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Characterization of Çeşni Tiles from the Tekfur Palace Excavations by Portable X-ray Fluorescence Spectrometry

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Abstract: After the 2010s, numerous examples of *çeşni* fragments—used as test pieces to evaluate color performance and glaze compatibility—were unearthed during the İznik Tile Kilns Excavation (Bursa), while comparable sherds were also recovered from excavations at Tekfur Palace in Istanbul. Considering historical evidence indicating the involvement of İznik craftsmen in tile production at Tekfur Palace, this study investigates the technological compatibility of these *çeşni* examples with İznik production traditions. To this end, glazes, decorative pigments, and ceramic bodies were analyzed using portable X-ray fluorescence (pXRF) spectroscopy. The chemical composition data reveal the presence of two principal production groups. The first group consists of tiles with stonepaste bodies, low lead oxide contents in the glaze (<10 wt%), and an average tin oxide content of approximately 2 wt%. The second group is characterized by lead–alkali glazes applied over ceramic bodies rich in lime and clay, indicating the use of different raw materials and technological choices. These results suggest that multiple production practices were employed during the relatively short-lived tile manufacture at Tekfur Palace. The decorative palette encompasses a wide chromatic range, including yellow, red, brown, black, blue, green, and turquoise. pXRF analyses identified the use of Naples yellow for yellow decoration, chromite–spinel mixtures or pure spinel for black areas, and cobalt ores both with and without arsenic for blue decoration. Overall, the study provides new archaeometric evidence that enhances our understanding of technological diversity in Ottoman tile production during the 18th century.

Keywords: Tekfur Palace, Ottoman tiles, 18th-century, cobalt blue, Naples yellow.

Tekfur Sarayı Kazılarında Ortaya Çıkarılan Çeşni Çinilerinin Taşınabilir X-ışını Floresans Spektrometresi ile Karakterizasyonu

Özet: 2010'lu yıllardan sonra, renk performansını ve sır uyumluluğunu değerlendirmek amacıyla test parçaları olarak kullanılan çok sayıda çeşni parçası, İznik Çini Fırınları Kazısı (Bursa) sırasında ortaya çıkarılmış; benzer nitelikteki parçalar İstanbul'daki Tekfur Sarayı kazılarında da ele geçirilmiştir. Tarihsel veriler, Tekfur Sarayı'ndaki çini üretiminde İznikli ustaların yer aldığını göstermektedir. Bu bağlamda, bu çalışma söz konusu çeşni örneklerinin İznik üretim gelenekleriyle olan teknolojik uyumluluğunu araştırmaktadır. Bu amaçla, sırlar, bezeme pigmentleri ve seramik hamurlar taşınabilir X-ışını floresans (pXRF) spektrometresi kullanılarak analiz edilmiştir. Kimyasal bileşim verileri iki ana üretim grubunun varlığını ortaya koymaktadır. İlk grup, sert çini (*stonepaste*) hamurlu gövdelere sahip, sırlarında düşük kurşun oksit içeriği (<%10 ağırlıkça) bulunan ve ortalama yaklaşık %2 ağırlıkça kalay oksit içeren çinilerden oluşmaktadır. İkinci grup ise, kireç ve kil bakımından zengin seramik bünyeler üzerine uygulanmış kurşun–alkali sırlarla karakterize edilmekte olup, farklı hammadde kullanımlarına ve teknolojik tercihlere işaret etmektedir. Bu sonuçlar, Tekfur Sarayı'ndaki görece kısa süreli çini üretimi sırasında birden fazla üretim pratiğinin uygulandığını düşündürmektedir. Bezeme paleti; sarı, kırmızı, kahverengi, siyah, mavi, yeşil ve turkuvazı içeren geniş bir renk aralığını kapsamaktadır. pXRF analizleri, sarı bezemede Napoli sarısının, siyah alanlarda kromit–spinel karışımlarının ya da saf spinelin, mavi bezemede ise arsenikli ve arseniksiz kobalt cevherlerinin kullanıldığını ortaya koymuştur. Genel olarak bu çalışma, Tekfur Sarayı çini atölyelerinde 18. yüzyılda yürütülen Osmanlı çini üretimine ait teknolojik çeşitliliğin anlaşılmasına yönelik yeni arkeometrik kanıtlar sunmaktadır.

Anahtar Kelimeler: Tekfur Sarayı, Osmanlı çinileri, 18. yüzyıl, kobalt mavisi, Napoli sarısı.

Article

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1.Introduction

Tile production at Tekfur Palace, located in the Fatih district of Istanbul, was initiated in the 18th century during the reign of Sultan Ahmed III. Archaeological excavations that began at Tekfur Palace in 1993 recovered a large number of ceramic fragments, including tiles, European porcelains, and various red- and white-bodied wares. In addition to these ceramic finds, raw materials and pigments, as well as frit and slag samples, were also identified (Geçkinli, Göktaş, Süer, and Yenişehirlioğlu, 2001).

The identification of tile kilns during the excavation campaigns conducted between 1993–1995 and 2000–2001 clearly demonstrated that production was carried out within the palace complex. These findings have provided detailed insights into the production process and technology. A portion of the materials recovered from the excavations is currently on display at the Tekfur Palace Museum, which opened to the public in 2019 (Yenişehirlioğlu, 2023).

According to Ottoman archival documents, Sultan Ahmed III (1703–1730) and Grand Vizier Nevşehirli Damat İbrahim Pasha aimed to transfer İznik tile production—already in decline since the mid-17th century—to Istanbul. To this end, tile craftsmen from İznik, together with kiln plans, were brought to Tekfur Palace, and production was initiated following an imperial decree. In 1718, two master tile makers were brought from İznik with the aim of producing tiles in the İznik style. However, the tiles produced at Tekfur Palace failed to reach the same technical and aesthetic standards as those of İznik, and production ceased by 1730 (Altun, 1997).

After the 2010s, experimental ceramic and tile fragments displaying brushstrokes of varying thickness, direction, and color beneath transparent glazes of different compositions (alkaline or lead-rich lead-alkali) were unearthed at the İznik Tile Kilns Excavation site. In Turkish art-historical scholarship, such experimental pieces are commonly referred to as çeşni. The discovery of comparable examples in the Tekfur Palace excavations indicates that the systematic experimental production process documented at İznik also continued at Tekfur Palace.

The examination of comparable examples using different characterization techniques provides valuable information on the raw materials used in production and serves as a reference for provenance determination. In this study, çeşni-style tiles excavated from the Tekfur Palace Tile Kilns between 1995 and 2001, and currently exhibited at the Tekfur Palace Museum, were investigated using a handheld portable X-ray fluorescence (pXRF) spectrometer. The aim was to determine the chemical compositions of the glazes and the colored decorative areas, covering a wide chromatic range including yellow, red, brown, black, blue, green, and turquoise. In addition, the body compositions of two tile sherds were also examined by pXRF.

2. Materials and Methods

2.1 Materials

In this study, a total of 10 tile samples decorated with colored paints and covered by a transparent glaze shown in Figure 1 were examined. The samples were coded using the abbreviation TKF, followed by the analysis number. Nine of these samples were fixed to cardboard on an inclined platform, while the larger sample was displayed in a showcase positioned in front of the platform. During the analyses, the detachment of one sample from the cardboard allowed ceramic body analysis to be carried out on the cross-sections of two samples. In addition, the transparent glazes and decorative colors of all samples were characterized using a pXRF instrument, and the results are presented as oxide weight percentages.

2.2 Methods

Elemental semi-quantitative analyses were performed non-destructively using a handheld X-ray fluorescence (XRF) spectrometer (Hitachi X-MET 8000 Expert Geo, Oxford Instruments, Abingdon, UK). The instrument was placed in direct contact with the sherds, on the surface for colored area and transparent glaze measurements and on the cross-section for body analysis when possible. The instrument is equipped with a rhodium (Rh) target X-ray tube (4 W, maximum 50 kV) and a silicon drift detector (SDD). Measurements were carried out using the Mining Light Elements method, which involves two shots: a low energy shot (10 keV) for the detection of elements with Z ≥ Mg, mainly in the ceramic body, and a high-energy shot (40 keV) to identify network modifiers in the glaze and coloring agents in the colored areas. Sodium cannot be reliably detected by handheld pXRF due to the strong absorption of its low-energy characteristic X-rays by air and the detector window.

The beam size at the sample surface was 10.7 × 9.4 mm, and a built-in camera was used to monitor the analyzed area. Due to variations in the mineral composition of the body and differences in glaze thickness, measurements were taken at a minimum of three different locations on the ceramic paste, glaze, and colored regions, with an acquisition time of 30 s per spot.

The results, calculated as the mean of three-point analyses, are reported for the ceramic body and each decorative color, including the transparent glaze layer, in terms of oxide weight percent.

Elemental data were obtained using the instrument's pre-installed calibration (Mining Light Elements method) and subsequently converted to oxides using appropriate stoichiometric conversion factors. The standard deviations for the most representative elements—Al, Si, K, Ca, Pb, and Sn—are ±0.03, ±0.04, ±0.006, ±0.008, ±0.03, and ±0.003, respectively. Only Mg, the lowest-Z element measurable by pXRF, exhibits a higher standard deviation of ±0.2.

For semi-quantitative evaluation, the Kα lines of major elements (Mg, Al, Si, K, Ca), transition metals (Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As), and trace elements (Rb, Sr, Zr, Ba, Bi), as well as the L lines of Pb and Sn, were considered. Instrument calibration was verified using mineral standards to ensure accurate measurements and high detection capability for ceramic materials.

3. Results and Discussion

3.1. Glaze and Body Analysis

In the scientific research project conducted by Prof. Dr. A. Emel Geçkinli (2001) on the finds from Tekfur Palace, the aim was to identify the differences between Tekfur Palace tiles and İznik ceramics in terms of body, slip, and glaze characteristics, and to shed light on the decline of Ottoman ceramic technology during the 18th century. Within this framework, the results of characterization studies carried out on a total of 11 decorated and undecorated tile samples selected from the Tekfur Palace excavations were reported.

According to the results, two different types of ceramic bodies were used in Tekfur Palace tiles; both the body and the slip were rich in clay, and the glazes exhibited a lead–alkali character, containing 30–50 wt% lead oxide. However, unlike İznik ceramics, these glazes were found to contain no tin oxide. In the study conducted in 2001, the absence of tin oxide in the glaze compositions was considered a noteworthy issue, despite the fact that ceramic production at Tekfur Palace was carried out by craftsmen brought from İznik (Geçkinli, 2005).

In another study focusing on tiles preserved in the storage rooms of the Topkapı Palace Museum, a comparable example dating to the 18th century and originating from the Hekimoğlu Ali Paşa Mosque in Istanbul—traditionally attributed to Tekfur Palace production—was examined. The ceramic body of the tile was identified as a stonepaste type containing coarse free quartz. Micro-analytical results of the glaze and body indicated a high lime content in the body (5–8 wt%) and a low clay content (2.2 wt% Al_2O_3). The glaze composition was found to contain an average of 36 wt% PbO, while no SnO_2 was detected. Comparison of the body composition with that of Kütahya tiles revealed a lower clay content (Geçkinli and Şimşek Franci, 2025).

Except for the studies conducted in 2001 and 2011, no comprehensive archaeometric investigation of tiles recovered from the Tekfur Palace excavations has been published to date. Among the ten samples examined in this study, two samples (TKF03 and TKF04) exhibit lead oxide contents of less than 10 wt% in their glazes, while the tin oxide contents were determined as 1.5 wt% and 2.7 wt%, respectively. These results shown in Table 1 differ markedly from previously reported data. In addition, the lime content in the glazes of these two samples is higher (4.5-5 wt%) than that observed in the remaining eight samples.

In contrast, the glazes of the other samples, excluding TKF03 and TKF04, contain between 23 and 38 wt% PbO, while SnO_2 is present only at impurity levels. The results obtained from the transparent glaze compositions indicate the presence of two main groups corresponding to distinct production technologies.

In a study conducted on tiles unearthed during the İznik Tile Kilns Excavation in 2019, it was found that tiles attributed to the late 16th–17th centuries contain tin oxide as a trace impurity (Simsek, Demirsar Arlı, Kaya, and Colomban, 2019). Therefore, the presence of tin oxide at trace levels in the glazes of the tiles—except for TKF03 and TKF04—does not indicate that they were not produced using İznik technology.

Because the samples were displayed attached to a cardboard support, it was not possible to perform body analyses on all of them. Owing to its small size, sample TKF04 became detached during the glaze analysis. As a result, it was possible to obtain body measurements from the cross-sections of the two sherds, TKF10 and TKF04. Even these two analyses were sufficient to identify the two groups previously distinguished on the basis of glaze analyses.

The body composition of sample TKF10 is consistent with a stonepaste tile, containing 80 wt% SiO_2, 4.5 wt% Al_2O_3, 3.1 wt% CaO, 0.6 wt% Fe_2O_3, 0.9 wt% K_2O, and 1.6 wt% PbO. In contrast, sample TKF04 contains 69.6 wt% SiO_2, 8.3 wt% Al_2O_3, 6.4 wt% CaO, 2.7 wt% MgO, 1.8 wt% Fe_2O_3, 1.6 wt% K_2O, and 0.5 wt% PbO. The ceramic body of TKF04 is characterized by higher lime and clay contents.

Accordingly, two main production groups were identified: one consisting of stonepaste body with a glaze containing low lead oxide and an average of ~2 wt% tin oxide, and another characterized by a lead-alkali glaze and body rich in lime and clay.

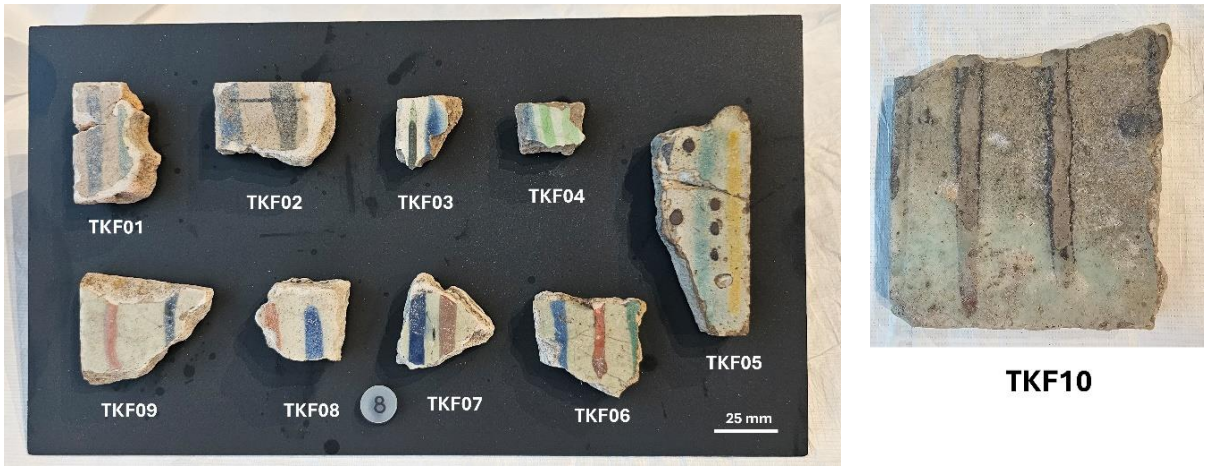


Figure 1. General view of the studied çeşni tiles exhibited in the Tekfur Palace Museum (TKF 01–TKF 10).
Şekil 1. Tekfur Sarayı Müzesi'nde sergilenen ve bu çalışmada incelenen çeşni çinilerinin genel görünümü (TKF 01–TKF 10).

Table 1. Mean values of representative glaze elements measured by pXRF and converted to their corresponding oxides using conversion factors (wt%).
Tablo 1. pXRF ile ölçülen temsili sır elementlerinin, dönüşüm faktörleri kullanılarak karşılık gelen oksitlerine dönüştürülmüş ortalama değerleri (ağırlıkça %).

Code	SiO_2	Al_2O_3	CaO	MgO	Fe_2O_3	K_2O	PbO	SnO_2
TKF01	54.9	3.1	2.9	0	0.4	1.1	29.7	0.06
TKF02	49.5	2.2	3.9	0.9	0.5	0.8	33.4	0.06
TKF03	73.9	3.1	4.5	1.6	0.6	2.2	5.1	1.5
TKF04	69.5	2.9	5.2	1.7	0.7	2.4	8.7	2.7
TKF05	59.8	3.7	3.0	0	0.5	1.8	23.5	0.2
TKF06	47.1	1.7	2.9	1.0	0.3	0.9	38.6	0.3
TKF07	48.0	1.8	2.8	1.2	0.3	0.9	38.8	0.1
TKF08	61.9	2.4	2.9	1.2	0.4	1.4	23.4	0.04
TKF09	61.4	3.2	3.2	0.8	0.5	1.6	22.9	0.04
TKF10	48.3	3.5	4.4	1.6	0.6	1.2	32.6	0.05

3.2. Colouring Agents
3.2.1 Blue

Blue is the most frequently used color in Ottoman tiles, regardless of the production center. For this reason, the determination of the chemical composition of cobalt pigments, together with their trace-element signatures, provides valuable information not only on production periods but also on workshop-specific practices. The ternary diagrams presented in Figure 2 take into account transition metals commonly associated with cobalt (Ni, Zn, Fe, Cu, and Mn), as well as elements belonging to the so-called “Five Elements vein” (Bi and As) which follows the classification of Kissin (1992).

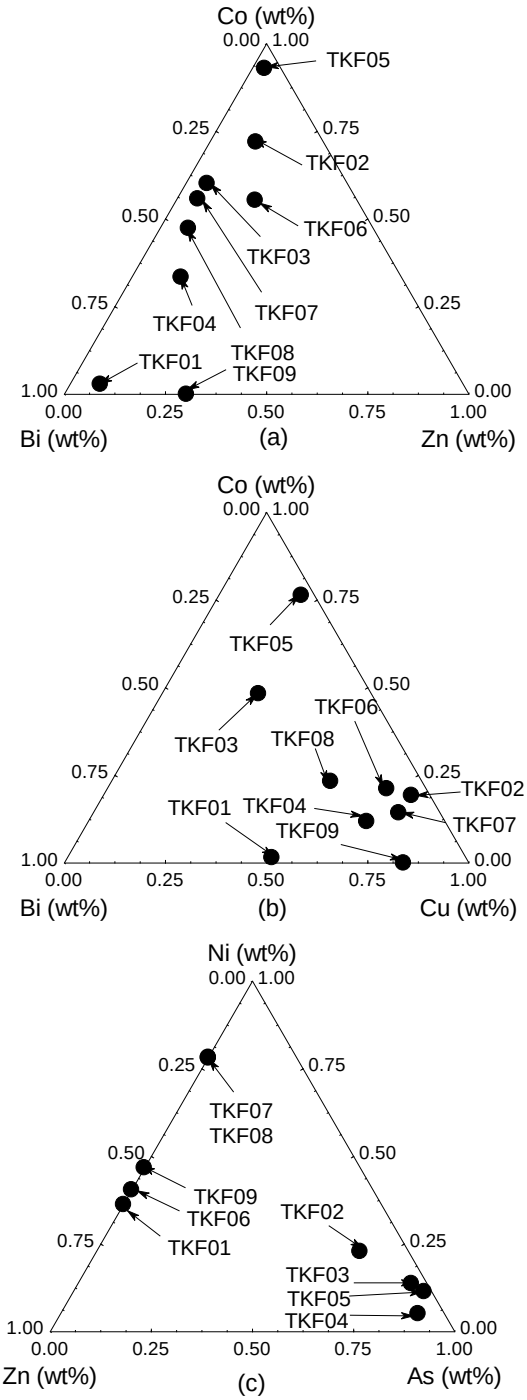


Figure 2. Ternary scatter plots illustrating the compositional distribution (wt%) of (a) Co–Bi–Zn, (b) Co–Bi–Cu, and (c) Ni–Zn–As in the blue decorative areas of the studied çeşni tiles.
Şekil 2. Çalışılan çeşni çinilerinin mavi bezemelerinde (a) Co–Bi–Zn, (b) Co–Bi–Cu ve (c) Ni–Zn–As bileşimlerinin dağılımını (ağırlıkça %, wt%) gösteren üçlü saçılım diyagramları.

The presence or absence of arsenic in cobalt-containing blue pigments can be interpreted in light of historical metallurgical practices. In medieval Europe, particularly in the Erzgebirge mining district, cobalt was not exploited as a primary raw material but obtained as a by-product of silver smelting, as described by Agricola (1556) in the 16th century. During this process, cobalt was retained in the silicate-rich slag, whereas arsenic was largely eliminated through volatilization or removal during smelting. Consequently, the cobalt materials used for coloring ceramics and other artefacts typically contain little to no residual arsenic. This metallurgical pathway therefore provides a key criterion. It allows the distinction of European cobalt sources used in ceramic production before approximately 1600–1650 from those derived from the direct processing of arsenic-rich cobalt minerals. However, Chinese texts from the 16th-century inform us the use of a mixture of the two types of cobalt, likely in the form of asbolite and arsenate (rich in arsenic) (Colomban, Kırmızı, and Şimşek Franci, 2021). The Ni–Zn–As ternary scattering diagram (Figure 2, left) reveals three distinct compositional groups in the blue decorations: (i) samples characterized by high nickel–low zinc contents (TKF07, TKF08), (ii) high zinc–low nickel contents (TKF01, TKF06, TKF09), and (iii) arsenic-bearing compositions (TKF02, TKF03, TKF04, TKF05). The groupings observed in these diagrams are consistent with previous analytical studies carried out on samples recovered from the Edirne and İznik Tile Kiln excavations. In that study, the blue decorations of the Edirne tiles were found to plot along the Ni–Zn trend. In contrast, some İznik productions clustered along the Ni–Zn line, while others followed the Ni–As line. In the same work, the Co–Bi–Zn distribution was examined, showing that almost all samples, including Edirne and İznik tiles, plotted along the Co–Bi trend. Only a few İznik tiles fell along the Bi–Zn line, as also observed in the present study (Agricola, 1556).

The Co–Bi–Cu ternary scatter diagram (Figure 2, center) further indicates that the blue pigments in samples TKF01 and TKF09 are compositionally similar and contain only trace amounts of cobalt. In contrast, the cobalt present in sample TKF05 is free of Bi and Cu. Samples TKF03, TKF08, and TKF04 exhibit Co–Bi–Cu in varying proportions, whereas samples TKF02, TKF06, and TKF07 are characterized by higher copper contents and are nearly devoid of bismuth. These results indicate that, even within the same production period, different raw materials were employed to achieve blue coloration.

3.2.2 Yellow, Red and Brown

Only sample TKF05 exhibits yellow coloration and dark spots tending toward brown (Figure 3). pXRF analysis of the yellow areas detected antimony and tin. This information indicates that a tin-bearing variant of Naples yellow ($Pb_2(Sb,Sn)_2O_7$ or $Pb(Sb,Sn)_2O_6$) was used in the yellow decoration (Geçkinli and Şimşek Franci, 2025). The brown spots contain a high amount of iron (2.20 wt%). In contrast, the red decoration of sample TKF06 contains 3.6 wt% iron, whereas the red colors in the other samples contain 0.2–0.9 wt% iron. Sample TKF07 differs slightly from the others due to the presence of 0.12 wt% tin. However, its iron content is 0.24 wt%. The absence of yellow among the underglaze decorative colors in İznik production distinguishes sample TKF05 from Tekfur tiles produced using İznik technology.

3.2.3 Black

Previous studies (Burlot, Waksman, Bellot-Gurlet, and Simsek Franci, 2020; Geçkinli and Şimşek Franci, 2025) have shown that black contours were produced using spinel, chromite, or a mixture of spinel and chromite. In the present group, the absence of chromium and the presence of only Mg and Fe in

sample TKF07 indicate the exclusive use of spinel, whereas the black decoration of TKF02 and TKF03 suggests the use of a mixture of chromite and spinel (Figure 4).

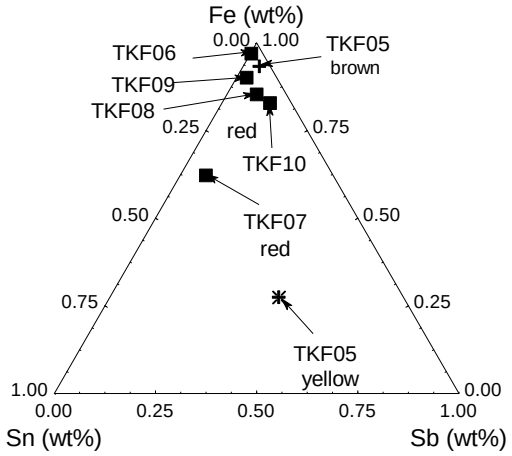


Figure 3. Ternary scatter plot illustrating the compositional distribution (wt%) of Fe-Sn-Sb in the red, yellow, and brown-colored decorative areas of the studied çeşni tiles.
Şekil 3. Çalışılan çeşni çinilerinin kırmızı, sarı ve kahverengi renkli dekoratif alanlarında Fe–Sn–Sb bileşimlerinin dağılımını (ağırlıkça %, wt%) gösteren üçlü saçılım diyagramı.

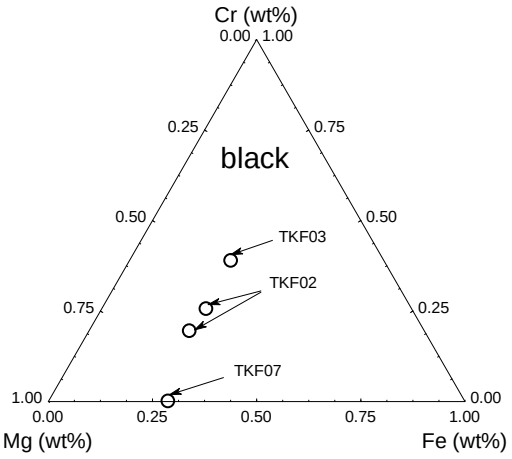


Figure 4. Ternary scatter plot illustrating the compositional distribution (wt%) of Cr-Mg-Fe in the black-colored areas of the studied çeşni tiles.
Şekil 4. Çalışılan çeşni çinilerinin siyah renkli alanlarında Cr-Mg-Fe bileşimlerinin dağılımını (ağırlıkça %, wt%) gösteren üçlü saçılım diyagramı.

3.2.4 Green and Turquoise

In terms of turquoise coloration, sample TKF05 again differs from the others, exhibiting high amounts of chromium and copper (Figure 5). The green and turquoise areas of samples TKF01, TKF04, and TKF06 contain nearly identical amounts of copper; however, chromium levels are higher in TKF01 and TKF06. Visually, TKF06 is clearly green, whereas TKF01 is turquoise. This difference is attributable to the glaze composition: the turquoise glaze of TKF01 contains 29.7 wt% lead oxide, while the green decoration of TKF06 contains 38.6 wt% lead oxide. As the lead content in the glaze increases, the color shifts toward a vivid green, whereas increasing alkali content—that is, decreasing lead oxide—results in a turquoise hue (Simsek and Geckinli, 2012).

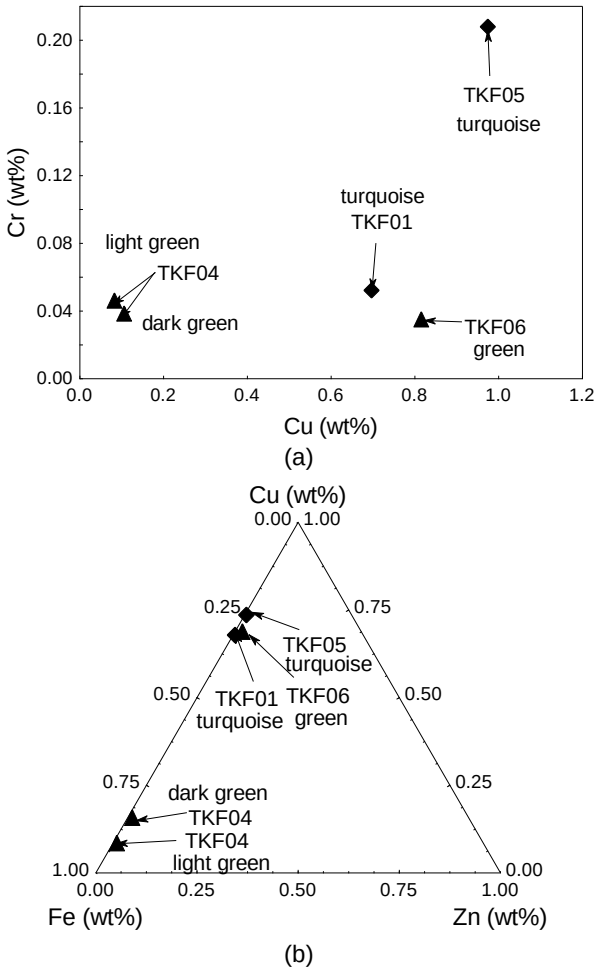


Figure 5. (a) Binary scatter plot illustrating the compositional distribution (wt%) of Cr versus Cu and (b) ternary scatter plot illustrating the compositional distribution (wt%) of Cu-Fe-Zn in the turquoise and green-colored decorative areas of the studied çeşni tiles.
Şekil 5. (a) Çalışılan çeşni çinilerinin turkuvaz ve yeşil renkli dekoratif alanlarında Cr–Cu bileşimlerinin dağılımını (ağırlıkça %, wt%) gösteren ikili saçılım diyagramı ve (b) Cu–Fe–Zn bileşimlerinin dağılımını (ağırlıkça %, wt%) gösteren üçlü saçılım diyagramı.

4. Conclusion

This study was undertaken to compare similar decorative samples recovered from the İznik Tile Kilns excavation and, consequently, to evaluate tile production in İznik and at Tekfur Palace. Chemical composition analyses of ten samples with transparent underglaze decoration indicate that different technologies and/or raw materials were employed during the short-lived tile production at Tekfur Palace. The transparent glazes are lead–alkali in composition, occurring both as tin-opacified and tin-bearing at trace (impurity) levels, while the ceramic bodies comprise both stonepaste and clayey–calcareous types.

The comparison of transparent glazes from Tekfur productions with İznik examples revealed that, except for TKF03 and TKF04, the çeşni tiles correspond to 17th-century İznik production due to their moderate PbO contents and the absence of tin oxide (SnO_2). In contrast, although TKF03 and TKF04 tiles contain amounts of tin oxide characteristic of 16th-century classical İznik production, they differ markedly from İznik glazes by exhibiting very low lead oxide contents. Although they resemble tin-opacified İznik glazes, their chemical compositions do not reflect İznik glaze technology.

The decorative palette of these çeşni tiles includes yellow, red, brown, black, blue, green, and turquoise. pXRF analyses identified the use of Naples yellow in the yellow decoration. For the black decoration, both a chromite–spinel mixture and the exclusive use of spinel were detected. In the blue decoration, cobalt ores both with and without arsenic were identified.

This study provides an important dataset for future archaeometric research on Tekfur Palace tiles and ceramics, as well as on Istanbul ceramics more broadly.

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6. Conflicts of Interest

The authors declare no conflict of interest.

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