Determination of Kendi's Provenance Through the Panofsky Approach and Combination of Handheld Raman Spectroscopy, X-Ray Fluorescence

RESEARCH ARTICLE

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ABSTRACT

This study focuses on ceramic artifacts, specifically Kendi I and Kendi II, housed in the Museum of Asian Art (MoAA) at Universiti Malaya. The artifacts exhibit similarities that complicate their originality, authenticity, age, and provenance assessments. To address this, the research integrates both art historical analysis and scientific material characterization. Employing Panofsky's approach, the study analyzes ceramic types and decorative elements-colors, patterns, and shapes-reflecting the expected dynasty's reign. Concurrently, modern scientific techniques, including portable X-Ray Fluorescence (XRF) and handheld Raman Spectroscopy, are used to identify the chemical compositions (silica, alumina, and various fluxing agents) and mineralogical phases (quartz, mullite, anatase, albite). Raman peaks indicative of quartz and albite, along with XRF ratios aligning with known Ming Jingdezhen compositions, support the findings. The combined data from both analytical methods suggest that Kendi I likely originated from Jingdezhen during the Ming Dynasty, with Kendi II potentially having the same origin. The robust evidence from Panofsky's approach and material characterization helps clarify ambiguities regarding the artifacts' originality.

1. Introduction

Archaeological ceramic artefacts are typically kept as collections at universities, museums, or other institutions. The Museum of Asian Art (MoAA) at Universiti Malaya holds among the largest public collection of ancient kendi, with 156 kendis and 24 related vessels. The MoAA collection of ancient kendi is believed to originate from various countries in East and South-East Asia including Cambodia, China, India, Indonesia, Japan, Pakistan, Thailand, and Vietnam. Protection and conservation of rare specimens are for display and future research (Khoo and Rooney, 1991). For these reasons, MoAA kendi collection is continuously being studied, reassessed, and perfected through re-cataloguing, research, and exhibitions.

Kendi is a liquid-holding and pouring pitcher with a spout that is positioned diagonally between the body and shoulders to facilitate pouring. This shape is widely known across East and Southeast Asia, with special historical significance in the latter region. Despite its significance, little is known about kendi (Cort, 2017). The uniformity of pottery in terms of form, look, and quality may imply local manufacturing, according to archeological data (Lahlil etal., 2009). Ceramic identification is essential for archaeological research because ceramic fragments can provide information about the sources of clay and the tools used (Xanthopoulou et al., 2020).

Art historical techniques are a well-established method for artefact identification, assessing formal qualities, provenance, and context. Many methods have been used, including Panofsky's three-stage analysis (Iconographical Description, Iconographical Analysis, and Iconological Interpretation) (Abdullah et al., 2020; Franklin and Boak, 2019). According to Dias et al. (2013) and Ionescu and Hoeck (2020), traditional identification focuses on visual inspection of shape, decoration, color, texture, and manufacturing style, but it can be unreliable and inconsistent (Ionescu and Hoeck, 2020; Dias et al., 2013).

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Scientific characterization supplements traditional methods by providing objective data on raw materials, production techniques, and provenance. Crystalline structures, chemical composition, thermal stability, and microstructural changes in ceramics can be revealed by methods like Fourier Transform Infra-Red (FTIR), Raman Spectroscopy, X-Ray Diffraction (XRD), and Therma Gravimetric Analysis (TGA) (Xanthopoulou et al., 2020; Maritan, 2020; Montana, 2020; Gliozzo, 2020, Liu et al., 2023). For dating and determining origin, geochemical study of glazes and ceramic bodies is especially helpful (Bronitsky, 1986; Pollard and Hatcher, 1994; Pradell and Molera, 2020). Current research shows how integrating scientific analysis with art historical approaches improves knowledge of provenance, cultural context, and ceramic technology (Freitas et al., 2018; Botticelli et al., 2020; Quinn, 2018).

The MoAA kendi collection, which was catalogued by Oxford University Press in 1991 (Khoo and Rooney, 1991), contains a lot of information on the nation and time period. The provenance and authenticity of these vessels can be further ascertained by examining the quality of the raw materials, decorative elements, and production processes. Using both art historical and scientific methodologies, this study attempts to forecast the authenticity, age, and provenance of certain kendi vessels. The goal of the combined method is to provide a more precise understanding of these old artifacts while also reducing ambiguity.

2. Materials and Methods

This study focused on two East Asian kendi vessels that were identified from the 1990's catalogue of which their exact site of origin had not been identified with certainty. There were two types of kendi provided by the MoAA catalogue. The first vessel, Kendi I, (Serial number UM 78.774), was identified in the catalogue as a Ming Dynasty (1368-1644 CE) porcelain of the late 15th century. This was a miniature kendi with a dimension of 7.5 cm height X 8.2 cm depth. It had a distinctive spout in the shape of a hen's head with a decorative tail on the opposite shoulder as shown in Fig 1. It had a cup-shaped neck with flaring lips and broad shoulders, with a thick body and unglazed foot. It was decorated with a greyish blue and white underglaze decorated with tendrils, buds, and flowers (Khoo and Rooney, 1991). As shown in Fig 2, the second vessel is Kendi II (Serial number UM 78.646), identified in the 1991 catalogue as a 17th century celadon porcelain ware with a dimension of 17 cm height X 9.7 cm depth. The globular body, tall tubular neck, mammiform spouts, dry foot ring, and glazed base had an embossed ring and ribbed decoration (Khoo and Rooney, 1991).

The provenance of the two ancient ceramic kendi vessels were identified by using two combined methods, namely, Panofsky's approach and devices for materials characterization. The three stages in Panofsky's approach consist of iconographical description, iconographical analysis, and iconological interpretation (Cui, 2017).

Figure 1. Kendi I (Serial number: UM 78.774) Late 15th century porcelain

Figure 2. Kendi II (Serial number: UM 78.646) 17th century celadon porcelain.

For Kendi I, notable features include a globular body, distinct mouth shape, ruyi lappets on the shoulders, thin-lined foot, and blue-and-white glaze marked by crazing and grey weathered spots. Kendi II showcases a globular body with a tall tubular neck and mammiform spouts, ribbed decorations, and a solid light-greenish celadon body. Applying Panofsky's approach, observations made on the vessels were determined and defined visuals and highlighted any prior literary, cultural, or artistic features. The historical approach was employed to look into civilizations, classes, societal attitudes, and philosophical and theological viewpoints. Consequently, the origin of the kendi can be predicted by reconstructing and understanding the development of art history.

The body and glaze signature of the kendi were recorded using a handheld Rigaku ResQ Raman Spectrometer with an advanced 1064 nm excitation laser to acquire Raman spectra at 9-10.5 cm-1 resolution over a spectra range of 200-2500 cm-1. The measurements were performed on the glazed surface region of the body and the rim at the bottom of each kendi. The total observation time is 15 seconds with an exposure time of 2000 ms for all cases. Well-defined crystalline phases were revealed, and the peaks for specific atom bonding were correlated to the existence of chemical compounds in the body and the glaze of the vessels.

In addition to the Raman spectroscopy, the aforementioned evidence was supported by utilizing devices such as the handheld X-Ray Fluorescence (XRF). It extracted material components in the body and on the surface of the kendi. The XRF enabled the identification of any heavy metal oxide presence within the body of the kendi. The XRF was performed using the Thermo Scientific Niton XL3T Goldd+ at 50 kV and 200 µA. The beam was channelled towards the body of each kendi with a spot size of 20 mm.

The art historical approach of ceramic artefacts were based on a quantitative analysis of attributes based on its aesthetics. Material characterization described the fundamental properties of the material.The art historical approaches with different scientific material characterization techniques were carried out to determine the provenance of the ceramic artefacts. Thus, the main aim was to explore the possibility of supporting the historical approach with data from modern material characterization techniques.

3. Results and Discussion

The origin of the kendi can be predicted by reconstructing through understanding its development in art history. Panofsky's approach of combining the meaning of images with Cassirer's philosophy and Warburg's cultural history is applied in this study (Elsner and Lorenz, 2012).

3.1 Panofsky's Approach

The MoAA catalogue of the kendi collection published by the Oxford University Press in 1991 was used in this analysis (Khoo and Rooney, 1991). Additionally, other historical facts about the kendi based on the published catalogues from various museums and auction websites were also referred to as reliable resources in this study (Cornell University, 2020; Metropress Ltd., 2016). The Herbert F. Johnson Museum of Art, Cornell University, identified a vessel like Kendi I in their catalogues (Christie Manson & Woods Ltd, 2016). Based on the catalogues from these two auction websites, namely, LiveAuctioneers (LiveAuctioneers, 2015), and Metropress Ltd, (t/a Auction Technology Group) (Metropress Ltd, 2016), Kendi II may possibly originate from China or Japan. However, the 1991 MoAA's kendi catalogue identified Kendi II as a Japanese ware. The vessels in Fig 1 have ruyi lappets on the shoulders and flowers with tendrils on the main body. The MoAA kendi, i.e., Kendi I, does not have any decoration on the foot other than a thin line and a different opening mouth shape. The blue glaze section has crazy glazing with grey weathered spots in the dark and light blue areas and the white glaze section had crazed glazing in a vivid bluish-white tint.

In Fig 2, Kendi II had a round dry foot ring, a globular body, a tall tubular neck, mammiform spouts, and a glazed base. It also had a ribbed design on the body and spout, and an embossed ring at the point where the neck and body meet. The analysed shape and design are similar to Chinese kendi (University 2020; Metropress Ltd, 2016).

Based on art-historical facts, the shape and decorations of ancient China porcelain was full of auspicious symbols. The visual characteristics of Kendi I was closely related to ancient Chinese porcelain in the shape of a chicken (Welch, 2013). During the Ming dynasty between 1368 – 1644, the chicken was attributed to have five merits, namely. literacy, martial, bravery, benevolence, and honesty (Cui, 2017). The rise of chicken motifs on porcelain during the Chenghua Emperor was due to his desire for peace, harmony, and family. Kendi I was evidence of the antiquarian tradition in the 15th century of the Chinese dynasty (Miller and Louis, 2012). The symbol of ruyi on Kendi I was related to the Daoist symbols of longevity and a wish for a peaceful life (Jenjarassakul et al., 2000). Meanwhile, plants and flowers symbolize a maxim, moral attribute, or personification through their tendrils, buds, and flowers (Welch, 2013). Porcelain from Jingdezhen in Jiangxi Province had become a major part of Chinese culture by the late 17th century, with white and cobalt blue underglaze designs (Witkowski, 2016). Blue-and-white porcelain was widely sold to Western nations during the Ming dynasties, and later successive Qing dynasties (of around the year 1632 – 1912), making it an iconic Chinese ceramic (Wen et al., 2019).

The art-historical fact based on the catalogues published by auction websites Strausso&Co (Strausso&Co, 2019) and Ashmolean Museum, University of Oxford (Ashmolean Museum, 2013) indicates that Kendi II was highly likely a celadon kendi made in Japan. Arita ware was the main celadon manufacturing centre in Japan in the mid-17th century that produced Chinese-style celadon and blue-and-white porcelain for the Southeast Asian export trade (Lim, 2011). The Japanese wares were exported via Dutch and Chinese trading ships (Cullen, 2017). In fact, when it came to exports to the Southeast Asian market, Japanese production started in earnest at the end of the Ming dynasty to replace what was no longer available from China (Ford and Impey, 1989).

This was due to the impact of maritime bans on trading ceramics during the Ming and Qing dynasties (Tai et al., 2020). Based on the similarity in colour and shape, Kendi II could have originated from China (Metropress Ltd, 2016; Welch 2013). The kendi's solid, light-greenish body is typical of Longquan celadon ware, which China classifies as a form of porcelain (Prinsloo et al., 2005). Thus, it was possible that Kendi I and Kendi II both originated from China, but further investigation using the scientific method was still required to determine their origin. Further investigation based on material characterization was presented next.

3.2 Modern Analytical Characterization

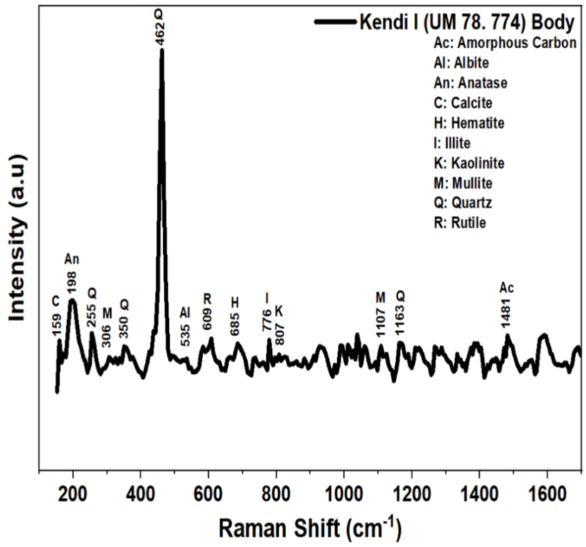
Based on Panofsky's Approach, Kendi I and Kendi II were highly probable to be from China. However, the scientific evidence may support the kendi's uniqueness by qualitatively detecting materials that was present in the body as well as the glaze on its surface. The information was compared with the data obtained from other reported literature to predict the originality of the kendi.

3.2.1 Raman Spectroscopy Analysis of Bodies of Kendis

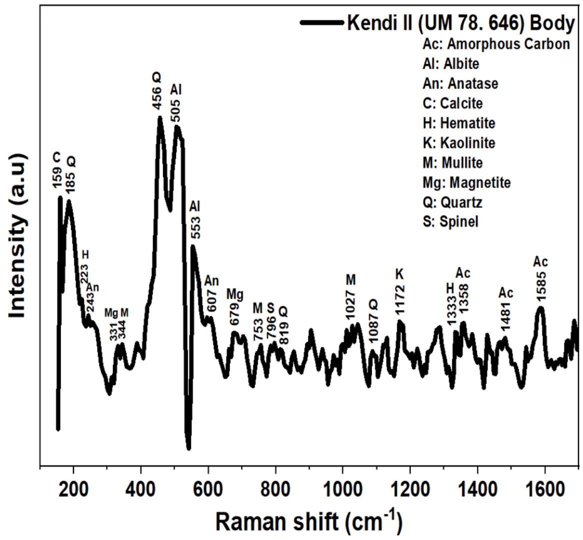
Raman Spectroscopy generated a spectrum of components in the material as shown in Fig 3. Fig 3 (a) and (b) are the spectrums taken at the bottom rim of both spouted vases. The bottom spot is the best location to represent the body of the kendi since all other parts are covered with glaze.

Fig 3(a) displayed a spectrum representing Kendi I. The figure shown that it was silica-rich with α-quartz peak at 462 cm^{-1}. That was consistent with the documented ingredients of raw materials used in South Chinese high-fired ceramics (Prinsloo et al., 2005). Meanwhile, calcite was found at 159 cm^{-1}, and it was also reported to be present in old ceramics (Lahlil et al. 2009). Oxide mineral of rutile was found at 609 cm^{-1} (Ricci et al., 2016). Its presence leads to the lack of any purification of the raw materials such as clay, kaolin and sand during the fabrication of the ancient Asian porcelain (Simsek Franci et al., 2020). Its presence also suggests that it was probably fired at a higher temperature during the Yuan or early Ming period (Prinsloo et al., 2005). In Fig 3 the Raman spectrum also showed a small peak at 685 cm^{-1} indicating Hematite (Simsek Franci et al., 2020). In addition to hematite, illite, anatase, polycrystalline mullite, and amorphous carbon were observed at 772 cm^{-1}, 198 cm^{-1}, 776 cm^{-1}, 306 cm^{-1} as well as 1107 cm^{-1}, and 1481 cm^{-1}, respectively (Prinsloo et al., 2005; Shoval et al., 2011). The presence of a large peak of polycrystalline mullite itself was a phase of well-fired porcelain (Prinsloo et al., 2005). The presence of all these elements confirms that Kendi I was an ancient Chinese ceramic.

Fig 3(b) showed a spectrum representing element presence in Kendi II. Quartz peaks were observed at 185 cm^{-1} (Widjaja et al., 2011), 456 cm^{-1} (Prinsloo et al., 2005; Shoval et al. 2011), and 1087 cm^{-1} (Bahçeli et al., 2016). Meanwhile, α-quartz covered a broad band at 458 cm^{-1} which was typical of glassy silica (Prinsloo et al., 2005).



(a)



(b)

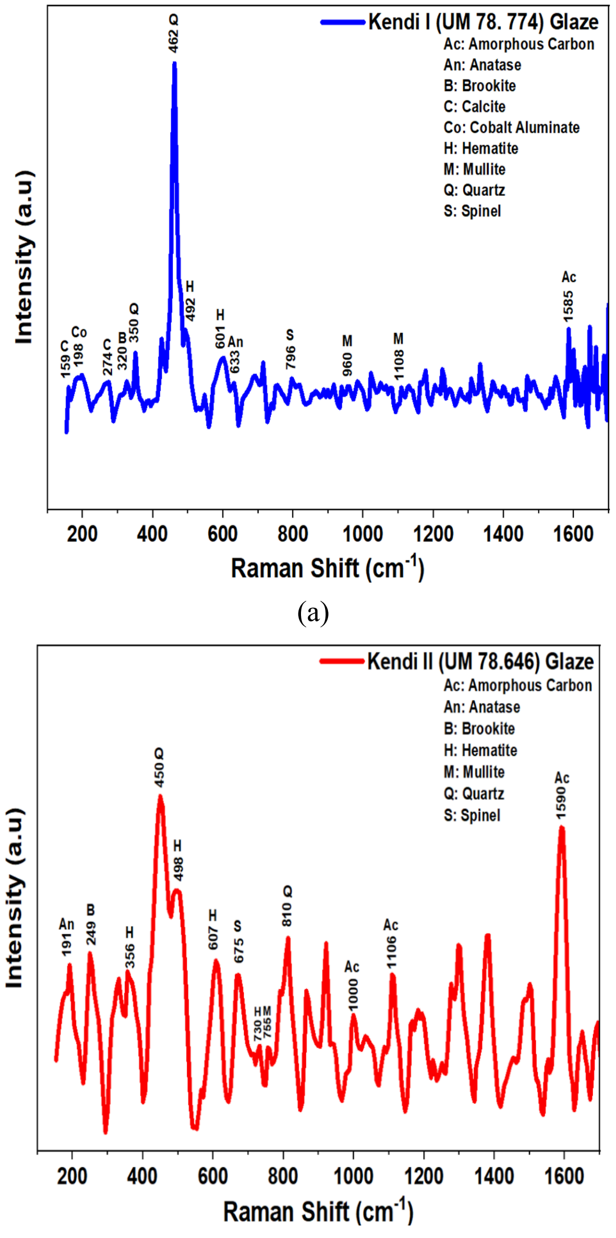
Figure 3. Raman pattern of kendi bodies **(a)** Kendi I **(b)** Kendi II

A peak of 159 cm^{-1} was identified as calcite (Bahçeli et al., 2016; Wen et al., 2019; Kock and De Waal, 2007). The presence of calcite and quartz in ceramics had a significant historical role in understanding the evolution of ancient Chinese ceramics (Wen et al., 2019). Additionally, hematite and magnetite appeared at 223 cm^{-1} (Ricci et al., 2016; Bahçeli et al., 2016), 1333 cm^{-1} (Bahçeli et al., 2016), and 331 cm^{-1} (Simsek Franci et al., 2020), 679 cm^{-1} (Bahçeli et al., 2016), respectively. Magnetite had a high atomic number and its presence beneath the burnished surface was caused the body to appear bright (Ionescu and Hoeck, 2020). The observation of such brightness could be observed in Kendi II. Among the peaks in this spectrum, albite was found at 505 cm^{-1} and 553 cm^{-1} peaks. A combination of quartz and albite indicated that these elements were utilized as the porcelain stone at the main manufacturing site in Jingdezhen as reported by Dias et al. (2013). The rest of the peaks were listed as: 243 cm^{-1} and 607 cm^{-1} which included anatase (Kock and De Waal, 2007); mullite: 344 cm^{-1}, 753 cm^{-1}, and 1027 cm^{-1} (Shoval et al., 2011), amorphous carbon: 1358 cm^{-1} (Kock and De Waal, 2007), and 1481 cm^{-1} (Bahçeli et al., 2016), and spinel: 796 cm^{-1} (Simsek Franci et al., 2020). The presence of amorphous carbon in ancient Chinese ceramics at 1481 cm^{-1} (Ricci et al., 2016; Ionescu and Hoeck, 2020) was reported to had firing temperature of 800-850 °C. The collection of these elemental compositions was consistent with the literature. Therefore, it was with cautious, evidence-linked that Kendi II originated from ancient China.

3.32 Raman Spectroscopy Analysis of Glazes of Kendis

Fig 4 (a) showed elements of glazes based on Raman spectroscopy. The primary peaks of quartz were located at 350 cm^{-1} (Widjaja et al., 2011) 462 cm^{-1} (Bahçeli et al., 2016; Prinsloo et al., 2005; Kock and De Waal, 2007) accordingly. Besides, calcite was displayed at 154 cm^{-1} and 274 cm^{-1} (Wen et al., 2019). The peaks at 492 cm^{-1} (Bahçeli et al., 2016) and 601 cm^{-1} (Kock and De Waal, 2007) indicated the presence of hematite (α-Fe_2O_3) (Simsek Franci et al., 2020) to indicate that Kendi I originated from the Ming dynasty (Kock and De Waal, 2007). Anatase was identified at 633 cm-1 (Prinsloo et al., 2005). The peaks among others were as follows: Brookite with the polymorphs of TiO_2: 320 cm^{-1} (Prinsloo et al., 2005); Mullite: 960 cm^{-1} (Simsek Franci et al., 2020) and 1108 cm^{-1} (Prinsloo et al., 2005); spinel-type phase at a temperature of 1000 °C: 796 cm^{-1} (Simsek Franci et al., 2020); Amorphous Carbon:1585 cm^{-1} (Kock and De Waal, 2007), and cobalt blue: 198 cm^{-1}. Carbon and cobalt blue pigments were mixed in Ming ceramics, resulting in a more intense blue colour (Kock and De Waal, 2007). Cobalt blue was used as a pigment in Chinese porcelain during the Ming Dynasty (Widjaja et al., 2011; Ricci et al., 2016, Germinario et al., 2024). Based on these relevant references and arguments, it was confirmed that Kendi I originated from the Ming Dynasty, China which existed between 1368 to 1644.

Crystalline phases in Kendi II was also displayed in Fig 4 (b). Primary peaks of quartz with glassy alumina silicate were discovered at 450 cm^{-1} and 810 cm^{-1} (Prinsloo et al., 2005). Hematite was also observed at locations 356 cm^{-1}, 730 cm^{-1} (Simsek Franci et al., 2020), and 607 cm^{-1} (Bahçeli et al., 2016). The peak at 191 cm^{-1} was exhibited by the anatase phase of TiO_2. Most Chinese ceramics contained TiO_2 (0.2–2.0%) as a raw material. When it was fired in reducing atmospheric pressure, the relative ratio of TiO_2 to iron oxides influences the shade of green colour in celadon glazes (Prinsloo et al., 2005). Other peaks that could be highlighted are brookite: 249 cm^{-1} (Prinsloo et al. 2005); mullite: 765 cm^{-1} (Simsek Franci et al., 2020); amorphous carbon: 1000 cm^{-1}, and spinel (Fe_2TiO_4): 675 cm^{-1} (Simsek Franci et al., 2020).



(a)

(b)

Figure 4. Raman pattern of kendi glaze for **(a)** Kendi I **(b)** Kendi II

The presence of amorphous carbon was related to carbonaceous which had been reported in pottery glazes for Ming porcelain (Prinsloo et al., 2005). Furthermore, spinel (Fe TiO) was said to had been highly fired at a temperature of more than 1000 °C when used in soft porcelain in 18th century (Simsek Franci et al., 2020). Based on the consistency of the materials found in the literature, Kendi II was hypothesized to have originated from the Ming dynasty in China.

3.2.3 XRF Analysis of Kendi I (Body and Glaze)

Blue-and-white porcelain was one of the most well-known porcelains, which was exported to Western nations during the Ming and Qing dynasties (Wen et al., 2019). The Jingdezhen underglaze blue porcelains were mainly composed of silica-alumina (i.e., SiO2-Al2O3) with the addition of flux agents in which primary components consisted of iron, manganese, cobalt, and nickel (Tite et al., 2012). The porcelain was said to be in abundance in quartz, with a high SiO2/Al2O3 weight percent ratio in the range of 4:1 to 5:1, according to Table 1 (Prinsloo et al., 2005). The main body had contents of low Al2O3, high SiO2, and high K2O concentrations in the range of 19.12% - 21.25%, 71.88% - 74.26%, and 3.61% 3.74% respectively. Other minor metal oxides can also be found as shown in Table 1. Table 1 also tabulated a list of weight percentages of metal oxides in the body of Kendi I as well as its glaze based on the dynasties. Among the familiar dynasties were Song (960-1279), followed by Yuan (1260 – 1368) and Ming (1368 -1644). Table 1 showed that Kendi I had a lower percentage of mullite. Alumina (Al2O3) as a composite in Mullite was thought to originate from Southern China, according to Table 1.

Subsequently, the presence of other metal oxides in Kendi I indicate that it had many similarities with the blue-white porcelain from Yuan or Ming dynasty of Jingdezhen Royal Kiln, South China (Wu et al., 2020). To ascertain these ambiguities, Jinxiu Wen defined a function (F) based on the porcelain compositions to distinguish porcelains from the Yuan, Ming, and Qing dynasties. If F (K2O, CaO, Al2O3) is less than 85.1, it indicated that the dynasty could be either Yuan or Ming. Whereas, if F (K2O, CaO, Al2O3) was greater than 85.1, the Qing dynasty can be proposed (Wen et al., 2019).

$$\mathbf{F(K_2O, CaO, Al_2O_3) = 5.37K_2O + 4.1CaO + 2.81Al_2O_3 \quad (1)}$$

Calculations showed that percentage of porcelain in Kendi I was 73.39 which was less than 85.1. Therefore, it was suggested that Kendi I originated from the Ming dynasty located in Jingdezhen, South China.

During Ancient China calcium-rich porcelain glazes were used for centuries, but after the Southern Song Dynasties, potassium-rich glazes replaced them (Simsek et al. 2015). The Mn-rich asbolite ores in the folk kilns of Jingdezhen throughout the Ming dynasties had MnO/CoO ratios ranging from 5.3 to 11.8 (Wen et al., 2019; Fischer and Hsieh, 2017; Simsek Franci, 2020) and similarly for Fe2O3/CoO the range was within 0.4 to 3.7 (Fischer and Hsieh, 2017; Simsek Franci, 2020). For Kendi I the ratio of MnO/CoO of blue-white underglaze porcelain was 9.84 and 2.68 for Fe2O3/CoO. These ratios were like that used in Jingdezhen folk kilns during the Ming dynasty.

Meanwhile, the chemical composition of the glaze can be used to estimate the age of Jingdezhen porcelains manufactured in any dynasty. The formulae of Si (Wen et al. 2019), in which S1, S2 and S3 denote Yuan, Ming and Qing dynasties, respectively, were manipulated in this determination.

Table 1. Chemical Composition of Porcelain Ceramic Bodies and Glazes wt (%) of Kendi I

Location	Dynasty	SiO_2	Al_2O_3	K_2O	CaO	TiO_2	MnO	Fe_2O_3	CoO	Na_2O	MgO	Reference
Body	SC	75.77	17.62	3.37	0.70	0.02	--	1.1	--	<1	0.30	(Tite et al., 2012)
	NS	64.05	28.96	1.8	1.72	0.86	0.05	0.84	--	0.54	1.18	(Tite et al., 2012)
	SS	78.62	15.89	2.80	0.70	0.05	--	0.60	--	0.80	0.20	(Tite et al., 2012)
	Yuan	72.39	20.52	3.40	0.13	0.05	--	1.23	--	1.90	0.16	(Tite et al., 2012)
	Ming	74.04	19.58	3.44	0.61	0.05	--	0.96	--	1.29	0.21	(Simsek et al.,2015)
	Kendi I	75.40	17.83	3.65	0.90	0.04	--	1.44	--	--	--	
Glaze	Kendi I	70.26	6.04	7.79	4.38	0.05	8.17	2.23	0.83	--	--	

*SC: Southern China, NS: Northern Song, SS: Southern Song

$$S_1 = 22.15K_2O + 6.02CaO + 25.79Na_2O + 10.83MnO - 100.35 \tag{2}$$

$$S_2 = 25.06K_2O + 5.99CaO + 24.42Na_2O + 13.37MnO - 105.86 \tag{3}$$

$$S_3 = 19.47K_2O + 5.03CaO + 18.72Na_2O + 9.99MnO - 67.42 \tag{4}$$

The calculated Si (i=1,2,3) value of Kendi I were 74.39, 100.23, and 89.79 with respect to Yuan, Ming, and Qing Dynasties. The maximum value of Si is found to match S2. Therefore, this proved that the blue-and-white porcelain Kendi I originated from the Ming dynasty from the kiln located in Jingdezhen.

3.2.4 XRF Analysis of Celadon Porcelain Kendi II (Body and Glaze)

It had been reported that the porcelain celadon ceramic kendis of Southern dynasty had relatively high silicon but low iron and aluminium contents. Whereas, celadon from the Northern part showed the contradictory. At the same time, content of specific oxides varied from one dynasty to another (Sang et al., 2019). It had also been reported that celadon bodies from Jingdezhen contained more CaO and raw materials used in Jingdezhen kilns had a significant content of albite. The body composition of celadon ceramics was tabulated in Table 2. It showed that the body is enriched with a combination of Al2O3 and SiO2, with relatively large amounts of flux oxide K2O.

Table 2. Chemical Composition Analysis of Kendi II Compared to Celadon Bodies and Glazes wt (%)

Location	Dynasty	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	CaO	MgO	K_2O	Na_2O	MnO	Reference
Body	TD	69.39	20.94	0.22	1.69	0.51	0.59	5.13	0.31		(Sang et al., 2019)
	FD	62.93	28.38	1.13	2.5	0.92	1.06	1.75	0.21		(Sang et al., 2019)
	Song	67.03	25.33	0.77	2.06	0.38	0.83	2.28	0.29		(Sang et al., 2019)
	NS	68.99	21.71	0.14	1.86	0.16	0.33	5.51	0.30		(He et al., 2016)
	SS	67.85	22.62	0.15	2.28	0.23	0.36	5.16	0.35		(He et al., 2016)
	Jin	70.67	21.36	0.67	1.98	0.41	1.03	2.46	0.39		(Sang et al., 2019)
	Yuan	67.06	23.55	0.67	2.23	0.16	0.36	5.13	0.37		(He et al., 2016)
	Ming	72.40	19.62	0.08	1.28	0.51	0.39	4.20	0.52		(He et al., 2016)
	Kendi II	77.27	14.41	0.10	1.53	2.11	---	4.67	--		
Glaze	TD	62.5	11.43	0.18	2.04	15.81	1.62	2.7	--	0.7	(Wu et al., 2015)
	FD	59.4	16.0	0.4	1.8	16.0	2.0	3.4	0.3	0.6	(Prinsloo et al., 2005)
	NS	63.2	16.8	0.2	1.4	13.0	1.1	3.3	0.6	0.4	(Prinsloo et al., 2005)
	SS	68.6	14.3	0.02	0.7	10.4	0.4	5.0	0.1	--	(Prinsloo et al., 2005)
	Yuan	67.4	16.7	0.2	1.5	6.8	0.6	5.5	1.1	0.4	(Prinsloo et al., 2005)
	Ming	67.6	15.0	0.3	1.4	6.3	1.7	6.5	1.1	--	(Prinsloo et al., 2005)
	LS 1	67.1	15.7	0.2	2.63	4.37	1.22	6.53	0.82	0.22	(Prinsloo et al., 2005)
	LS 2	68.19	15.72	0.13	2.03	4.48	0.52	6.98	0.99	0.19	(Prinsloo et al., 2005)
	Kendi II	68.1	9.00	0.16	3.41	5.02	0.98	10.16	--	0.21	

*TD: Tang Dynasty, FD: Five Dynasty, NS: Northern Song, SS: Southern Song, LS: Literature Sample

The mineral albite was found in the body of Kendi II as observed in the Raman spectroscopy is comparable to the principal raw material of potassium feldspar (He et al., 2016). The body had a relatively low amount of Al2O3 (14.41%) with a high amount of SiO2 (77.27%). Apart from these two minerals, Kendi II also possessed a low amount of Fe2O3 and TiO2 but a higher amount of K2O minerals. These facts match well with the celadon kendis that were found in Jingdezhen, Southern China (Franklin and Boak, 2019; Tite et al., 2012). Low Al2O3, Fe2O3, TiO2 but high SiO2 and K2O indicated that the celadon Kendi II may have originated from Jingdezhen, Southern China during the Ming dynasty (Franklin and Boak, 2019; Tite et al., 2012).

The glaze used to decorate the ceramics basically depends on CaO, Fe2O3, MgO, K2O, and MnO mineral contents. As an example, the density of a green glaze is determined by the iron oxide content which was affected by the fire's redox atmosphere (Sang et al., 2019). The analysis by Li shows that Chinese Celadon wares had high concentrations of K2O, CaO, TiO2, Fe2O3, CoO, and MnO. These metal oxides work best as ceramic colours (Li et al., 2012). The main difference between these dynasties was the ratio of CaO to K2O. Fig 5 was plotted to visualize the spread of the ratio based on the different dynasties (Tite et al., 2012). The results include the ratio embedded in Kendi II. It was observed that the ratio gradually decreases as the different dynasties progress. Worth to note that results of the LS 1 and LS 2 were originated from the Ming dynasty. Since the ratio executed from Kendi II had a ratio of 0.5, which is nearest to the Ming dynasty, it is that Kendi II originated in the Ming dynasty. This prediction indirectly refutes the vague claim that Kendi II is Japanese ceramic porcelain as reported by Jee et al. (Khoo and Rooney, 1991).

4. Conclusion

In this study, two kendis named as Kendi I and Kendi II, were investigated to predict their originalities in terms of provenance. This may lead to also determining the dynasty and respective period they came from. The combination of two methods used such as art historical and material characterization techniques to analyse the kendis. For art historical method, the Panofsky Approach was applied for analysing aesthetic views like attributions and motifs. Further confirmation proceeded to determine the composition of materials in body and glaze of the kendis with the help of a handheld XRF and Raman spectroscopy. It is predicted with strong evidence that Kendi I originated from Jingdezhen during the Ming Dynasty (1368-1644 CE), China. Although Kendi II was reported earlier as a Japanese ceramic celadon, this study could safely predict that it originated from China during the Ming Dynasty (1368-1644 CE). The synergy contributed from both methods has enriched the knowledge and technique in predicting the provenance of these two ceramic kendis.

Data Availability

All data produced in this study are available under request.

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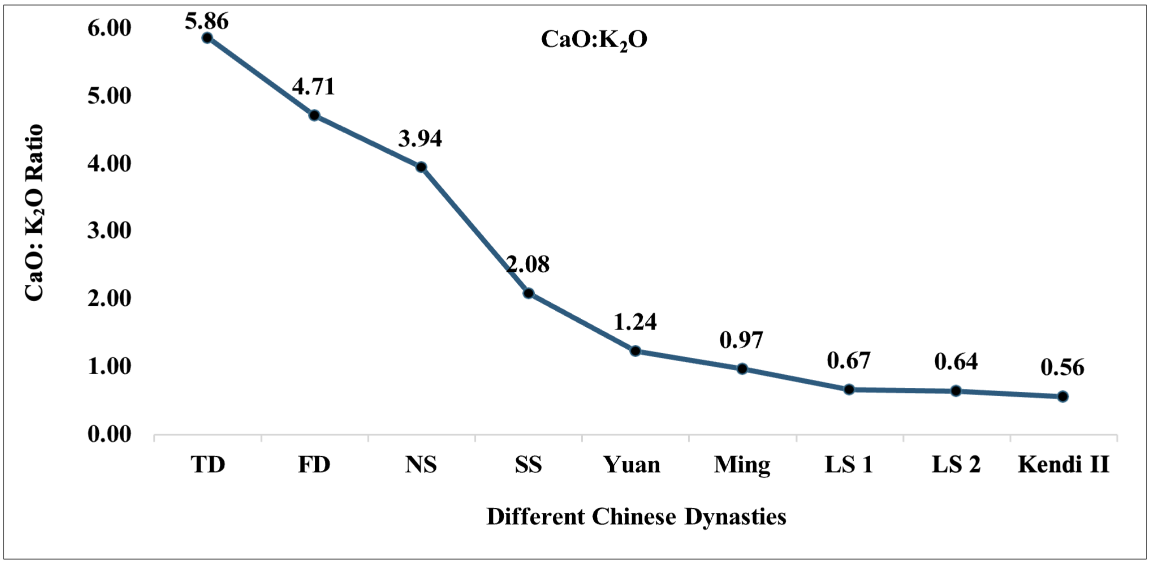

Figure 5. Comparison of CaO:K_2O in different dynasties of celadon glaze.

Conflict of Interest

The authors declare that they have no conflicts of interest.

Declaration

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

References

Abdullah, A. H., Ibrahim, Y., & Khalid, R. I. R. (2020). An iconographical analysis based on the Erwin Panofsky theory on the Malayness in the paintings of Amron Omar and Haron Mokhtar. International Journal of Academic Research in Business and Social Sciences, 10(9). https://doi.org/10.6007/ijarbss/v10-i9/7835

Ashmolean Museum, University of Oxford. (2013). Beginnings of the European export trade. http://jameelcentre.ashmolean.org/collection/4/1238/128 1

Bahçeli, S., Güleç, G., Erdoğan, H., & Söğüt, B. (2016). Micro-Raman and FT-IR spectroscopic studies of ceramic shards excavated from ancient Stratonikeia city at Eskihisar village in West-South Turkey. Journal of Molecular Structure, 1106, 316–321. https://doi.org/10.1016/jmolstruc.2015.10.036

Botticelli, M., Mignardi, S., de Vito, C., Liao, Y. W., Montanari, D., Shakarna, M., … Medeghini, L. (2020). Variability in pottery production at Khalet al-Jam'a necropolis, Bethlehem (West Bank): From the Early-Middle Bronze to the Iron Age. Ceramics International, 46(10), 16405–16415. https://doi.org/10.1016/j.ceramint.2020.03.200

Bronitsky, G. (1986). The use of materials science techniques in the study of pottery construction and use. Advances in Archaeological Method and Theory, 9, 209–276. https://doi.org/10.1016/b978-0-12-003109-2.50008-8

Christie Manson & Woods Ltd. (2016). An Arita celadon kendi (pouring vessel), Edo period (late 17th century). https://onlineonly.christies.com/s/japanese-art-its-influence-european-court/arita-celadon-kendi-

Cort, L. A. (2017). Container jars from the Maenam Noi kilns, Thailand: Use and reuse along maritime trade routes in Asia. *Bulletin de l'École Française d'Extrême-Orient, 103*(1), 267–296. https://doi.org/10.3406/befeo.2017.6252

Cornell University. (2020). Chicken-shaped ewer. Herbert F. Johnson Museum of Art, Ithaca, New York.

Cui, Y. (2017). *Speaking for the chicken cup: A case study in Chinese art collecting* (Doctoral dissertation, The Australian National University).

Cullen, L. (2017). The Nagasaki trade of the Tokugawa era: Archives, statistics, and management. *Japan Review, 31*, 69–104. https://www.jstor.org/stable/44427700

Dias, M. I., Prudêncio, M. I., Pinto De Matos, M. A., & Rodrigues, A. L. (2013). Tracing the origin of blue and white Chinese porcelain ordered for the Portuguese market during the Ming dynasty using INAA. *Journal of Archaeological Science, 40*(7), 3046–3057. https://doi.org/10.1016/j.jas.2013.03.007

Elsner, J., & Lorenz, K. (2012). The genesis of iconology. *Critical Inquiry, 38*(3), 483–512. https://doi.org/10.1086/664548

Fischer, C., & Hsieh, E. (2017). Export Chinese blue-and-white porcelain: Compositional analysis and sourcing using non-invasive portable XRF and reflectance spectroscopy. *Journal of Archaeological Science, 80*, 14–26. https://doi.org/10.1016/j.jas.2017.01.016

Ford, B. B., & Impey, O. R. (1989). *Japanese art from the Gerry Collection in the Metropolitan Museum of Art*. Metropolitan Museum of Art.

Franklin, K., & Boak, E. (2019). The road from above: Remotely sensed discovery of early modern travel infrastructure in Afghanistan. *Archaeological Research in Asia, 18*, 40–54. https://doi.org/10.1016/j.ara.2019.02.002

Freitas, R. P., Coelho, F. A., Felix, V. S., Pereira, M. O., de Souza, M. A. T., & Anjos, M. J. (2018). Analysis of 19th century ceramic fragments excavated from Pirenópolis (Goiás, Brazil) using FT-IR, Raman, XRF and SEM. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, 193*, 432–439. https://doi.org/10.1016/j.saa.2017.12.047

Germinario, C., Cultrone, G., De Bonis, A., Izzo, F., Langella, A., Mercurio, M., Nodari, L., Vyhnal, C. R., & Grifa, C. (2024). μ-Raman spectroscopy as a useful tool for improving knowledge of ancient ceramic manufacturing technologies. *Applied Clay Science.* https://doi.org/10.1016/j.clay.2024.107347

Gliozzo, E. (2020). Ceramic technology: How to reconstruct the firing process. *Archaeological and Anthropological Sciences, 12*(11). https://doi.org/10.1007/s12520-020-01133-y

He, Z., Zhang, M., & Zhang, H. (2016). Data-driven research on chemical features of Jingdezhen and Longquan celadon by energy dispersive X-ray fluorescence. *Ceramics International, 42*(4), 5123–5129. https://doi.org/10.1016/j.ceramint.2015.12.030

Ionescu, C., & Hoeck, V. (2020). Ceramic technology: How to investigate surface finishing. *Archaeological and Anthropological Sciences, 12*(9). https://doi.org/10.1007/s12520-020-01144-9

Jenjarassakul, W., Chinalai, V., & Chinalai, L. J. (2000).*Yao Lin Tan Shaman's Robes* (pp. 94–99). London.

Khoo, J. E., & Rooney, D. (1991). *Kendi: Pouring vessels in the University of Malaya collection*. Oxford University Press

Kock, L. D., & De Waal, D. (2007). Raman studies of the underglaze blue pigment on ceramic artefacts of the Ming dynasty and of unknown origins. *Journal of Raman Spectroscopy, 38*(11), 1480–1487. https://doi.org/10.1002/jrs.1805

Prinsloo, L. C., Wood, N., Loubser, M., Verryn, S. M. C., & Tiley, S. (2005). Re-dating of Chinese celadon shards excavated on Mapungubwe Hill, a 13th century Iron Age site in South Africa, using Raman spectroscopy, XRF and XRD. *Journal of Raman Spectroscopy, 36*(8), 806–816. https://doi.org/10.1002/jrs.1367

Li, L., Feng, S. L., Feng, X. Q., Xu, Q., Yan, L. T., Ma, B., & Liu, L. (2012). Study on elemental features of Longquan celadon at Fengdongyan kiln site in Yuan and Ming dynasties by EDXRF. *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, 292*, 25–29. https://doi.org/10.1016/j.nimb.2012.09.034

Lim, T. (2011). Re-centering trade periphery through fired clay: A historiography of the global mapping of Japanese trade ceramics in the premodern global trading space. *Sino-Japanese Studies, 18*.

Liu, S., Wu, H., & Zhao, X. (2023). Non-destructive provenance analysis of 15th–17th century export porcelains to Europe using portable XRF and Raman spectroscopy. *Journal of Archaeological Science: Reports*, 55, 103925. https://doi.org/10.1016/j.jasrep.2023.10392

LiveAuctioneers. (2015). 17th c. Ming dynasty celadon kendi [Auction listing]. https://www.liveauctioneers.com/item/34896239_17th-c-ming-dynasty-celadon-kendi-17th-c-ming-dynasty

Maritan, L. (2020). Ceramic abandonment: How to recognise post-depositional transformations.*Archaeological and Anthropological Sciences, 12*(8). https://doi.org/10.1007/s12520-020-01141-y

Metropress Ltd (t/a Auction Technology Group). (2016). A good 17th/18th century Chinese celadon-glazed porcelain kendi, with ribbed sides and spout [Auction listing]. https://www.the-saleroom.com/en-gb/auction-catalogues/john-nicholson/catalogue-id-srjo10119/lot-dea18a26-3e98-49bb-98a8-a66c00c37f33

Miller, P. N., & Louis, F. (2012). *Antiquarianism and intellectual life in Europe and China, 1500–1800.*University of Michigan Press.

Montana, G. (2020). Ceramic raw materials: How to recognize them and locate the supply basins—Mineralogy, petrography. *Archaeological and Anthropological Sciences, 12*(8). https://doi.org/10.1007/s12520-020-01130-1

Pollard, A. M., & Hatcher, H. (1994). The chemical analysis of Oriental ceramic body compositions: Part 1: Wares from North China. *Archaeometry, 36*(1), 41–62. https://doi.org/10.1111/j.1475-4754.1994.tb00710.x

Pradell, T., & Molera, J. (2020). Ceramic technology: How to characterise ceramic glazes. *Archaeological and Anthropological Sciences, 12*(8). https://doi.org/10.1007/s12520-020-01136-9

Prinsloo, L. C., Wood, N., Loubser, M., Verryn, S. M. C., & Tiley, S. (2005). Re-dating of Chinese celadon shards excavated on Mapungubwe Hill, a 13th century Iron Age site in South Africa, using Raman spectroscopy, XRF and XRD. *Journal of Raman Spectroscopy, 36*(8), 806–816. https://doi.org/10.1002/jrs.1367

Quinn, P. S. (2018). Scientific preparations of archaeological ceramics: Status, value and long term future. *Journal of Archaeological Science, 91*, 43–51 https://doi.org/10.1016/j.jas.2018.01.001

Ricci, G., Caneve, L., Pedron, D., Holesch, N., & Zendri, E. (2016). A multi-spectroscopic study for the characterization and definition of production techniques of German ceramic sherds. *Microchemical Journal, 126*, 104–112. https://doi.org/10.1016/j.microc.2015.12.009

Sang, Z., Wang, F., Duan, X., Mu, T., Ren, Z., Wei, X.,Jiao, Y. (2019). Analysis of the celadon characteristics of the Yaozhou kiln. *Ceramics International, 45*(17), 22215–22225. https://doi.org/10.1016/j.ceramint.2019.07.245

Shoval, S., Boudeulle, M., & Panczer, G. (2011). Identification of the thermal phases in firing of kaolinite to mullite by using micro-Raman spectroscopy and curve-fitting. *Optical Materials, 34*(2), 404–409. https://doi.org/10.1016/j.optmat.2011.08.031

Simsek, G., Colomban, P., Wong, S., Zhao, B.,Rougeulle, A., & Liem, N. Q. (2015). Toward a fast non-destructive identification of pottery: The sourcing of 14th–16th century Vietnamese and Chinese ceramic shards. *Journal of Cultural Heritage, 16*(2), 159–172. https://doi.org/10.1016/j.culher.2014.03.003

Simsek Franci, G. (2020). Handheld X-ray fluorescence (XRF) versus wavelength dispersive XRF: Characterization of Chinese blue-and-white porcelain sherds using handheld and laboratory-type XRF instruments. *Applied Spectroscopy, 74*(3), 314–322. https://doi.org/10.1177/0003702819890645

Simsek Franci, G., Akkas, T., Yildirim, S., Yilmaz, S., & Birdevrim, A. N. (2020). Characterization of a Jian-like sherd with the optical microscope, confocal Raman, wavelength-dispersive X-ray fluorescence, and portable XRF spectrometers. *Journal of Raman Spectroscopy, 51*(8), 1343–1352. https://doi.org/10.1002/jrs.5904

Strausso & Co. (2019). An Arita celadon kendi. https://www.straussart.co.za/auctions/lot/18-mar-2019/124

Tai, Y. S., Daly, P., McKinnon, E. E., Parnell, A., Feener, R. M., Majewski, J., … Sieh, K. (2020). The impact of Ming and Qing dynasty maritime bans on trade ceramics recovered from coastal settlements in northern Sumatra, Indonesia. *Archaeological Research in Asia, 21*, 100174.https://doi.org/10.1016/j.ara.2019.100174

Tite, M. S., Freestone, I. C., & Wood, N. (2012). An investigation into the relationship between the raw materials used in the production of Chinese porcelain and stoneware bodies and the resulting microstructures. *Archaeometry, 54*(1), 37–55. https://doi.org/10.1111/j.1475-4754.2011.00614.x

Welch, P. B. (2013). *Chinese art: A guide to motifs and visual imagery*. Tuttle Publishing.

Wen, J., Chen, Z., Zeng, Q., Hu, L., Wang, B., Shi, J., Zhang, G. (2019). Multi-micro analytical studies of blue-and-white porcelain (Ming dynasty) excavated from Shuangchuan Island. *Ceramics International, 45*(10), 13362–13368. https://doi.org/10.1016/j.ceramint.2019.04.031

Witkowski, T. H. (2016). Early history and distribution of trade ceramics in Southeast Asia. Journal of Historical Research in Marketing, 8(2), 216–237. https://doi.org/10.1108/JHRM-07-2015-0026

Widjaja, E., Lim, G. H., Lim, Q., Mashadi, A. B., & Garland, M. (2011). Pure component Raman spectral reconstruction from glazed and unglazed Yuan, Ming, and Qing shards: A combined Raman microscopy and BTEM study. *Journal of Raman Spectroscopy, 42*(3), 377–382. https://doi.org/10.1002/jrs.2721

Wu, J., Ma, H., Wood, N., Zhang, M., Qian, W., Wu, J., & Zheng, N. (2020). Early development of Jingdezhen ceramic glazes. *Archaeometry, 62*(3), 550–562. https://doi.org/10.1111/arcm.12539

Wu, J., Zhang, M., Hou, T., Li, Q., & Wu, J. (2015) Analysis of the celadon of the Tang and the Five Dynasties unearthed from Nan Kiln and Lantian Kiln site of Jingdezhen, China. *Ceramics International, 41*(5), 6851–6857. https://doi.org/10.1016/j.ceramint.2015.01.134

Xanthopoulou, V., Iliopoulos, I., & Liritzis, I. (2020). Characterization techniques of clays for the archaeometric study of ancient ceramics: A review *Scientific Culture, 6*(2), 73–86. https://doi.org/10.5281/zenodo.3724849