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Revealing invisible stews: new results of organic residue analyses of Beveled Rim Bowls from the Late Chalcolithic site of Shakhi Kora, Kurdistan Region of Iraq

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A R T I C L E I N F O

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A B S T R A C T

Beveled Rim Bowls (BRBs) are the most iconic and well-known vessel type of ancient Southwest Asia. Roughly and carelessly produced, these conical bowls are attested in their thousands at 4th millennium BCE sites from southern Iraq and the Persian Gulf to the highlands of eastern Turkey and Iran. Questions regarding their function and relationship with emergent state institutions have stood at the centre of nearly a century of debates about the nature of early Mesopotamian urbanism and the so-called Uruk Expansion. In this paper we present the results of organic residue analyses of 10 BRBs from the site of Shakhi Kora in the Sirwan/Upper Diyala River Valley in the Kurdistan Region of north-east Iraq. Our analytical results challenge traditional interpretations that see BRBs as containers of cereal-based rations and bread moulds. The presence of meat- and potentially also dairy-based foods in the Shakhi Kora vessels lends support to multi-purpose explanations and points to local processes of appropriation of vessel meaning and function.

1. Introduction

Beveled Rim Bowls (BRBs) are thick-walled, conical vessels with flat bases, which were formed either by hand (Chazan and Lehner 1990, 25) or in a mould (Beale 1978, 289; Algaze 1993, 67; Goulder 2010, 353), tempered with ample chaff and lightly fired; resulting in rough and uneven forms (Fig. 1).

BRBs were first recorded in the Susiana plain of western Iran, at Chogha Mish and Susa, and at Uruk-Warka in southern Iraq, where they were found in large quantities, often in stacks and deliberately turned upside-down (Delougaz and Kantor, 1996: 50, pl. 15: A-C). Over the course of the 4th millennium BCE, BRBs also appear in varying quantities, alone or together with other southern cultural traits, at sites in Syria, eastern Turkey, upland Iran and Pakistan, but would seem to be largely locally produced (Sanjurjo-Sánchez et al. 2016; Emberling and Minc 2016; Blackman 1981; Alizadeh, Delougaz, and Kantor 2008; Lewis, Quinn, and Carter 2020; Schwartz and Hollander 2016). This spread of Mesopotamian material culture to regions with otherwise distinct cultural traditions is conventionally interpreted as a varyingly nuanced lowland colonial enterprise, aimed at channelling resources from resource-rich upland regions into the emergent political economies of early urban centres such as Uruk-Warka, which grew to an unprecedented c. 250 ha in the second half of the 4th millennium BCE (Algaze 1993, 2008; Stein, 1999).

The purpose and use of BRBs has been a topic of debate for over a century (Potts 2009, 1-2). Early suggestions include a ritual use, as the upturned BRBs found near the Ishtar temple at Nineveh reminded the excavators of later depositions of Aramaean incantation bowls (Campbell Thompson and Hutchinson 1931). BRBs from Telloh have also been interpreted as holding aromatics burnt at burial sites to purify the air

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Fig. 1. Stack of Beveled Rim Bowls from Shakhi Kora in the Sirwan/Upper Diyala River Valley, Kurdistan Region of north-east Iraq (photo: Sirwan Regional Project).

(Buchanan 1967, 539). Discussing the pottery from the Diyala region, Delougaz proposed that the porous fabric of BRBs could point to a function in food processing, such as separating whey from curds (Delougaz 1952, 128-129). They have also been interpreted as single-use elite feasting equipment (Forrest, 1987), and as utensils for the production and distribution of salt cakes (Buccellati 1990). Others have advocated for multi-purpose interpretations and drawn attention to their inherent disposability (Le Brun 1980, 66; Abdi 1999, 223; cf. Potts 2009).

Most widely accepted have been interpretations that associate BRBs with the distribution of rations. This hypothesis was first formulated by Nissen following a mass find of 1520 BRBs in a sounding at Uruk-Warka (Nissen 1970, 137). The ration hypothesis also hinges on the identification of the archaic pictogram GAR = NINDA as a BRB (Potts 2009, 3), and on the sign GU_7, which combines a BRB and a human head and means ‘to eat’, to stand for ‘ration’ in Archaic texts (Green et al., 1997 153–154). Assumptions about their mass-production and deliberate standardisation based on vessel volume further added weight to this interpretation (Johnson 1973; but see Beale 1978; Frangipane 1989).

Developing the hypothesis of BRBs as ration containers, Susan Pollock (2003, 28) proposed that BRBs formed part of a fundamental and centrally orchestrated transformation of food-consumption in southern Mesopotamia, aimed at producing new types of subject positions. This involved the disruption of earlier kin-based social relationships as expressed in household-based food preparation and consumption, and their replacement with ‘fast-food’ hand-outs to state-dependent workers, who would have been eating ‘on the job.’ This new mode of consumption, Pollock proposes, strengthened a new and state-centred understanding of community (Pollock 2003, 32).

What exactly those rations were that may have been distributed in BRBs, has also been the subject of much discussion. Most popular in recent decades have been hypotheses that link BRBs with the production of leavened bread (Schmidt 1982; Millard 1988; Chazan and Lehner 1990; Wengrow 2001, 171), either to feed state-dependent workers (Potts 2009) or to supply bureaucratic elites with distinctly formed bread-loaves (Goulder 2010).

Organic residue analysis (ORA) has the potential to shed a new and more conclusive light on questions of BRB contents and functionality. To date ORA on BRBs, however, has been limited. One BRB from Tepe Sofalin on the Tehran plain contained residues of beeswax, which may have acted as a sealant (Mayyas et al. 2012). BRBs from sites in the Syrian Middle Euphrates were analysed by pyrolysis coupled to gas chromatography and mass spectrometry (Py-GC–MS) (Sanjurjo-Sánchez, Kaal, and Fenollós 2018), with results that only very cautiously appear to support the leavened bread hypothesis.

Our analyses of 10 BRBs from Late Chalcolithic (LC)[1] occupation phases at the site of Shakhi Kora in north-east Iraq, which we present below, add a further distinct pattern of BRB use.

2. Shakhi Kora

The site of Shakhi Kora is located on the west bank of the Upper Diyala/Sirwan River, c. 10 km south of the modern town of Kalar (Fig. 2). Excavation and survey results suggest that the site is at least 6 ha in size, with an occupation sequence that stretches from the early 4th to the turn of the 3rd millennium BCE (Fig. 3). This makes Shakhi Kora the largest LC settlement recorded to date along the Sirwan/Diyala River (Adams 1965; Killick 1988). The Sirwan/Diyala River Valley forms a strategic communication corridor that connects the plains of Mesopotamia with the Zagros highlands and forms part of the later Khorasan Highway and Silk Routes.

The site was first recorded by the Garmian Department of Antiquities in April 2018 because of reports of illicit digging/looting. The Sirwan Regional Project (SRP), in collaboration with the Garmian Department of Antiquities and with the permission of the General Directorate of Antiquities in Erbil, carried out a survey and test sounding in 2018, commencing larger-scale excavations in 2019.

The largest exposure to date is the step-trench AA21 on the eastern, river-facing edge of the site, where we excavated a sequence of spaces closely associated with the production, storage, and distribution of food at what would appear to be considerable, and perhaps supra-household, scales. Charcoal-derived radiocarbon dates place these contexts to between c. 3780 to 3377 cal. BCE (at two sigma; AA114846 and AA114848).

The latest exposed food production area consists of a brick-wide L-shaped wall feature and a series of *in situ* complete and fragmentary storage, cooking and consumption vessels, including numerous BRBs (Fig. 4). To the south of the wall feature, bowls – mainly BRBs – and cups dominate, to the north were found a series of large and medium-sized storage jars sunk into the ground. A pebbled floor leads from a collection of jars and spouted vessels into the northern portion of the trench and towards a U-shaped mud-brick feature, which appears to have contained an irregularly shaped oven. An earlier floor surface also produced ubiquitous BRBs and other consumption and storage vessels. Five BRB samples from this latter floor (Locus 5) are included in this study, a further five derive from the sealed and ash-filled destruction horizon of an earlier mudbrick structure that contained large quantities of pottery, again mainly BRBs. Some BRBs were found neatly stacked upside down in two parallel rows along one of the walls, as well as large quantities of shallow dishes (Locus 9). Further excavations are needed to determine more conclusively the nature of these contexts and to situate them within the wider architectural and social fabric of the Late Chalcolithic community at the site. The overabundance of BRBs and other coarsely produced serving vessels as well as their neat arrangement in the lowest step, closely echoing finds contexts from Chogha Mish (Delougaz and Kantor, 1996: 50, pl. 15: A-C), however, may point towards successive institutional households of some kind.

In cultural terms, we can cautiously characterise the settlement at Shakhi Kora as a local community, which develops increasingly close

[1] Approximate dates: LC1 c. 4700–4500, LC2 c. 4500–3900, LC3 c.3900–3700, LC4 c. 3700–3400, LC5 c. 3400–3200 BCE.

Fig. 2. Map showing the location of Shakhi Kora.

ties with the south Mesopotamian Uruk world over the course of the 4th millennium BCE. In its earliest phases, the Shakhi Kora community is culturally closely connected to other contemporary sites in the western Zagros piedmont zone (Vallet et al. 2017; Renette et al. 2021) and the north-Mesopotamian cultural sphere of the early-to-mid 4th millennium BCE, while also incorporating a limited range of south Mesopotamian Uruk-related ceramic types as early as the LC2. In the later LC3 and LC4, which includes ORA sampled contexts in the lowest step of AA21, the settlement continues to be characterised mainly by local ceramic types, while the assemblage overall is dominated by Uruk-related BRBs. Uruk cultural connections increase and diversify in the LC4-5, which is represented by ORA sampled contexts in the upper steps of AA21, as well as in a neighbouring trench that produced a collection of *in situ* storage vessels, including classic Uruk pierced noselug jars with cross-hatched incised decorations.

3. Organic residue analyses of BRBs from Shakhi Kora

Lipid residues from 10 BRBs were analysed using gas chromatography-mass spectrometry (GC–MS) and gas chromatography-combustion-isotope ratio mass spectrometry (GC-C-IRMS). Nine sherds were sampled at or near the base and one sherd (3539) was sampled closer to the rim (Table 1).

3.1. Methodology

3.1.1. Sample preparation

Ceramic vessels were handled with cotton gloves and sampled on-site with acetone-sterilised instruments (tweezers and hammer) and immediately wrapped in tin foil (combusted at 450 °C for 8 hours before use) for protection during transportation. This prevented modern contaminants from the excavation and post-excavation process (i.e. fingerprint residues, sunscreen, contamination from plastic bags, etc.) to affect analytical results, which is otherwise a well-known problem in archaeological ORA. Samples of soil around vessels were also collected for analysis to provide a picture of potential contamination from the burial environment (e.g. leaching from decaying plant matter). Both inner and outer surfaces of the samples were drilled using a cordless Dremel 8200 with an abrasive point as grinding tool (also cleaned with acetone before use) to remove potential exogenous contamination and kept for ORA to assess once again contamination from the burial environment or from handling and storage.

The drilled ceramic fragments were then crushed into powder using an agate mortar and a pestle, also cleaned with acetone, and put into 40 ml glass vials, previously combusted in an oven with a 450 °C temperature programme that runs for 8 hours. Lipids were extracted from matrices using a Dionex Accelerated Solvent Extractor (ASE) 350 in a mixture of dichloromethane and methanol (9:1 v/v DCM:MeOH). We investigated the total lipid extract (TLE) by transferring the sample into 2 ml vials and derivatised by heating at 80 °C for two hours with addition of 50 μl of the reagent N,O-bis(trimethylsilyl) trifluoroacetamide (BSTFA) and 10 μl of Pyridine added as a basic catalyst. The samples were derivatised before each run on the GC-FID, GC–MS and GC-C-IRMS. Trimethylsilyl (TMS) esters are stable for the first 12 hours but their stability decreases for the remaining 48 hours. We re-derivatised samples, if needed.

Finally, a constant amount (100 μl) of a solution of C_{22} *n*-alkane in hexane with a known concentration (9.15 μg/mL) was added to the samples before analysis for quantification. Separation of lipid classes was not carried out due to the small TLE concentration (Table 1).

Fig. 3. Aerial view (looking north) of Shakhi Kora and excavation trenches Z19 (left) and AA21 (right) in the foreground (photo: Sirwan Regional Project).

Fig. 4. Aerial view (looking west) of step-trench AA21 (photo: Sirwan Regional Project).

3.1.2. Gas chromatograph – Flame ionization detector (GC-FID) and gas chromatograph - mass spectrometer (GC–MS)

Analysis of lipids from ceramic sherds compared to control samples (drilled outer and inner surfaces of samples and laboratory blanks) presents the first step towards the identification of the original vessel content.

Samples were run on the Agilent 7890 GC-FID for biomarker quantification and then on the Agilent 5977 GC–MS for biomarker identification. One microlitre of each sample was injected into Restek Rtx-1 fused silica column (60 m × 0.25 mm × 0.25 μm). The analysis time was 63 min (starting at 7 min) and a specific column oven temperature programme was created for this analysis. The GC oven temperature was

Table 1
Summary table of BRB samples analysed in this study with the amount of lipids extracted per gram of sherd for each BRB (TLE (μg) / PWD (g)).

ID	Site	Trench	Locus	Type	TLE(μg) / PWD(g)
3530	SK	AA21	5	Body/Base	42.1
3533	SK	AA21	5	Body/Base	20.1
3536	SK	AA21	9	Body/Base	13.7
3539	SK	AA21	9	Rim/Body	24
3542	SK	AA21	9	Base	23.6
3548	SK	AA21	5	Body/Base	51.2
3551	SK	AA21	9	Base	16.4
3557	SK	AA21	5	Body/Base	852.5
3560	SK	AA21	5	Base	20.4
3563	SK	AA21	9	Body/Base	297.6

held at 60 °C for 2 min, then increased 30 °C/min up to 120 °C, then increased 5 °C/min up to 300 °C, then increased 5 °C/min up to 340 °C held isothermally for 15 min.

3.1.3. Gas chromatography – Mass spectrometry – Combustion – Isotope ratio mass spectrometry (GC-C-IRMS)

For GC-C-IRMS, an Isoprime Vision linked to a Hewlett Packard 7890B series GC (Agilent Technologies) with an Isoprime GC5 interface was used. One microlitre of each sample was injected into HP-5MS ultra-inert fused-silica column (30 m x 0.25 mm x 0.25 μm). Eluted products were ionised in the mass spectrometer by electron impact and ion intensities of *m/z* 44, 45 and 46 were recorded for automatic computing of the $^{13}C/^{12}C$ ratio of each peak in the extracts. Integration (Fig. 5) and computation was carried out with IonVantage and IonOS software and was based on comparisons with standard reference gas (CO_2) of known isotopic composition that was repeatedly measured.

The results of the analysis were expressed in per mill (‰) relative to an international standard, V-PDB. The accuracy and precision of the instrument was determined on *n*-alkanoic acid ester standards of known isotopic composition (Indiana mix standard A7). Standards were run between triplicate sample sets to ensure linearity of the instrument. Each sample was measured in replicate to take into account the mean and standard deviation of $\delta^{13}C_{16:0}$ and $\delta^{13}C_{18:0}$. Corrections were also made on the fatty acid trimethylsilyl (TMS) esters to remove the isotopic contribution from the trimethylsilyl group added during derivatisation using the following formula:

$$\delta^{13}C_{FA} = \frac{(n+3)\ x\ \delta 13CFAtms\ -\ (3x\ -\ 35.05)}{n}$$

Where:

- $\delta^{13}C_{FA}$ represents the $\delta^{13}C$ of the given FA prior to derivatisation

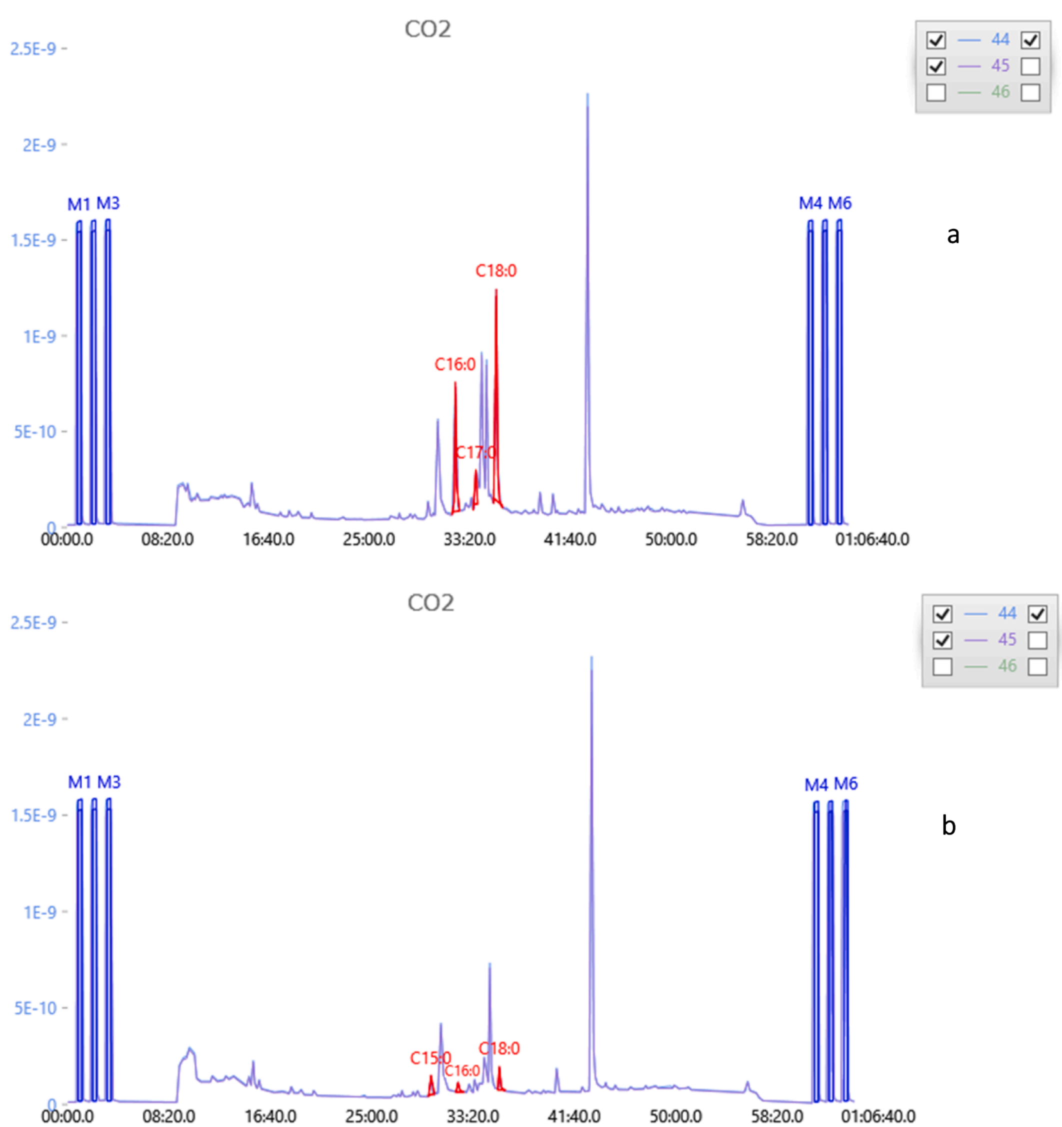

Fig. 5. GC-C-IRMS chromatogram and the integration of $C_{16:0}$ and $C_{18:0}$ in samples 3557 (a) and 3530 (b).

- $\delta^{13}C_{FAtms}$ is the $\delta^{13}C$ value of the measured FA TMS
- −35.05 (±0.83) is the $\delta^{13}C$ of BSTFA (with 1 % TMCS) used during the derivatisation
- n is the number of carbon atoms in the fatty acid

4. Results

4.1. Lipid preservation and profiles of Shakhi Kora samples

Lipid extracts were obtained for all the samples (potsherds: c. 10 g) The solvent extracts of the 'cleaned' sherds (after removal of c. 1 mm of inner and c. 1 mm of outer surfaces) ranged from 13 $\mu g.g^{-1}$ to more than 800 $\mu g.g^{-1}$ (Table 1) and were analysed quantitatively and qualitatively.

Overall, the lipid profiles are characterised by a complex mixture of aliphatic compounds, encompassing saturated fatty acids ranging from $C_{8:0}$ to $C_{24:0}$, monounsaturated fatty acids ranging from $C_{9:0}$ to $C_{21:0}$ and branched fatty acids (branched $C_{17:0}$, $C_{16:1}$, $C_{18:1}$ and $C_{20:1}$). $C_{16:0}$ and $C_{18:0}$ clearly dominate the fatty acid signatures. All the samples presented scarce amounts of monoacylglycerols ($C_{16:0}$ and $C_{18:0}$) apart from sample 3530. Traces of odd chain *n*-alkanes were identified in most of the sherds.

Only one sample (3563) displayed a slightly different molecular profile (Figure 11 in Supplementary material), with the additional presence of long-chain even-numbered palmitate wax esters (palmityl palmitate $C_{32}H_{64}O_2$ and stearyl palmitate $C_{34}H_{68}O_2$) which could be of plant or animal origin. The identification of long chain wax esters is often interpreted as evidence for the coating of ceramic vessels (Chasan et al. 2021; Charters et al. 1995; Buchwald et al. 2009; Regert et al. 2001). In our case, without additional evidence, the presence of those wax esters alone is not sufficient to prove the presence of coating of the vessels.

Fatty acids (FAs) are the most abundant class of lipids encountered in archaeological materials and are derived from both animal fats and plant oils. To assist in the identification of the original sources of archaeological residues and provide further information regarding the contents of the BRBs, this study combined two complementary analyses: fatty acids ratios and compound-specific stable isotopes.

FAs content can play a role in identifying the major food sources such as terrestrial mammal fats or plants, but should be used cautiously due to the potential mixing of sources as well as complexities of FAs degradation over time (Heron and Evershed 1993) and contamination (pre- and post-excavation). For instance, it has been shown that unsaturated fatty acids are less stable and thus far more vulnerable to degradation than saturated fatty acids (Korf et al. 2020). Hence, ancient fatty materials are typically dominated by several common saturated fatty acids (especially $C_{16:0}$ and $C_{18:0}$) with lower amounts or even absence of unsaturated fatty acids. While there are several pitfalls that may be encountered when using lipids profiles only (in particular non-specific biomarkers, such as fatty acids) to infer on the content of ceramic vessels (Whelton et al. 2021), using the calculation of the fatty acid ratios and another set of data, such as the identification of characteristic biomarkers or compound-specific stable isotopes is reasonable (Whelton et al. 2021; Rosiak, Kałużna-Czaplińska, and Gątarek 2020). Here we combined the use of fatty acid ratios in conjunction with compound-specific stable isotopes to increase their specificity. Compound-specific $\delta^{13}C$ analysis has proven to be powerful in resolving the origins of FAs. Compound-specific $\delta^{13}C$ of $C_{16:0}$ and $C_{18:0}$ of ruminant (e.g. sheep/goat and cattle) and non-ruminant (e.g. pig or wild boar) adipose fats as well as dairy fats have been shown to be readily distinguishable (Evershed, Harden, et al. 2002; Evershed et al. 2008; Cramp et al. 2014; Evershed, Dudd, et al. 2002; Dudd and Evershed 1998).

4.2. Fatty acid ratios

Following the work of Eerkens (2005), supported by additional studies (Buonasera et al. 2015), we investigated the ratios of the main FAs in three BRB samples that presented sufficient lipid concentrations: 3551, 3557 and 3563 (Table 2 and Fig. 6) with the aim of identifying the FAs source type. Apart from $C_{16:0}$ and $C_{18:0}$, fatty acids were found in too low concentrations in samples 3530, 3533, 3536, 3539, 3542, 3548 and 3560 to be quantified with certainty. Using discriminant analysis of modern and experimentally aged residues, Eerkens demonstrated that ratios of $C_{16:0}$ to $C_{18:0}$ versus $C_{12:0}$ to $C_{14:0}$, and $C_{16:1}$ to $C_{18:1}$ versus $(C_{15:0} + C_{17:0})/C_{18:0}$ correctly classified a sample of residues as terrestrial mammals, fish, seeds, greens or roots about 72 % of the time (Eerkens 2005).

As shown in Figure 6, 3557 and 3563 fall inside the range of values for mammals, while 3551 falls into the range of values for plants, and more specifically seeds. 3551 yielded possible traces of stigmasterol, a phytosterol and plant-derived lipid (Fig. 7 in Supplementary material) which could support the presence of seeds in BRB 3551.

4.3. Compound-specific $\delta^{13}C$ analysis

When working with compound-specific $\delta^{13}C$ analysis, several parameters have to be considered. The $\delta^{13}C$ values of the individual FAs are affected by a range of environmental variables that increase the range of carbon isotope values for FAs depending on climatic influences and the presence of plants with varying $\delta^{13}C$ values, e.g. C_3 versus C_4, (Mukherjee et al. 2005). Plotting $\Delta^{13}C = \delta^{13}C_{18:0} - \delta^{13}C_{16:0}$ values removes environmental influences expressed in the raw $\delta^{13}C$ values (Copley et al. 2005) and has been widely used to discriminate ruminant adi-pose and dairy fats from other non-ruminant sources (Colonese and Lucquin, 2017; Craig and Saul, 2013; Craig and Steele, 2011; Taché and Craig, 2015; Lucquin, 2016).

The standard deviation is a crucial parameter to consider in the interpretation of results. Lipids in low but sufficient concentration and repeated injection could explain the high standard deviation obtained for some of the samples (Table 3).

In general, the carbon isotopic values from our BRB samples provided $\delta^{13}C$ values of $C_{16:0}$ and $C_{18:0}$ fatty acids consistent with ruminant adipose fats, confirming the results of the molecular analysis (Table 3 and Fig. 7). The majority of the samples, i.e. 3533, 3536, 3539, 3557 and 3551, plot within the ruminant adipose fats domain in concordance with what the fatty acid ratios previously demonstrated. However, sample 3551 has presented fatty acid ratios falling into the plant range. Distinguishing the $\delta^{13}C$ values of $C_{16:0}$ and $C_{18:0}$ fatty acids of plant oils from animal fats in the archaeological record has been shown to be difficult (Steele, Stern, and Stott 2010). Moreover, it has been demonstrated that the plot of $\Delta^{13}C = \delta^{13}C_{18:0} - \delta^{13}C_{16:0}$ versus $\delta^{13}C_{16:0}$ values does not differentiate plants from non-ruminant and ruminant adipose fats (Grillo et al. 2020), and thus plant oils will be interpreted as animal fats "if there is no indicative biomolecular or archaeological evidence" (Steele, Stern and Stott, 2010: 3482).

Furthermore, 3530 and 3548 plot within the range of non-ruminant adipose fats. It is possible that those two bowls would have contained meats from non-ruminant animals, such as pigs or wild boar. Unfortunately, samples 3530 and 3548 did not present FAs in sufficient

Table 2
Fatty acid concentrations (in µg/mL) and ratios calculated for three BRBs in order to distinguish their source types (based on Eerkens, 2005:91).

Sample	$C_{12:0}$	$C_{14:0}$	$C_{15:0}$	$C_{16:0}$	$C_{17:0}$	$C_{16:1}$	$C_{18:1}$	$C_{18:0}$
3563	0.06	1.01	0.22	9.12	0.17	0.11	0.42	3.43
3557	0.01	0.11	0.07	2.43	0.06	0.04	0.07	0.82
3551	0.08	0.09	0.02	0.53	0.01	0.01	0.04	0.08

Sample	$C_{12:0}/C_{14:0}$	$C_{16:0}/C_{18:0}$	$C_{15:0}+C_{17:0}/C_{18:0}$	$C_{16:1}/C_{18:1}$
3563	0.06	2.65	0.11	0.26
3557	0.05	2.95	0.16	0.53
3551	0.89	6.60	0.41	0.15

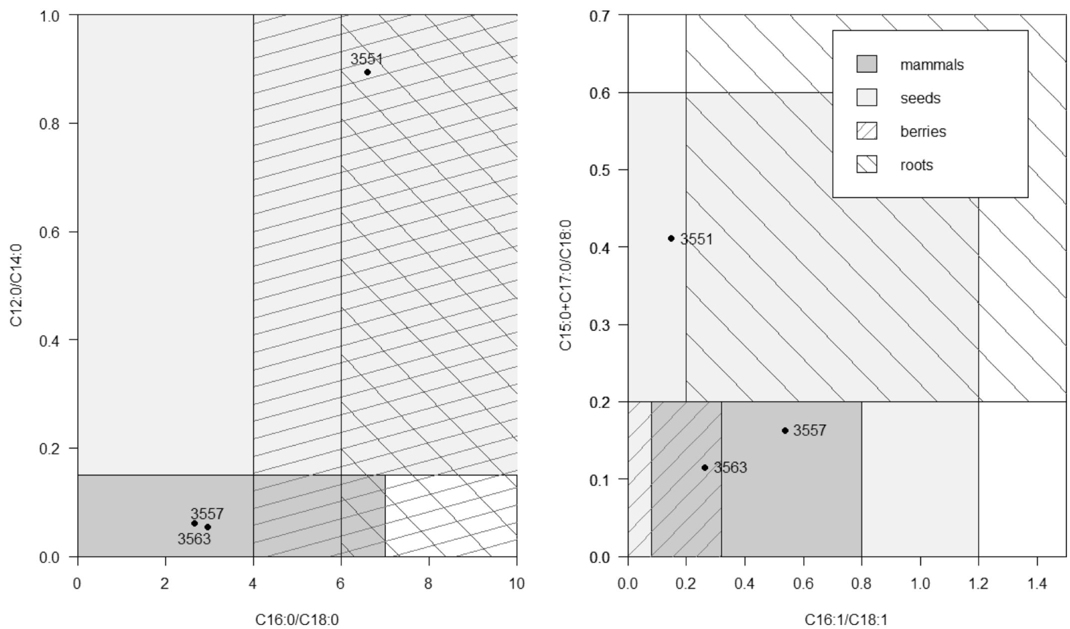

Fig. 6. Archaeological sherds plotted by two fatty acid ratios. First plot: $C_{16:0}$ /$C_{18:0}$ versus $C_{12:0}$/$C_{14:0}$, Second plot: $C_{16:1}$/$C_{18:1}$ versus ($C_{15:0}$ + $C_{17:0}$)/$C_{18:0}$, Categories' range values by Eerkens, 2005.

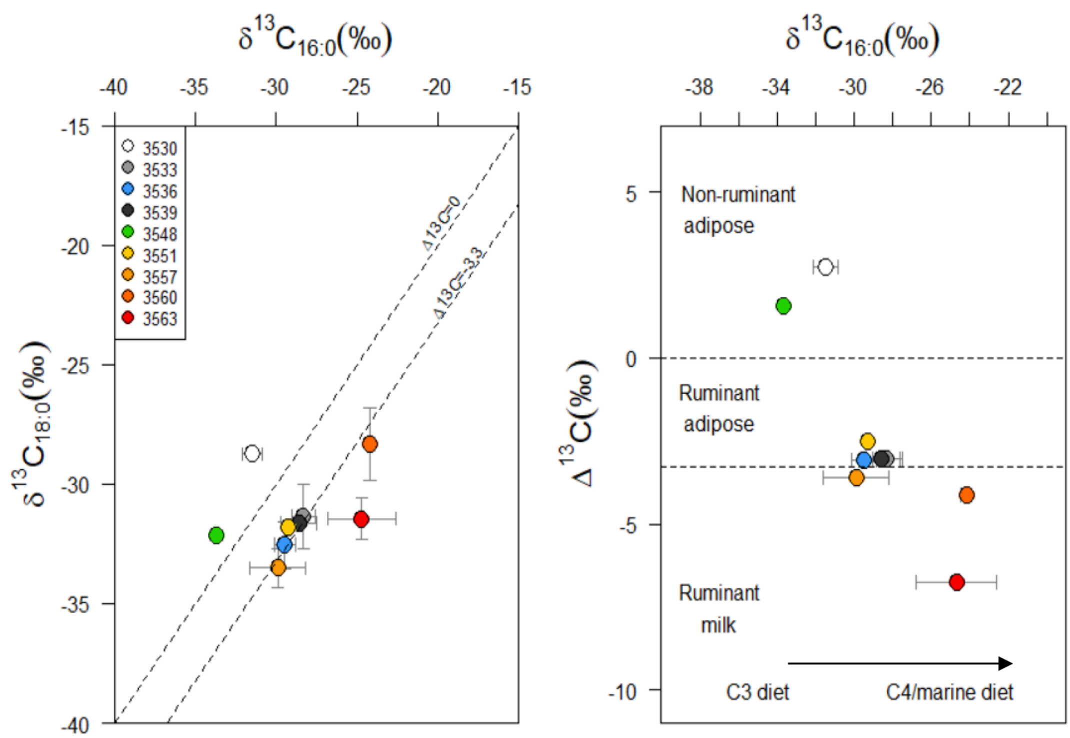

Fig. 7. Stable carbon isotope measurements of $C_{16:0}$ and $C_{18:0}$ fatty acids obtained from our samples of pottery sherds Plot of $\delta^{13}C_{16:0}$ and $\delta^{13}C_{18:0}$ values with SD/2. b Plot of $\Delta^{13}C$ ($\delta^{13}C_{18:0}$ - $\delta^{13}C_{16:0}$) values against $\delta^{13}C_{16:0}$ values with SD/2 obtained from ceramic matrices. NB: We were unable to perform an analysis in triplicate for sample 3542 thus not appearing in the graph (**see** Table 3).

concentration to calculate and plot their ratios (apart from $C_{18:0}$ and $C_{16:0}$). As established, plant foods have low lipid content. Another possibility would be that these two bowls contained plants, since, as already mentioned, differentiating plants from non-ruminant and ruminant adipose fats can be extremely difficult through the sole use of compound-specific $\delta^{13}C$ analysis (Steele, Stern and Stott, 2010: 3482).

Shakhi Kora sample 3560 plots at the limit between ruminant adipose and dairy fats, while 3563 plots within the range of dairy fats. While it is possible that this BRB contained dairy fats, it is also possible that it did not. Reber and Evershed (2004) suggested that a mixture of different fatty acids from different sources within one pot can produce a signature of a completely different fat that was never present. It has been shown, for instance, that dairy $\Delta^{13}C$ values are easily generated by mixing C_3 ruminant adipose fats with C_4 plants (Hendy et al. 2018; Roffet-Salque et al. 2016). 3563, for instance, yielded wax esters that could be diagnostic of plant or animal wax coating of the interior of the

Table 3
Results of compound-specific $\delta^{13}C$ analysis for each sample analysed in triplicate (apart from sample 3542 not analysed in triplicate) with standard deviation (SD) before and after correction. These results are visualised in the plots presented in Fig. 7.

Samples	Average $\delta^{13}C_{16:0}$	Average $\delta^{13}C_{18:0}$	Average $\delta^{13}C_{16:0}$ (after correction)	Average $\delta^{13}C_{18:0}$ (after correction)	SD $\delta^{13}C_{16:0}$ (after correction)	SD $\delta^{13}C_{18:0}$ (after correction)
3530	−32.03	−29.13	−31.47	−28.15	1.29	0.84
3533	−29.37	−31.87	−28.31	−31.34	1.41	2.70
3536	−30.35	−32.91	−29.47	−32.55	1.29	1.97
3539	−29,62	−32.13	−28.60	−31.64	2.21	0.28
3542	NA	NA	NA	NA	NA	NA
3548	−33.91	−32.55	−33.70	−32.14	0.32	0.42
3551	−30.19	−32.27	−29.28	−31.81	0.29	0.05
3557	−30.71	−33.73	−29.90	−33.51	3.45	1.66
3560	−25.90	−29.28	−24.18	−28.32	0.55	3.02
3563	−26.34	−31.96	−24.70	−31.45	4.18	1.73

vessels, which could significantly impact our results of stable isotopic analyses for this vessel.

5. Discussion of results

The combined data of the FA ratios and compound-specific $\delta^{13}C$ analyses strongly indicate that BRBs at Shakhi Kora were used to serve and consume a range of different foods, including meat-, and possibly also dairy- and seed/plant-based products.

Ruminant animals make up a significant proportion of the mammalian faunal assemblage at the site. A preliminary study of the zooarchaeological assemblage from Shakhi Kora identified the remains of caprines, with goats dominating over sheep, and some cattle. There were also two fragments of pig, which are non-ruminant animals (Heimvik, 2022). Recovery of botanical samples has been limited in the first two seasons of excavations, with finds to date attesting emmer (grain and glume base) and a series of wild taxa, primarily grasses.

Six of the 10 analysed BRBs present a ruminant stable carbon isotope signature $\Delta^{13}C$ values < -1 (Fig. 7). The evidence of animal fats is further supported by the FA ratios of BRB 3557. The FA ratios of BRB 3551 are falling in the seeds range while presenting ruminant stable carbon isotope signatures (Table 4). This can be explained by the fact that $\Delta^{13}C$ values of plant oils are generally indistinguishable from ruminant and non-ruminant adipose fats (Steele, Stern, and Stott 2010). It is also possible that animal carcass fats and seeds or seed oils would have been mixed in this BRB.

BRB 3563 and BRB 3560 are the only BRB presenting a ruminant dairy stable carbon isotope signature. BRB 3563 also presents a lipid profile that could potentially point to the presence of a coating of the interior vessel walls with either plant or animal wax, perhaps similar to the beeswax identified in a BRB from central Iran (Mayyas et al. 2012), and the bitumen coating observed on vessel interiors at Hacınebi Tepe (Schwartz and Hollander 2000, 2016). This could suggest, in conjunction with the results of compound-specific stable isotope analysis, that some BRBs at Shakhi Kora were intended to contain liquids. However, further work needs to be conducted to provide a clear answer.

Table 4
Summary table of the identification of the residue source for each BRB based on FA ratios and $\delta^{13}C$ analysis.

Samples	Locus	FAs ratios	$\delta^{13}C$ analysis
3530	5	NA	Non-ruminant
3533	5	NA	Ruminant
3536	9	NA	Ruminant
3539	9	NA	Ruminant
3542	9	NA	NA
3548	5	NA	Non-ruminant
3551	9	Seeds	Ruminant
3557	5	Mammals	Ruminant/dairy
3560	5	NA	Dairy
3563	9	Mammals	Dairy

No ketones, and thus evidence of heating, were identified in our lipid extracts. Although preservation issues can never be excluded, the persistent absence of ketones suggests that BRBs at Shakhi Kora were not used as cooking vessels, but rather functioned in the serving or distribution of foods and their consumption.

6. Concluding discussion

The presence of meat-based foods in several of the analysed Shakhi Kora BRBs raises a number of questions regarding their preparation, and how a meat-based content articulates with traditional state-centred ration hypotheses for BRBs. A greater number of analytical samples will be required to conclusively answer these questions, but we can nevertheless constitute a number of points of departure from cereal-based ration- and bread-centred interpretive models on the basis of our analytical results and their wider archaeological context.

In a series of recent papers, Carolin Jauβ, Bianca D'Anna and Susan Pollock have drawn attention to the general scarcity of fire installations at classic Uruk-related LC sites, the small size of Uruk cooking vessels, and their likely association with secondary products preparation, such as clarifying butter, rather than with the preparation of daily meals (Jauβ 2015; D'Anna and Jauβ 2015; Pollock 2012, 2015). This would mean that large-scale state-organised food distributions did not involve large amounts of cooked foods, but focused on foods prepared with other methods that did not involve much heat such as brewing, drying, and pickling (Pollock 2012). Heat-based food preparation, as indexed by hearths and ovens, by contrast, would seem to have been concentrated in houses and perhaps in temple complexes. In the case of the latter, Pollock (2015) suggested, food production would have been focused on festivals and on nourishing the gods and their servants.

There is clear evidence for heat-based cooking activities at Shakhi Kora, including remnants of hearths and ovens. More detailed use-wear analyses have yet to be conducted, but several small to medium jars recovered from floor surfaces show signs of secondary burning suggestive of their use as cooking vessels. Associated faunal assemblages bear witness to marrow and grease extraction, a butchery practice where bones are broken down to access the marrow and fragments are subsequently boiled to extract the fat. The high frequency of bones showing signs of marrow and grease extraction supports the identification of excavated contexts as cooking and consumption locales, with animals probably being slaughtered elsewhere.

There is no evidence, by contrast, that BRBs themselves were used in heat-based food preparation, as the leavened bread hypothesis assumes. Instead, lack of ketones suggests their use in the serving and consumption of potentially liquid or semi-liquid foods, such as the broths or stews that the faunal remains and their method of butchery point towards.

The size of the excavated food preparation areas, especially the large quantities of associated BRBs and their distinctive storage arrangements, as well as other serving and consumption vessels, may point to a supra-household scale of production and consumption. Our main working hypothesis at the moment is that these may be the potential remnants of successive institutional households.

If this interpretation is correct, BRBs at Shakhi Kora, rather than containing breads or cereal-based rations, which would have been of comparatively low cost to produce and distribute to large numbers of consumers, contained meals produced at potentially greater economic expense. On the one hand, this may point to special occasions, or more distinguished consumers. On the other hand, it could point towards differences in the local economy and a greater focus on pastoralism at the site, which falls into the 'zone of uncertainty' for rainfed agriculture. In the latter scenario, animal products would have been more widely available and perhaps incorporated more regularly into daily meals at Shakhi Kora than in southern Mesopotamia. The broths or stews based on, or flavoured with, bone and marrow in the BRBs present the careful extraction of all available calories from slaughtered animals rather than the festive cuts of meat one would expect to be served at special social occasions. This would, thus, favour a quotidian and possible ration scenario. It is also possible that the proportions of animal products in these broths and stews, especially the meat content, would have varied according to social context and occasion.

It is notable that the $\delta^{13}C$ signatures for ruminant adipose fats in BRBs were found in vessels recovered from two chronologically distinct contexts, suggesting continuities in use-practices across different occupation phases, and including what appears to have been a significant conflagration and destruction event on the one hand, and increasingly close cultural connections with the Uruk world in the later phase of BRB use on the other. Whether this relates to any centralising institution or authority at Shakhi Kora, or alternatively to community-based daily food production, or – perhaps least likely - the preparation of festive meals, will have to await further work.

What we can say with confidence at this point is that the Shakhi Kora samples contribute to a growing body of evidence that supports multi-functional explanations of BRBs, and that this in turn points to the appropriation and transformation of both meaning and function of BRBs among local communities over the course of the 4th millennium BCE that diverged from their uses at lowland Mesopotamian urbanising centres.

Declaration of Competing Interest

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

Data availability

Data will be made available on request.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jasrep.2022.103730.

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