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ARTICLE

Farmers with a Taste for Fish: New Insights into Iroquoian Foodways at the Dawson Site

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Abstract
Iroquoian groups inhabiting the St. Lawrence Valley in the fifteenth and sixteenth centuries AD practiced agriculture and supplemented their diet with fish and a variety of wild plants and terrestrial animals. Important gaps remain in our knowledge of Iroquoian foodways, including how pottery was integrated to culinary practices and the relative importance of maize in clay-pot cooking. Lipid analyses carried out on 32 potsherds from the Dawson site (Montreal, Canada) demonstrate that pottery from this village site was used to prepare a range of foodstuffs—primarily freshwater fish and maize, but possibly also other animals and plants. The importance of aquatic resources is demonstrated by the presence of a range of molecular compounds identified as biomarkers for aquatic products, whereas the presence of maize could only be detected through isotopic analysis. Bayesian modeling suggests that maize is present in all samples and is the dominant product in at least 40% of the potsherds analyzed. This combination of analytical techniques, applied for the first time to Iroquoian pottery, provides a glimpse into Iroquoian foodways and suggests that *sagamité* was part of the culinary traditions at the Dawson site.

Résumé
Les groupes iroquoiens habitant la vallée du Saint-Laurent au 15^{e} et 16^{e} siècle après J.-C. pratiquaient l'agriculture et complétaient leur alimentation avec du poisson et une variété de plantes sauvages et d'animaux terrestres. Des lacunes importantes subsistent dans notre connaissance des habitudes alimentaires iroquoiennes, incluant la manière dont la poterie était intégrée aux pratiques culinaire et l'importance relative du maïs dans les cuissons en pot. Des analyses lipidiques réalisées sur 32 tessons de poterie du site Dawson (Montréal, Canada) démontrent que les céramiques de ce site villageois étaient utilisées pour préparer diverses denrées alimentaires, principalement des poissons d'eau douce et du maïs, mais peut-être aussi d'autres animaux et/ou plantes. L'importance des ressources aquatiques est démontrée par la présence d'une gamme de composés moléculaires identifiés comme biomarqueurs des produits aquatiques, tandis que la présence de maïs n'a pu être détectée que par des analyses isotopiques. Une modélisation bayésienne suggère que le maïs est présent dans tous les échantillons et qu'il constitue le produit dominant dans au moins 40% des tessons analysés. Cette combinaison de techniques analytiques, déployée pour la première fois sur la poterie iroquoienne, donne un aperçu des habitudes alimentaires iroquoiennes et suggère que la *sagamité* faisait partie des traditions culinaires au site Dawson.

Keywords: Iroquoians; Northeastern North America; pottery; lipid analysis; Bayesian modeling

Mots-clés: Iroquoiens; Nord-est américain; poterie; analyses lipidiques; modélisation bayésienne

About 1,000 years ago, First Peoples began to establish increasingly larger settlements in different regions of northeastern North America, often at localities where they had gathered for several generations already. These settlements may have generated a sense of belonging and triggered the expression of local identities. The consolidation of Iroquoian-speaking people in semipermanent settlements along the St. Lawrence Valley is but one reflection of such a social transformation (Birch and Williamson 2012; Chapdelaine 1989, 2019; Engelbrecht 2003; Heidenreich 1971; Jamieson 1990; Tremblay 2006). Inhabitants of these villages made and used clay containers that were typically subglobular in shape and of variable sizes. This was by no means the beginning of ceramic technology in northeastern North America, given that pottery was introduced in this region more than 3,000 years ago. But these pots differ from those of previous times. Although an increasing number of studies are now revealing more technological diversity than previously thought in ceramics of all periods and throughout northeastern North America (Braun 2012; Hawkins et al. 2021; Michelaki 2007; Taché 2005), the association of distinct pottery styles with specific and limited geographic ranges, larger vessel sizes, reduced temper size, and a predominance of the modeling over the coiling forming technique have been said to distinguish Iroquoian ceramics from earlier pottery traditions (Hart and Brumbach 2009; Kooiman 2021; Ritchie and MacNeish 1949; Snow 1995). Knowledge of how these pots were used and whether they represented a fundamental change in foodways is crucial to understanding Iroquoian lifeways.

It is often assumed that pottery recovered from Iroquoian villages was at least partly involved in the preparation of maize-based recipes, a crop known to have been introduced in temperate northeastern North America as early as 300 years BC (Albert et al. 2018; Gates St-Pierre and Thompson 2015; Hart et al. 2003, 2007). Such an assumption is supported by archival documents written by seventeenth- and eighteenth-century European explorers and missionaries, which provide interesting information about Iroquoian foods and foodways (Kalm 1977; LeJeune 1897; Sagard 1632; Waugh 1916). These sources describe the various ways maize was prepared, some of which required grinding maize into a fine flour (Waugh 1916). Grinding tools in Iroquoian village sites are thought to reflect this practice. A recipe often mentioned in ethno-historical documents is *sagamité*—a maize-based soup that simmered in receptacles placed over coals and into which any available fish, fowl, fruits, or meat could be added (Kalm 1977; LeJeune 1897; Sagard 1632; Waugh 1916). Iroquoian ceramics' shapes and sizes are consistent with this method of cooking maize. This observation, added to a few decorative motifs and a presumed link between the pottery and the products of agriculture, broadly speaking, probably contributed to the long-held assumption that where maize is a significant portion of the diet, it would likely have been cooked in ceramic vessels (Blake 2015; Chilton 1999; Hart 2012).

But the accumulation of archaeological data is revealing a reality that is much more complex and diverse, with the relative importance of different food resources among Iroquoian-speaking people inhabiting the St. Lawrence Valley now appearing to have varied across time and space. Although several researchers have contributed to better understanding this variability—in particular, through zooarchaeological, paleobotanical, and isotopic studies (e.g., Booth 2014; Cossette 1993; Feranec and Hart 2019; Glencross et al. 2022; Guiry et al. 2021; Hart 2023; Hawkins et al. 2019; Katzenberg et al. 1995; Monckton 1992; Pfeiffer et al. 2014, 2016; Plourde 2012; Stewart 1999)—much remains to be learned on this topic. The use of chemical approaches to directly determine the use of pottery offers an approach to further investigate the diversity of Iroquoian foodways. For example, was maize used systematically in clay pot cooking, what was the proportion of maize versus other food sources cooked in pots (together or in subsequent uses), and how did the use of pottery vary from site to site and through time? To begin to address these questions, we present one of the few lipid residue analyses of Iroquoian pottery (see also Kooiman et al. 2022; Reber and Hart 2008), focusing on the Dawson site, a village settlement occupied by Iroquoian-speaking people in the fifteenth and sixteenth centuries. We deploy a combination of molecular and isotopic approaches, in addition to Bayesian models, to examine mixing of resources in pots, either as single events or through sequential uses of pottery. This methodology is applied here for the first time to Iroquoian pottery.

The Dawson Site

The Dawson site was discovered in 1859 when construction workers unexpectedly unearthed human remains, potsherds, and charcoal from ancient cooking fires in an area now located in downtown Montreal (Figure 1). Set on sandy soils, this Iroquoian village was bordered by a small stream at the time of occupation. It has long been a favored candidate in the search for the famous village of Hochelaga, encountered by Jacques Cartier during his second trip to the St. Lawrence Valley in 1535 (Pendergast and Trigger 1972), but a consensus on this question has yet to be reached. Following its accidental discovery, what remained of the site was investigated by John William Dawson, then director at McGill College, now McGill University (Dawson 1860, 1861). Sherds from more than 250 ceramic vessels were collected, in addition to ceramic pipes, bone objects, and stone tools. As one of the first Iroquoian sites ever described, the Dawson collection became seminal in the history of Northern Iroquoian archaeology. It was properly studied in the late 1960s by Bruce Trigger and James Pendergast (Pendergast and Trigger 1972). As famous as the Dawson site was, the nature of the data—recovered in an antiquarian manner characteristic of the mid-nineteenth century—has long been a limit to interpretations.

In 2016, small remaining portions of the Dawson site at some distance from the original discoveries were unearthed during construction work. The firm Ethnoscop Inc., in collaboration with Ville de Montréal, conducted salvage archaeological excavations between 2016 and 2019 (Ethnoscop 2018, 2023). After a gap of more than a century and a half, the Dawson site was suddenly revealing some new, rigorously excavated material to work with. This provided an opportunity to apply state-of-the-art analytical methods to new data from an old site. The ceramic material reported here comes from these excavations. Recent excavation at the Dawson site led to the recovery of potsherds from 122 ceramic vessels. Typologically, the pottery found at Dawson has been dated to a time frame ranging from the late fourteenth to the sixteenth centuries AD. To determine the chronological window of occupation at

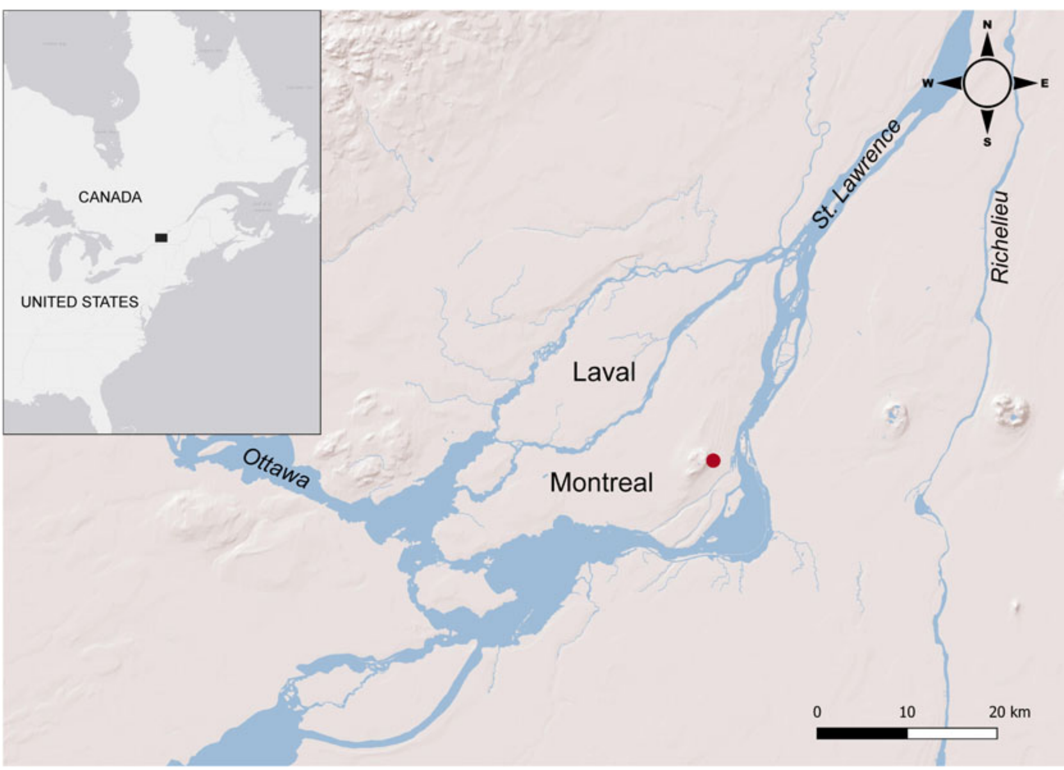

Figure 1. Location of the Dawson site in the St. Lawrence Valley.

Dawson more precisely, 16 radiocarbon dates were obtained on various materials (wood charcoal, pottery residue, charred maize kernel) from the site. Results seem to indicate an occupation in the third quarter of the fifteenth century (Supplemental Table 1). A Bayesian analysis of the chronological data is currently being applied and will soon refine our understanding of the site chronology (Tremblay and Gates St-Pierre 2019).

Faunal remains uncovered at Dawson comprise several mammal and bird species, including deer (*Odocoileus virginianus*), caribou (*Rangifer tarandus*), moose (*Alces alces*), beaver (*Castor canadensis*), wolf (*Canis lupus*), muskrat (*Ondatra zibethicus*), bear (*Ursus americanus*), and snowshoe hare (*Lepus americanus*; GAIA 2018a; Ostéothèque de Montréal 2023). At first sight surprising, the small presence of beluga (*Delphinapterus leucas*) and harp seal (*Pagophilus groenlandicus*) in the list bear witness to ties with the St. Lawrence Iroquoian communities in the Quebec City area, whose archaeology revealed their exploitation of estuarine resources farther downriver (Plourde 2012; Rioux and Tremblay 1998; Tremblay 1993). This marine mammal presence is represented by one beluga tooth and two metacarpal fragments of harp seal, constituting a negligible proportion of the total faunal remains, and therefore likely not representing a significant part of the local subsistence. Birds are represented by the passenger pigeon (*Ectopistes migratorius*) as well as unspecified Phasianidae and Anatidae remains. As for fish, the catadromous Atlantic eel is present, but all other species are freshwater. These include walleye (*Sander* spp.), smallmouth bass (*Micropterus dolomieu*), lake sturgeon (*Acipenser fulvescens*), white sucker (*Catostomus commersonii*) and river redhorse (*Moxostoma carinatum*), channel catfish (*Ictalurus punctatus*), brown bullhead (*Ameiurus nebulosus*), freshwater drum (*Aplodinotus grunniens*), and northern pike (*Esox lucius*).

Macrobotanical remains have been associated with both cultivated and wild plant species (GAIA 2018b, 2023). The list of plant resources identified at Dawson includes, as one would expect, the triad comprising maize (*Zea mays*), common beans (*Phaseolus vulgaris*) and cucurbits (*Cucurbita* spp.), with tobacco (*Nicotiana rustica*) also present. As for the wild plant species, they are mostly fruits, such as wild cherries (*Prunus* spp.), elderberries (*Sambucus* spp.), blueberries (*Vaccinium* spp.), raspberries and blackberries (*Rubus* spp.), hawthorn (*Crataegus* spp.), staghorn sumac (*Rhus typhina*), and wild sarsaparilla (*Aralia nudicaulis*). Butternut (*Juglans cinerea*) is also present.

Material and Methods

In this study, we extracted lipids from 32 potsherds recovered from secure stratigraphic contexts during the 2016–2019 excavations at the Dawson site using the acidified methanol protocol (Craig et al. 2013; Supplemental Table 2). These 32 sherds include 17 rims (including 2 from the same vessel) and 15 neck/body sherds representing a minimum of 25 distinct vessels, with ($n = 13$) or without ($n = 5$) a collar (vertical extension of variable height at the mouth), on which most of the decorative motifs are applied (Figure 2). Such a sample is stylistically representative of the ceramic assemblage at the site and corresponds to about 20% of the 122 vessel units recently identified at Dawson. Unfortunately, the disturbed urban context of these excavations prevented the selection of pottery sherds from distinct spatial contexts (e.g., longhouses, pits, hearth features, etc.). The association of lipids and ancient pottery can occur in the form of visible residues, typically carbonized deposits adhering to vessel walls, or as absorbed residues invisible to the eye but present within the porous ceramic matrixes. Among the 32 sherds analyzed at Dawson, 11 with absorbed and visible residues provided two distinct samples, for a total of 43 samples subjected to elemental analysis–isotope ratio mass spectrometry (EA-IRMS), gas chromatography-mass spectrometry (GC-MS), and GC-combustion-isotope ratio-MS (GC-C-IRMS) using established protocols (Supplemental Text 1).

Results and Discussion

Survival of Absorbed and Visible Lipids

Eighty-two percent ($n = 9$) of the foodcrust samples and 88% ($n = 28$) of the absorbed residues exhibited satisfactory levels of lipid preservation (potsherds >5 $\mu g.g{-}1$; foodcrusts >100 $\mu g.g{-}1$; Craig et al. 2013; Evershed 2008). These interpretable samples represent altogether 28 vessel units. The average lipid concentrations are 104 and 356 $\mu g.g{-}1$ for the absorbed and foodcrust samples, respectively. Such levels are

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Figure 2. Rimsherds selected for analysis from the Dawson site. (Color online)

comparable to lipid yields reported in other studies of indigenous ceramics in northeastern North America (Taché and Craig 2015) and confirm that organic matter tends to preserve well in these contexts.

Molecular Characterization

Dawson lipid profiles contain an array of saturated fatty acids ($C_{8:0}$ to $C_{30:0}$) dominated by palmitic ($C_{16:0}$) and stearic ($C_{18:0}$) acids, monounsaturated fatty acids with even numbers of carbon atoms

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($C_{14:1}$ to $C_{24:1}$), and branched fatty acids ranging from C_{13} to C_{19}. Several samples also contain a range of dicarboxylic acids (C_6 to C_{18}), potentially representing oxidation products of unsaturated fatty acids, despite their occasional association with other degradation processes occurring during burial (Baeten et al. 2013; Copley et al. 2005; Regert et al. 1998). Cholesterol and products of its degradation (primarily Cholest-5-ene, 3-methoxy-, [3.beta.]-) are present in 10 samples, indicating that animal resources were processed in these containers (Whelton et al. 2021). In addition, plant biomarkers were recorded in 12 samples. These include methyl dehydroabietate and 7-oxo-dehydroabietate, biomarkers for pine resin (Jerković et al. 2011; Mitkidou et al. 2008; Modugno and Ribechini 2009; Regert 2004) in nine samples. These compounds may originate from the use of coniferous resin as a sealant (Reber and Hart 2008) or from the smoke of campfires if pine was being used as fuel (Reber et al. 2019). Stigmastanol is present in four samples, and α-amyrin (pentacyclic triterpenoid, common among angiosperm resins; Bondetti et al. 2019) was identified in one sample (Supplemental Table 3). Significantly, *n*-dotriacontanol, previously established as a potential maize biomarker (Reber et al. 2004), was not detected in the Dawson samples following TMS derivatization of the acid methanol extracts.

Instead, the most distinctive molecular feature of the Dawson pottery sherds is the presence of biomarkers for aquatic products—namely, long-chain C_{18}-C_{22} (o-alkylphenyl)alkanoic acids (APAAs) with C_{20}/C_{18} ratios above 0.06, along with isoprenoid fatty acids (4,8,12-Trimethyltridecanoic, phytanic, and pristanic acids; Bondetti et al. 2021; Craig et al. 2007; Evershed et al. 2008; Hansel et al. 2004). These account for 78% ($n = 29/37$) of the interpretable samples and 71% ($n = 20/28$) of the interpretable vessel units analyzed (Figure 3). Dihydroxy fatty acids, also used to identify aquatic resources (Cramp and Evershed 2014), were not detected in the Dawson residues. The APAAs form during the protracted heating of mono- and polyunsaturated fatty acids, implying that vessels were subjected to at least one hour of heating at 270°C, or at 200°C for five hours, conditions easily achieved through both boiling or roasting (Bondetti et al. 2021; Lucquin et al. 2018). The conditions required to form the highly diagnostic APAAs are not always met during food preparation, and both APAAs and isoprenoid acids, which occur at low concentrations relative to other lipid molecules, may be lost through exposure to the burial environment. In phytanic acid, a ratio of the diastereomers SRR/RRR (3S,7R,11R,15-phytanic acid/3R,7R,11R,15-phytanic acid) exceeding 75.5% has been shown to be characteristic of aquatic resources (Lucquin et al. 2016, 2018). In this study, 46% ($n = 11/24$) of the samples for which this value was obtained meet this criterion. The remaining samples, characterized by SSR/RRR ratios ranging from 41 to 72, may reflect the processing of ruminant resources, an interpretation further supported in cases where no aquatic biomarker is present (samples #1, 2, 7, 11, 12). Samples with SRR/RRR ratios below 75.5% and aquatic biomarkers may, on the other hand, reflect a mixture of ruminant and fish resources. The possibility that some of these containers (samples #21, 27, 33, 37, 41) were used to process freshwater shellfish, also shown to have lower diastereomer ratios (Admiraal et al. 2023), is worth considering despite the absence of bivalve shells in the faunal assemblage from Dawson. Nonetheless, aquatic resources clearly were a favorite ingredient among the Dawson cooks, but were these fish prepared alone or mixed with other foods? Isotopic measurements of fatty acids and bulk charred deposits provide a more quantitative measure of food input.

Isotopic Characterization

Bulk Stable Isotope Analysis. Despite limitations arising from uncertain isotope endpoints of different foodstuffs and diagenetic alteration (Heron and Craig 2015), EA-IRMS of charred deposits adhering to the interior walls of ceramic vessels can provide a number of useful lines of information, especially when combined with other analytical techniques (Hastorf and DeNiro 1985). Bulk $\delta^{13}C$ isotope values from 10 carbonized deposits range from −17.3 to −24.4‰, indicating variable C_3 and C_4 inputs that must include maize and that are consistent with a mixture of terrestrial C_3 and C_4 plants, terrestrial mammals, and freshwater fish. A comparison of the Dawson site carbon and nitrogen isotope values with previously published data obtained on the region's earliest pottery (ca. 3000–2400 BP) from a range of inland and coastal sites is informative (Taché and Craig 2015). Figure 4 shows almost no overlap between early pottery and Dawson $\delta^{13}C$ values. Although both the early and Dawson pots include samples with elevated carbon values, the early pottery samples systematically have higher $\delta^{15}N$ values.

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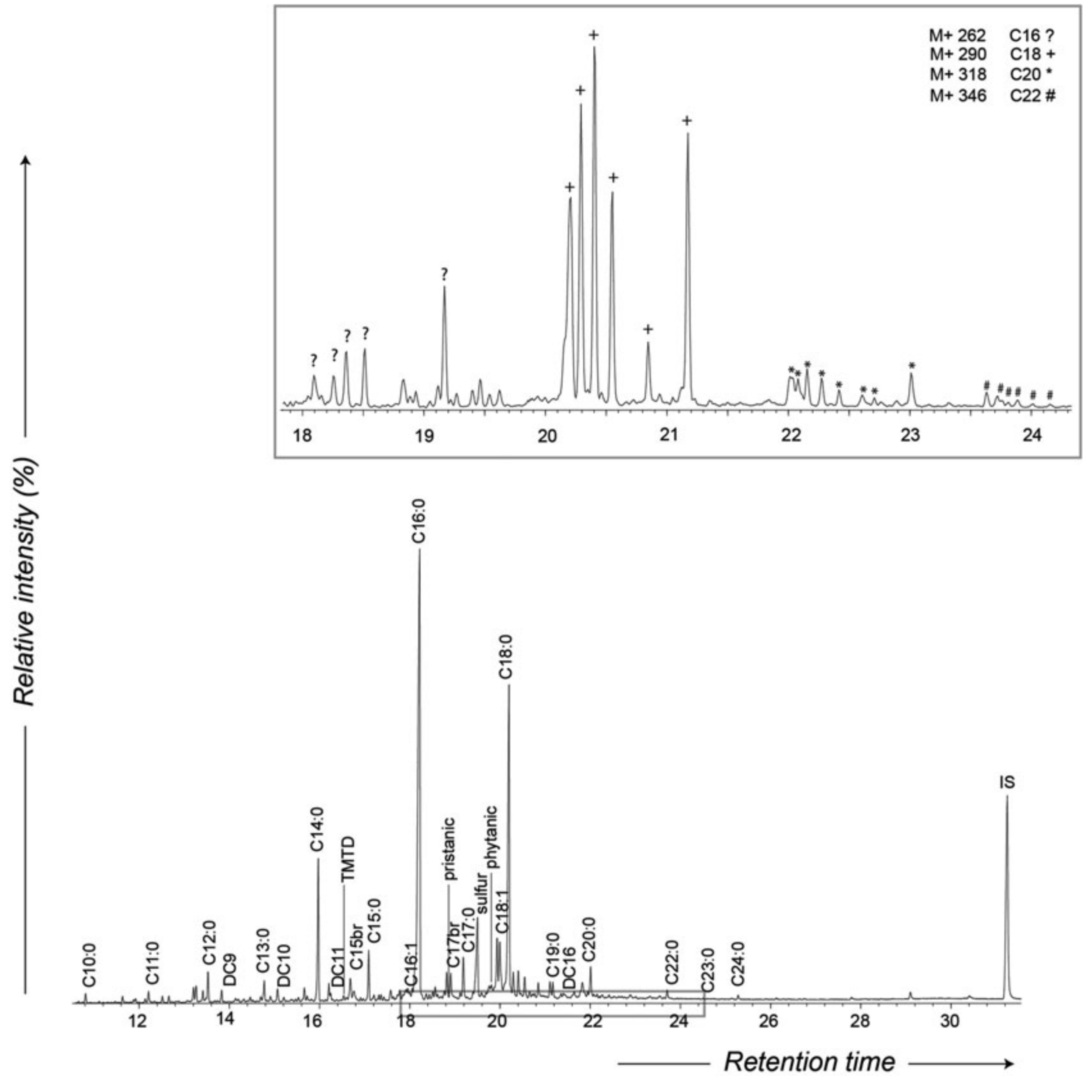

Figure 3. Typical partial gas chromatogram of a lipid extract from Dawson-site ceramics showing evidence of degraded aquatic oil from potsherd 9S3B (sample #19). The partial m/z 105 ion chromatogram (inset) shows ω-(o-alkylphenyl)alkanoic acids with 16 (?), 18 (+), 20 (*), and 22 (#) carbon atoms. Cn:x are fatty acids with carbon length n and number of unsaturations x; DCx are α,ω-dicarboxylic acids with carbon length x; br are branched-chain acids; TMTD is 4,8,12- trimethyltridecanoic acid; IS is internal standard (n-hexatriacontane).

In this case, the elevated carbon measurements are likely due to a contribution from marine resources, an interpretation further supported by the coastal location of these samples, the presence of aquatic biomarkers in the residues, and the absence of maize agriculture at this time. The comparatively low $\delta^{15}N$ values associated with samples from Dawson, on the other hand, leave little doubt that maize contributed to these residues—information that was not readily accessible through molecular characterization alone. Comparison between early pottery and Dawson C:N ratios also shows a tendency for higher C:N ratios at Dawson (unpaired t-test, $t = 2.79$; $p = 0.027$). Given that Atomic C:N ratios are indicative of the amount of protein versus other macromolecules such as carbohydrates and lipids (Bondetti et al. 2019), these higher values are consistent with a greater contribution from plant tissues at Dawson. The difficulty surrounding the identification of plant resources, maize specifically, through GCMS analysis of Dawson pottery likely results from a mixing of resources in these containers. Indeed, given that each lipid compound identified in a residue may derive from any single

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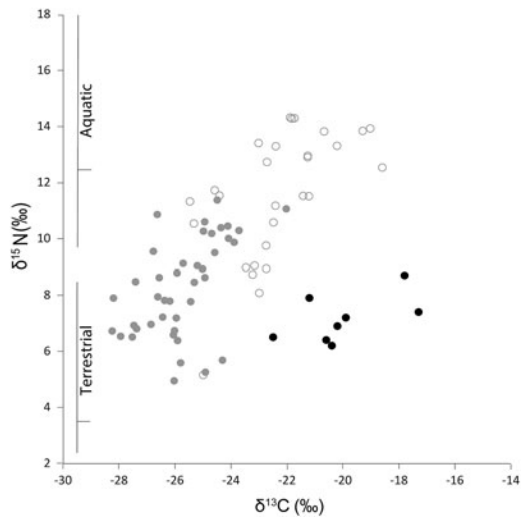

Figure 4. Bulk stable carbon and nitrogen isotope data obtained from internal carbonized residues adhering to Iroquoian pottery from the Dawson site (black circles) and the region's earliest (ca. 3100–2300 cal. BP) pottery from inland (filled gray circles) and coastal sites (open gray circles; data previously reported in Taché and Craig 2015). The median and ranges (2σ) of experimentally charred aquatic and terrestrial animals (Craig et al. 2013) are also shown.

resource ever processed in a pot, without biomarkers the contribution of plants to a chromatogram tends to go unnoticed if mixed with other lipid-rich resources (Evershed 2008).

Single-Compound Isotope Analysis. To further investigate the source of lipids recovered from the Dawson assemblage, the δ^{13}C values of the two main fatty acids—palmitic ($C_{16:0}$) and stearic ($C_{18:0}$)—was determined using GC-combustion-isotope ratio MS (GC-C-IRMS) analysis. Twenty-five absorbed lipid samples representing 24 distinct vessels were analyzed by GC-C-IRMS and compared to reference value ranges of the most likely food candidates to have been processed in these pots: freshwater aquatic oils (indistinguishable from nonruminant adipose and C_3 plants based on isotope values alone), wild ruminant adipose, and maize (Figure 5). An ellipse representing the reference value range for marine resources was also included in Figure 5 to illustrate potential equifinality issues met when interpreting residues representing mixing of resources; however, given the site's location and the extremely sparse findings of marine fauna (see above), fats derived from marine animals would seem highly improbable. The results show a wide range of δ^{13}C values for palmitic ($C_{16:0}$) and stearic ($C_{18:0}$) fatty acids from −21.8 to −30.9‰ (palmitic) and from −21.0 to −31.9‰ (stearic; Supplemental Table 3). Although several samples fall within the reference value ranges of freshwater aquatic oils and wild ruminant adipose, it is notable that almost half of the Dawson data ($n = 12$) are found outside the reference value ranges of the most likely food candidates to have been processed at Dawson. Although a contribution from anadromous/catadromous fish species (characterized by isotopic values falling between freshwater and marine taxa) cannot be excluded, a more likely explanation for these intermediate values considering other sources of data (faunal, botanical, isotopic, contextual) would be that, rather than a single source, residues from Dawson contain a complex distribution of lipids from C_4 plants (i.e., maize) and freshwater aquatic oils, at the very least. This independent line of evidence provided by GC-C-IRMS values provides further support to the combination of isotopic and molecular characterization of Dawson residues discussed above and requires further deconvolution.

Mixing Models

Identifying mixtures of foods, determining whether ingredients were cooked together or through sequential use of the pot over time, and making inferences about the relative proportions of various food types are major challenges met when interpreting lipid profiles, which, to this day, preclude the reconstruction of ancient recipes. To illustrate potential effects of mixing, we considered simple linear mixing models and more complex Bayesian mixing models. We also conducted actualistic experiments, where modern maize from an organic Amish farm in northern Washington County (New York state) and lake trout from Cayuga Lake (New York state) were mixed in 10% increments

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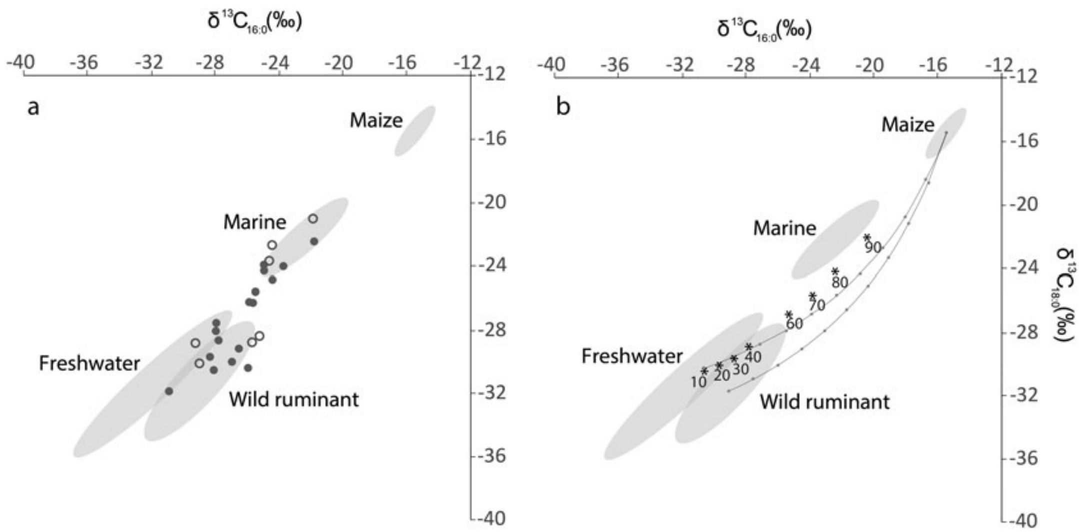

Figure 5. δ^{13}C values of $C_{16:0}$ and $C_{18:0}$ n-alkanoic acids extracted in (a) Dawson site samples with (filled gray circles) and without (open gray circles) aquatic biomarkers. The data are shown against modern reference values expressed as 68% confidence ellipses (Supplemental Table 4); (b) authentic mixes of maize and lake trout in 10% increments (asterisk symbols). The data are shown against modern reference values expressed as 68% confidence ellipses (Supplemental Table 4) and average isotopic endpoints and mixing lines in 10% increments for hypothetical mixes generated in R of maize with (1) freshwater aquatic resources and (2) wild ruminant adipose fats.

as described in Hart et alia (2018; Supplemental Text 1). The results of these validate the theoretical maize–freshwater fish mixing line and suggest the mixing of maize and freshwater aquatic oil as one likely explanation for the δ^{13}C measurements of palmitic and stearic fatty acids ($C_{16:0}$ and $C_{18:0}$) observed on, at least some, of the Dawson samples (Figure 5a). As recently proposed by Admiraal et alia (2023) using theoretical mixing curves, caution must be taken when interpreting Δ^{13}C values below −1.1 as evidence for the presence of ruminant adipose or dairy fats when C_4 plant oils are a plausible component. Indeed, Figure 5b shows—for the first time empirically—that such negative Δ^{13}C values could also be observed when mixing maize with aquatic oils. Of the Dawson vessels, six samples have Δ^{13}C values below −1.1 and therefore could be interpreted as a mixture of freshwater fish and maize, potentially with a ruminant fat—for example, from the artiodactyl (that is, deer and moose), which is plentiful at the site. Interpretations of such negative values are further complicated by the identification of the full set of aquatic biomarkers in four of these samples, whereas the other two contain all three isoprenoid acids and SRRs of 71% and 80%, also consistent with the processing of aquatic resources despite the absence of ω-(o-alkylphenyl)alkanoic acids. This raises the possibility that more than two food sources are represented in the residues.

The use of Bayesian mixing models was advocated to better understand the proportional contribution of more than two food sources to lipid residues (Fernandes et al. 2014). These models must rely on a range of reference data, ideally as representative as possible of the environmental and cultural contexts under investigation. Such a comparative baseline was sought for the Dawson site, where the limited reference values from northeastern North America were complemented with reference values obtained in comparable environmental contexts around the world (Supplemental Table 4). To verify the efficiency of our model parameters to estimate the relative contributions of different food sources to a residue, it was first tested against the authentic maize-lake trout mixtures. In the first test, where only two food sources (maize and freshwater fish) were included, the Bayesian model generated by FRUITS reliably estimated the proportions of both ingredients, despite relatively high uncertainty ranges (Figure 6). When a third food source (wild ruminant adipose) is considered as a potential explanation for the values associated with the lake trout–maize experimental mixtures, we observe a trend toward underestimating the proportion of freshwater fish in samples, except in cases where fish

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represent only a small proportion (less than 20%) of the mixes. It should also be noted that the contribution of wild ruminant adipose, which should be nil, is overestimated when standard deviations are considered, but significantly, the model predicts that a zero or negligible (less than 3%) percent contribution is credible in all cases at the 95% confidence interval. Despite the addition of wild ruminants as a potential food source in Figure 7, it is also reassuring that the predicted trends remain consistent with the gradual increase in maize / decrease in fish in the authentic mixes.

To illustrate the contribution of different food sources to 25 residues from the Dawson site, a Bayesian mixing model was implemented in FRUITS (Supplemental Text 1). In this model, $\delta^{13}C_{16:0}$ and $\delta^{13}C_{18:0}$ values were used as proxies, and three food groups were considered as potential sources: freshwater aquatic oils, C_4 plant oils, and ruminant adipose fats, with $\delta^{13}C_{16:0}$ and $\delta^{13}C_{18:0}$ reference ranges and concentrations as defined in Supplemental Table 5. Other potential sources—such as fruits, tubers, nuts, and leguminous plants—were not included in this model. Many of these have very low lipid content, whereas others, such as nuts, are likely to have values that overlap with freshwater aquatic oils. Given the predominance of aquatic biomarkers in our samples, the freshwater aquatic oil food source was favored. The mixing model presented here should thereby be viewed as illustrative rather than definitive. Its main utility undoubtedly lies in its ability to identify and estimate C_4 plant oil contribution to the residues, especially given that this foodstuff was invisible from the chromatographic profiles. Significantly, the model generated predicts the presence of variable amounts of maize in almost all the potsherds, with a 0% contribution credible in only two cases, represented by samples 15 and 27 (Figure 8a). According to the model, 40% ($n = 10$) of the samples contain over 50% of maize by dry weight. The latter have elevated isotope carbon values and significantly lower lipid yields (Mann-Whitney $U = 39$; $p = <0.05$) than the remaining 15 samples, indicating that these elevated carbon values reflect the presence of maize rather than marine aquatic resources in the residues from Dawson samples.

Despite higher standard deviations associated and general uncertainties with the predicted proportions of freshwater oil and ruminant fats, the Bayesian mixing model shows a general trend where the amount of aquatic resource is inversely proportional to the amount of maize (Figure 8b). The predicted proportion of ruminant varies in a less predictable manner. In this case, a percent contribution below 3% is credible in 52% ($n = 13$) of the samples, which, as mentioned earlier, could be observed in cases where a food source absent from the sample is added to the mixing model. On the other hand, a minimum percent contribution exceeding 10% in six samples (#17, 19, 16, 10, 11, 21) likely reflects a real presence of ruminant mammal fats in these containers, although exact proportions cannot be estimated due to high uncertainty ranges (Figure 8c).

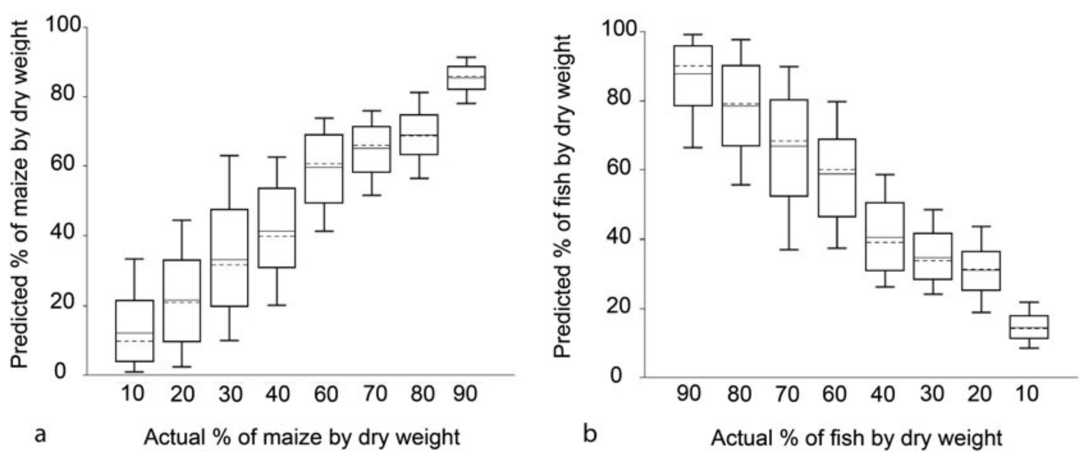

Figure 6. Actual against predicted percentage contribution of (a) C_4 plant oil and (b) freshwater aquatic oil obtained by applying FRUITS Bayesian modeling to experimental mixtures of modern maize and freshwater lake trout in 10% increments by dry weight. The boxes represent a 68% credible interval, whereas the whiskers represent a 95% credible interval. The horizontal continuous line indicates the mean, whereas the horizontal discontinuous line indicates the median.

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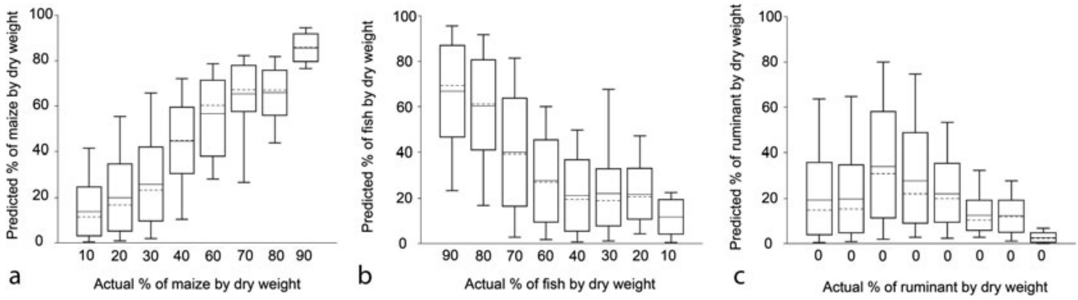

Figure 7. Actual against predicted percentage contribution of (a) C_4 plant oil, (b) freshwater aquatic oil, and (c) wild ruminant adipose fats obtained by applying FRUITS Bayesian modeling to experimental mixtures of modern maize and freshwater lake trout in 10% increments by dry weight. The boxes represent a 68% credible interval, whereas the whiskers represent a 95% credible interval. The horizontal continuous line indicates the mean, whereas the horizontal discontinuous line indicates the median.

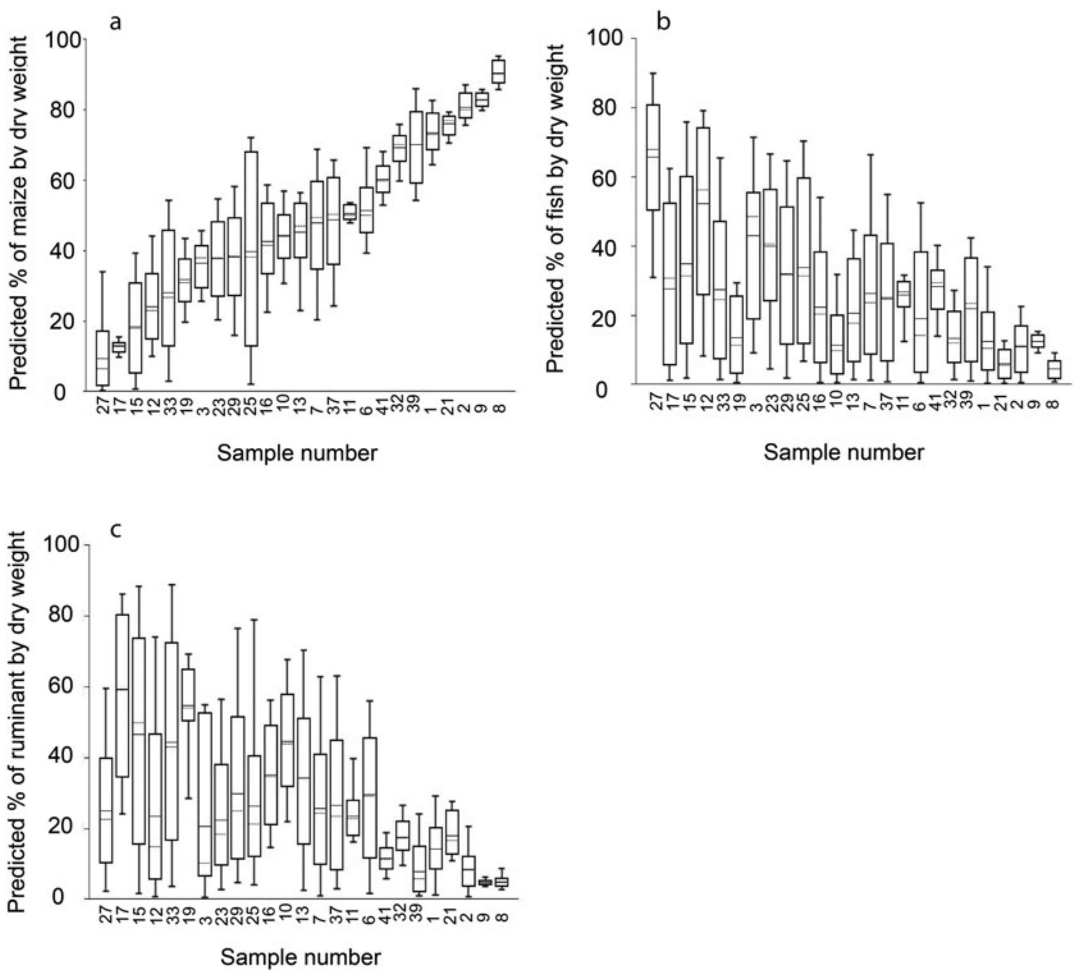

Figure 8. Estimated percentage contributions of lipids from different food sources to Iroquoian ceramics from the Dawson site using nonconservative model parameters. The boxes represent a 68% credible interval, whereas the whiskers represent a 95% credible interval. The horizontal continuous line indicates the mean, whereas the horizontal discontinuous line indicates the median.

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Discussion and Conclusion

Combining analytical techniques and improving our interpretative tool kit through the development of mixing models based on isotope values is essential to get the most out of ancient biomolecules preserved in the archaeological record. This is especially true when trying to assess the importance of a particular plant resource—in this case maize—to residues likely to represent a mixing of resources. This study combined molecular data (GCMS), bulk carbon and nitrogen isotope values (EA-IRMS), compound-specific isotope analysis (GC-C-IRMS), and Bayesian mixing to better characterize the relative importance of different food sources present in residues associated with Iroquoian ceramics recovered at the Dawson site and dating to the fifteenth and sixteenth centuries AD. Results from 32 potsherds demonstrate their use in preparing a range of foodstuffs, primarily freshwater fish and maize but possibly also other animals or plants. The presence of aquatic resources in most residues is convincingly demonstrated through GCMS analysis by the presence of a range of molecular compounds identified in the literature as biomarkers for aquatic products. Here, aquatic biomarkers were confidently assigned to freshwater fish based on site location and faunal record. It is worth noting, however, that even greater equifinality would result from a context where C_4 plants, freshwater fish, and marine fauna are all plausible targets, to the point that distinguishing between marine resources and maize could be difficult without the identification of biomarkers for maize. In line with previous findings (Admiraal et al. 2023; Hart et al. 2018), results also show that maize prepared with lipid-rich resources in pots will likely go undetected by molecular characterization alone, even when present in significant proportion. In this study, the presence of maize was detected through bulk and single-compound isotopic analysis, although both sets of values were intermediate between maize and other foodstuffs reference ranges, indicating mixing. Bayesian modeling allowed us to propose an omnipresence of maize, and it better estimates its proportion in individual potsherds. Interestingly, maize was shown to be the dominant product in at least 40% of pots, despite being "invisible" in the chromatographic profiles.

As recorded by early European explorers and missionaries, boiling maize kernels exposed to an alkaline solution was a widespread culinary tradition among agriculturalist populations in the Eastern Woodlands. This treatment increases the nutritional quality of maize and decreases the risk of malnutrition, prompting Briggs (2015:114) to suggest that "the hominy foodway, not the maize plant per se, was the dietary life-sustaining staple of the historic indigenous groups of the Eastern Woodlands." Because soaking and long-term boiling were necessary steps in such a nixtamalization process, ceramic containers would have facilitated the preparation of maize dishes (although see Ellwood et al. [2013] for experimental evidence indicating that limestone boiling rocks also increase the nutrient availability of maize through nixtamalization). Iroquoian populations inhabiting the St. Lawrence Valley from the fourteenth to sixteenth centuries could count on a diversified diet based on the Three Sisters (maize, squash, beans) and a variety of wild plants and animals to avoid malnutrition. But even if no longer serving nutritional benefits, the hominy foodway was commonly reported among Northern Iroquoian peoples of northeastern North America, perhaps as a relic of an ingrained culinary practice perpetuated across space and time (Briggs 2015:120). *Sagamité,* in particular, was a common recipe consisting of hominy corn pounded into meal, boiled in water, and enhanced with meat, fish, berries, or oil if available (Campanella 2013). Data reported here suggest that this dish was part of the culinary tradition at the Dawson site. Despite the limitation of organic residue analysis to distinguish between cooking events, the fact that all the carbonized deposits analyzed at Dawson contain lipids from several resources—minimally maize and fish—support this claim, given that it has been shown that such residues typically represent the last cooking event (Miller et al. 2020). No apparent differences in the use of collared versus noncollared vessels were noted, and with only six samples having associated radiocarbon dates (Supplemental Table 2), the detection of any chronological patterning in the use of pots at Dawson is currently out of reach.

Archaeologists are increasingly interested in highlighting the social dimensions of food and its role in the expression of identity (Bray 2003; Briggs 2015; Crabtree 1990; Crown 2000; Dietler and Hayden 2001; Graff and Rodríguez-Alegría 2012; Gumerman 1997; Hastorf 1991, 2016; Hudson 1993; O'Day et al. 2003; Parker Pearson 2003; Staller and Carrasco 2010; Twiss 2007, 2012, 2019). Beyond the

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identification of animal and plant species preserved in the archaeological record, this endeavor requires attention to the activities, cooking methods, rules, and meanings surrounding foods. The molecular tools deployed in this study shed light on pottery use and thereby contributed to the study of Iroquoian foodways. Here, data are consistent with mixing hominy corn meal with fish and possibly other ingredients in pots. Interestingly, the use of ceramics at different stages of maize transformations may be detected through molecular and isotopic analysis. Hart et alia (2009), for example, demonstrated through experiments that whole kernels and whole-grain hominy cooked in ceramics were largely masked by C_3 resources, whereas cornmeal tended to mask the isotopic signal of C_3 resources. Consequently, ceramics used in the transformation of ripe corn into hominy corn by boiling into a mixture of water and hardwood ashes, a method described in ethnohistorical documents (Waugh 1916), will almost certainly yield isotopic and molecular signatures different from those of the Dawson pots analyzed in this study. Future work could take several interesting directions but should involve the pursuit of culinary experiments in pottery vessels, the application of the biomolecular methods used at Dawson to a wider context to highlight culinary variability through time and between sites, and the incorporation of Indigenous knowledge in the research design. Indeed, the diversity of culinary behaviors, in all their nuances and complexity, can only be revealed through the application of interdisciplinary and integrative research perspectives.

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Data Availability Statement. The pottery sherds from which the lipid data were derived are stored at the Ville de Montréal archaeology reserve. All raw data obtained from molecular and isotopic analysis is presented in the manuscript or supplemental materials.

Competing Interests. The authors declare none.

Supplemental Material. For supplemental material accompanying this article, visit https://doi.org/10.1017/aaq.2024.51.

Supplemental Text 1. Methods and Instrumentation.

Supplemental Table 1. Dawson site radiocarbon dates.

Supplemental Table 2. Sample information.

Supplemental Table 3. Summary of molecular (GCMS) and isotope (EA-IRMS, GC-C-IRMS) data obtained on Iroquoian pottery from the Dawson site in Québec (Canada).

Supplemental Table 4. Compound specific carbon values of reference materials used in this study.

Supplemental Table 5. Mean, standard deviation, and concentration values of phytanic isomer SRR %, $\delta^{13}C_{16:0}$, and $\delta^{13}C_{18:0}$ for three different lipid groups.

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