over time. This contrasts with mortuary vessels, which began with higher variability but standardized more rapidly (Loftus 2022a). The difference in standardization practices can be attributed to the distinct functions and production intensities of these vessel types. Cooking jars were essential for daily use, necessitating consistent and reliable production to meet everyday needs. This demand for uniformity likely drove early standardization, as potters aimed to produce functional and reliable vessels efficiently. In contrast, mortuary vessels, primarily used for storage and funerary purposes, were produced less frequently and with more variability initially. What drove the rapid standardization of mortuary vessels will need to be explored in further studies.

Despite these insights, it is essential to recognize that this standardization pattern may not be universal across the Japanese archipelago. Different regions might have adopted agricultural practices and specialized production at varying rates, with some groups selectively integrating new technologies or cultural traits (Crema, Stevens, & Shoda, 2022). This process of “choosing” cultural traits continued well into the following ‘Kofun’ period, with evidence of outlying island cultures having continued extremely unique cultural trends such as

cranial modification for hundreds of years (Seguchi, Loftus, Yonemoto, & Murphy, 2023).

While this study contributes new understanding to the organization and specialization of pottery production in early Yayoi society, certain limitations should be considered. The study's reliance on geometric morphometric analysis, while effective in assessing shape variability and standardization, may not fully account for other factors such as resource availability, technological constraints, or cultural preferences for specific design elements. Moreover, the focus on pottery shape alone might provide an incomplete view of production dynamics, as additional factors like raw material sourcing and production techniques also play significant roles. Finally, while the findings suggest a link between demographic shifts and production organization, the exact causal mechanisms remain speculative. Future research that includes a broader range of archaeological data—such as raw material analysis, regional comparisons, and assessments of manufacturing techniques—could provide a more holistic view of production dynamics during the early Yayoi period.

8 Conclusions

This study examined pottery production organization during the early Yayoi period in the Hakata Bay region, utilizing geometric morphometric analysis to quantify standardization as a marker of craft specialization. The results reveal a trend toward reduced variability in pottery shapes, particularly in cooking jars, suggesting a shift from household-level production to more organized small-group production units as agricultural practices expanded. This transition aligns with demographic changes, such as population growth and the establishment of social hierarchies, which likely drove the need for efficient and standardized production methods. Differences in the standardization of cooking jars and mortuary vessels further highlight the role of function and production intensity in shaping craft specialization during this period.

To further elucidate the relationship between production organization and pottery standardization, future research should focus on comparing pottery assemblages with varying production rates within the same shape type. This would help isolate the effects of production intensity on standardization, providing a clearer understanding of how social learning strategies evolved in response to changing socio-economic conditions. Also, while the notion of differential usage based on shape-type affecting standardization was explored in this study, further work needs to be done to extrapolate how possible differential production methods (Jomon or Korean Mumun-influenced) could have affected the standardization noted.

The findings presented in this study underscore the importance of pottery standardization as an indicator of social change, enhancing our understanding of how early Japanese farming communities adapted production organization in response to demographic pressures and changes in societal structures. These insights could also extend beyond Japan, offering a valuable framework for investigating the relationship between craft specialization and social evolution in other early agricultural societies around the world.

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