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1 Boiled, fried, or roasted? Determining culinary practices in Medieval France 2 through multidisciplinary experimental approaches

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10 **Abstract:** While culinary practices evolved during the Middle Ages (historically dated between A.D. 476 and 1492), these
11 changes are difficult to detect as they are seldom studied. Around the 12th and 13th centuries A.D., changes can be seen in
12 the types of utensils and cooking hearths used, but also with the introduction of new animal and plant varieties, along with
13 recipes used by people in the upper echelons of society being put in writing. These novelties could be the result of changing
14 tastes and modes of preparing food, but to ascertain this we need to study the archaeological materials to determine the
15 cooking methods that may have been used and compare these to their context and time period. To this end, experiments
16 were designed and carried out to determine the traces left behind by different cooking methods. Our results have made it
17 possible to create a reference collection consisting of ceramics as well as faunal and botanical remains. The study of the
18 cooking traces, as well as the morphological changes visible on microscopic botanical elements—starch grains—have
19 allowed us to establish criteria that can be used in use-wear analysis. We then compared the experimental reference
20 collection to archaeological materials recovered from Couzan, a Medieval site in Forez, France. Our results support the
21 value of using starch grain analysis when studying the function of dark paste ceramics, and clearly demonstrate the interest
22 of bringing together different sub-disciplines in archaeology when using an experimental approach.

23 **Keywords:** Medieval period; experimental archaeology; ceramic use-wear; starch grains; function of ceramic vessels

24 25 26 27 28 1. INTRODUCTION AND PREVIOUS RESEARCH 29

30 In France, during the late Medieval period (between the 13th and 15th centuries A.D.), specialized studies
31 indicate a parallel evolution in the types of cooking vessels (Alexandre-Bidon 2005; Allios 2004; Husi 2015;
32 Ravoire 2006), hearths (Pesez 1986; Sirot 2011; Trochet 1998), as well as in the animals and plants consumed
33 (Clavel 2001; Ruas 1997; Yvinec 2012). While these different elements have never been fully considered
34 together before, they nevertheless seem to reveal a significant change in cooking practices during this time
35 period. The study of past ingredients is possible notably through the recovery of animal and plant remains:
36 archaeozoological and archaeobotanical studies respectively. Numerous sites in France have been studied,
37 through archaeobotanical and archaeozoological analyses, enabling us to learn about the diet, both animal and
38 plant-based, of people in the past. Residue analyses, recovered inside ceramic vessels, provide additional data.
39 Over the past 15 years, ancient diets have been further studied through isotopic studies. While these different

40 types of analyses have resulted in numerous publications and monographs, few however, provide useful
41 syntheses. For our specific study area and time period, several works exist on these different topics:
42 archaeobotany (Bakels 2005; Ruas 1997), zooarchaeology (Clavel 2001; Yvinec 2012), stable isotopes (Herrischer
43 et al. 2001), and residue analyses (Regert and Rolando 1995).

44 The way in which these foods were prepared remains a subject that has been more generally approached by
45 consulting ancient texts (Lambert 1992; Laurioux 1997, 2006). Indeed, cookbooks appeared in the second half of
46 the Middle Ages and became especially numerous between the 14th and 15th centuries. However, these were
47 aimed to be used by very high elites and do not, therefore, provide a more general panorama of food
48 preparation methods utilized by the vast majority of the population. Since the 1990s, ceramicists have
49 nonetheless become increasingly interested in the anthropological aspects of cooking vessels, by questioning
50 their functions and characteristics (Bats 1988; Lécuyer 1997; Ravoire and Diétrich 2009). The evolution of
51 cooking practices between the 13th and 15th centuries A.D. as reported by these afore-mentioned different
52 specialists, could in fact be understood if they were compared to one another, allowing to discern what was
53 happening in different regions and social spheres. In other words, where and when did these practices begin
54 and how did they diffuse. Thus, what can be determined about medieval cooking through material analyses?

55 As opposed to other techniques, the specificity of cooking techniques is that the product, the food itself, has the
56 vocation to disappear – in our digestive tracts - after being consumed. Consequently, it is of utmost importance
57 to consider all the elements that form part of the production process. Roasting, frying, boiling, and grilling¹ are
58 all parts of a system where the source of energy (the fire), the energy mediator (the container, and the water,
59 the air or the fat, depending on the type of cooking), and the transformed object (animal or plant-based food)
60 have to be considered as a whole². Each of these elements corresponds to evidence that can be subsequently
61 analyzed by archeologists.

62 In this article we present a multi-disciplinary experimental study that serves to better understand ancient
63 cooking practices of plant foods. More specifically this study consists of the boiling, frying, and roasting of peas
64 (*Pisum sativum* L.) and bread wheat (*Triticum aestivum* L.) using known Medieval techniques discerned from
65 historical texts, traces of fire exposure on ceramic vessels, and images in manuscripts and in various artistic
66 supports. While our original experiments also considered the cooking of animals— bones of sheep (*Ovis aries*)
67 and cow (*Bos taurus*), as well as pork (*Sus domesticus*) fat —, here we will only focus on the cooking of plant
68 foods; the experimental data collected from cooking animal matter will be presented elsewhere. The
69 experiments presented here allowed for the creation of a large reference collection of both ceramics and starch
70 grains. Subsequently, these markers (use-wear and starch grains) were used to study a selection of
71 archaeological ceramics from the medieval site of Couzan, France (Figure 1). The two methodologies are
72 detailed in the following sections.

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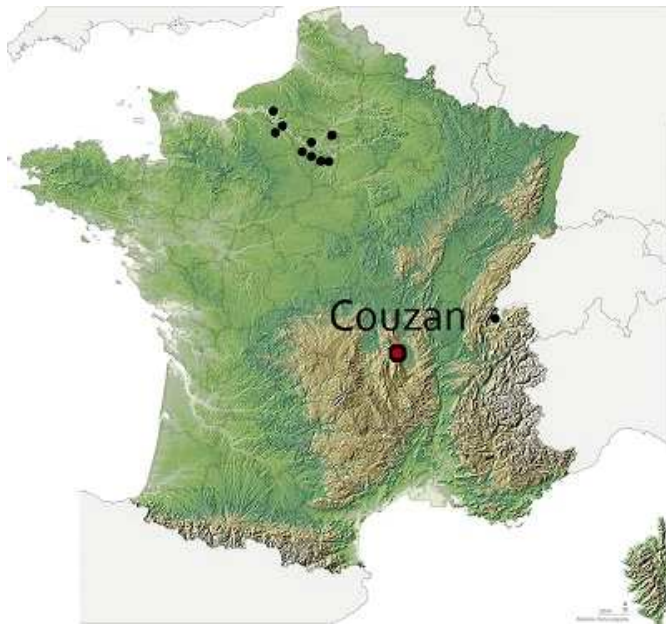
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1 Categories based on the use of heat “médiateurs” (water, fat, air) schematized in the cooking triangle, used by Michel Bats in his study of cooking vessels from Olbia in Provence, France (Bats 1988).

2 Analysis based on the methods employed for the study of archaeological techniques. See Bats (1988) and Boëda (2013).



80

81 Figure 1. Location of Couzan. Black dots indicate other sites where use-wear analyses have been carried out, and
 82 which are mentioned in the text.

83 1.1 Use-wear analysis

84 Pottery, or ceramic, is one of the materials most abundantly recovered during archaeological excavations in
 85 Medieval contexts in France. Ceramic studies, now almost systematically undertaken following archaeological
 86 excavations, make it possible most of the time to determine, within the vessels represented on a site, the share
 87 of culinary ceramics compared to the total ceramic assemblage. These identifications are based on functional
 88 typologies, often taking into account rough sketches of the traces drawn up by the ceramicists. Indeed, the use
 89 of fire in the context of cooking leaves marks on the surface of the containers, but also residues, preserved by
 90 charring or drying processes. Ceramics bearing this type of trace can therefore make it possible to know if a
 91 container was used for culinary purposes. In some well-documented contexts, we can also consider how these
 92 vessels were used based on the fire traces associated with the shape of the containers, as is the case with
 93 *coquemars*, which are cooking pots with a handle that could hold between 1 and 2 liters and were very
 94 widespread during the second half of the Middle Ages. These types of containers frequently present burn marks
 95 on the side opposite the handle, which makes it possible to determine that they were placed flat on the ground,
 96 against the fire (Durey-Blary 1999; Leenhardt and Vallauri 1997).

97 Although technical analyses of ancient ceramics have a long history (Bats 1988; Griffiths 1978; Henrickson and
 98 McDonald 1983), ceramicists have long remained attached to the technical properties of the ceramics
 99 themselves and their manufacture. The late 1990s saw a renewed interest in the value of ceramics (Leenhardt
 100 and Vallauri 1997), but studies specifically focused on anthropological questions remain rare. In recent years,
 101 studies, focusing on older periods - mainly the Neolithic, but also ancient Gaul - dwell on the traces left behind
 102 on these ceramics to better understand their use (Debels 2019; Saurel 2017; Vieugué 2014; Vieugué et al. 2016).
 103 Nevertheless, detailed approaches on the use of ceramics remain rare, especially for historical periods, where
 104 the existence of texts has tended to dominate the discourse on past cuisines, and this despite the biases that
 105 these texts present to address daily cooking.

106 In addition, studies on the residues present in ceramic vessels have also been carried out. Nicolas Garnier and
 107 colleagues propose in particular an identification of the chemical elements constituting these residues (Garnier
 108 2007). Lipid analyses can also be carried out (Drieu and Regert 2015). While these methods make it possible to

109 know to a certain degree the content of the ceramics and can shed light on cooking practices, for example by
110 highlighting the use of certain fats, they alone do provide data on the technical function of the containers.

111 The question regarding the role played by the different cooking methods that can be represented in a ceramic
112 set cannot therefore be evaluated based on the research mentioned above. To answer these questions, it was
113 therefore necessary to set up a use-wear study based on data acquired through research in this particular field.

114

115 **1.2 Starch grain analysis**

116 Starch grains are energy storage units of plants, composed of two different glucose chains (amylose and
117 amylopectin), and are tiny, ranging from 1 to 100 μm ($1 \mu\text{m} = 0.001 \text{ mm}$). They are synthesized in plastids during
118 photosynthesis and then primarily stored in roots, seeds, and fruits. Archaeological starch grains have been
119 successfully extracted from tools (Cagnato and Ponce 2017), ceramic vessels (Wang et al. 2016), organic vessels
120 (Duncan et al. 2009), dental calculus (Henry et al. 2011), coprolites (Horrocks 2006), intestinal remains (Cagnato
121 et al., *in press*), and sediments (Therin et al. 1999). The presence of starch in archaeological contexts has played
122 an important role in answering questions related to diets, past environments, domestication, food processing,
123 patterns of land use, and tool use (Crowther 2012; Horrocks et al. 2008; Piperno and Holst 1998). Starch grains,
124 like other macro- and microbotanical remains, display a range of characteristics that can lead to their taxonomic
125 identification, which include the size and shape of the starch grain that in some cases can be highly diagnostic.
126 Other important features that often allow them to be identified to taxon include the location of the hilum,
127 presence of lamellae, fissures, and the extinction cross (also known as the Maltese Cross), a pattern caused by
128 the orientation of the semi crystalline molecules that compose starch. This feature is visible only when viewed
129 under polarized light (Gott et al. 2006).

130 Importantly, starch grains are affected by cooking, which is an essential step for breaking down complex starch
131 polysaccharides into more easily digestible sugars and in many cases to remove toxins (Crowther 2012).
132 However, this not only alters the physical and compositional characteristics of starch grains but can also alter or
133 destroy the morphological and optical properties that allow analysts to identify them. In fact, two of the most
134 critical variables that affect a starch grain's response during cooking are temperature and moisture (Crowther
135 2012). Therefore, dry vs. wet cooking methods will impact the survival of starch grains differently, and it is this
136 reaction to cooking that can be used therefore to reconstruct the ancient techniques. Full gelatinization,
137 whereby the starch grain has irreversibly swollen and therefore structurally collapsed, occurs once a species-
138 specific temperature and degree of moisture has been reached.

139 Previous experimental studies have been published, whereby different plants have been cooked at different
140 temperatures and using diverse techniques. Notably, Henry et al. (2009) documented how starch grains of 10
141 domesticated plant species, with Old World origins, changed according to different cooking techniques. The four
142 legumes, and six grains from the Poaceae family, were exposed to boiling; grinding and then boiling, baking, and
143 soaking; parching, popping, fermenting, and grinding followed by fermenting. Maria del Pilar Babot (2003, 2006)
144 has documented the ways in which Andean plants such as maize (*Zea mays* L.), quinoa (*Chenopodium quinoa*
145 C.L. Willdenow (Willd.)), and potatoes (*Solanum tuberosum* L.) were modified by single or combined effects of
146 roasting, milling, freezing, and dehydration. Other experimental works have been carried out on maize and
147 manioc (*Manihot esculenta* Crantz) (Cagnato 2019a; Chandler-Ezell et al. 2006), while Pagan-Jimenez and
148 colleagues (2017) experimentally processed and cooked manioc and sweet potatoes (*Ipomoea batatas* L. (Lam.))
149 on griddles. The ways in which chili peppers (*Capsicum* sp.) react to heating and grinding has also been explored
150 (Cagnato 2019a). Experimental work specifically targeting other types of roots and tubers cooked in earthen
151 ovens has also shown interesting results (Messner and Schindler 2010; Thoms et al. 2015).

152

153

154 2. METHODOLOGY

155

156 2.1 Cooking experiments

157 To identify the traces left behind on archeological remains as a result of different cooking techniques, the first
158 step was to create a reference collection of such traces. In 2016, the first author designed and directed an
159 experimental project that led to the creation of a reference collection that consisted of ceramics³, as well as
160 plants and animal bones, cooked using a type of hearth typical of the Medieval period⁴.

161 The experiments took place at Orville Castle (Louvres, Île-de-France). For the boiling and frying experiments, a
162 brick hearth, based on some models seen at northern French castles (Château-Thierry, Chevreuse, etc.), was
163 built. The ceramic vessels were placed directly on the floor, the side opposite the handle flush against the fire.
164 To carry out the experimental roasting, an experimental oven made by François Gentili and his team in 2002,
165 based on Carolingian (7th-11th century A.D.) models, was used. The raw materials were selected with the intent
166 that these could be then compared to other archaeological remains. To this end it was important to choose
167 species that are commonly found at Medieval sites, notably peas and bread wheat⁵. Dried and fresh peas were
168 both selected to test whether humidity levels play a role in the type of traces left behind during cooking
169 practices, and in the modification of starch grains.

170 To study the physical and chemical effects of the different heat mediators used, the plants and animal bones
171 were boiled, roasted, and fried⁶. The latter cooking method consisted of using, separately, organic olive oil but
172 also pork lard, resources mentioned in medieval recipes as in *Le Viandier* (c. 1200 A.D.) (Scully 1988), *Le*
173 *Mesnagier de Paris* (14th century) (Brereton and Ferrier 1994), or *Du faitz de cuisine* (1420) (Scully 1985).

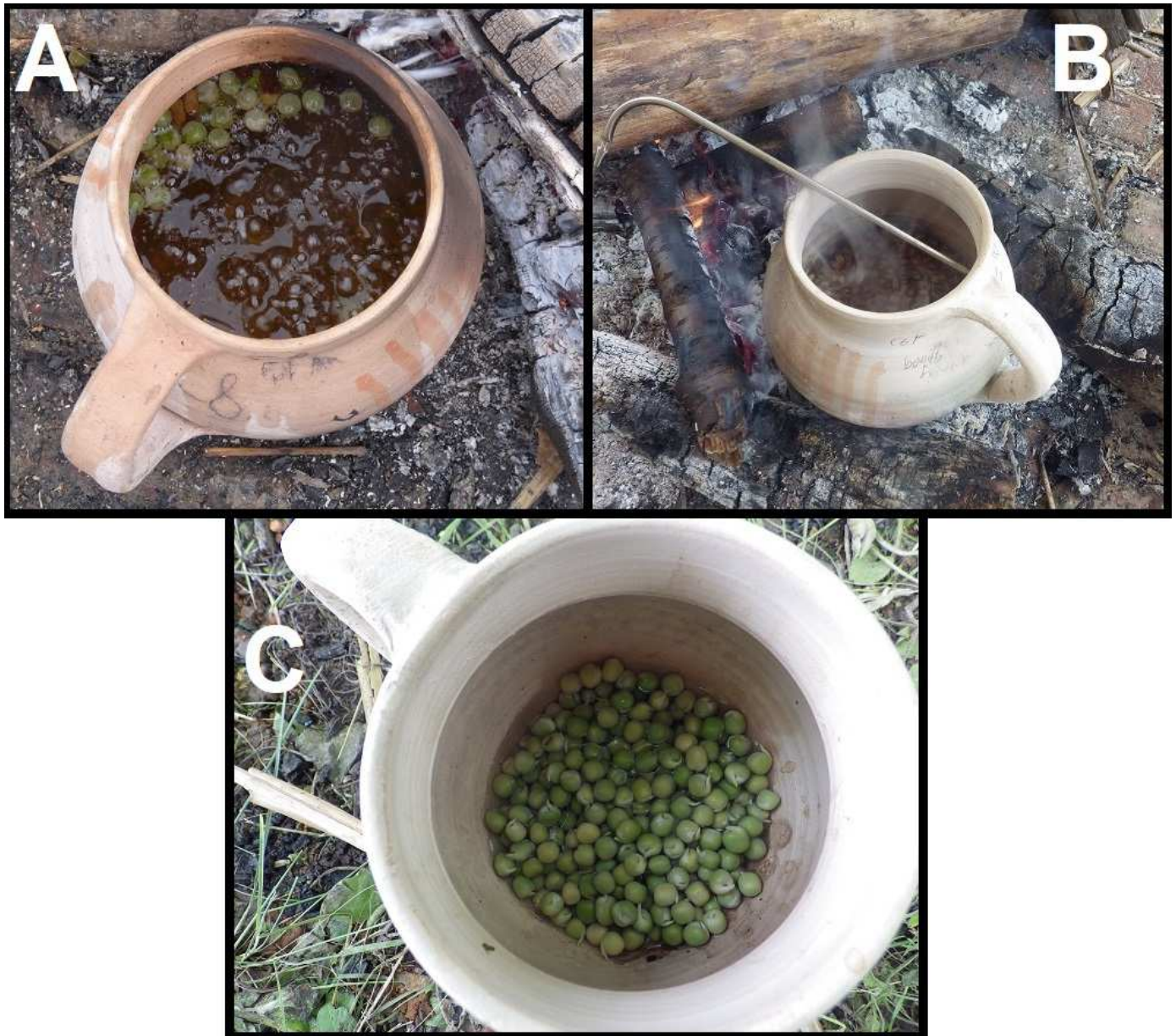
174 The grain and pulse (legume) samples were prepared in advance, each weighing 100 g. The dry peas were put to
175 soak in water for 12 hours before cooking. Each category of raw material was subsequently cooked using these
176 four methods for a short, medium, and long period of time (see Figure 3). At the end of each defined cooking
177 period, the cooked samples were extracted using a wooden spoon. The initial cooking times were established
178 based on contemporary cooking times, as recipes found in Medieval cookbooks never provide such details. As
179 frying wheat and peas is an unusual type of preparation, the cooking times were adapted in the field, following
180 an initial test. The cooking times and temperatures finally registered are reported in Figure 3.

3 Ceramics manufactured by Veronique Duray, in the “poterie des grands bois” workshop.

4 For a detailed description of the protocols of the experiment, see A. Chantran 2018.

5 The faba bean (*Vicia faba* L.), was initially considered as it is also commonly found at some archaeological sites. However, it would have been more complicated to obtain for our experimental work. There are numerous specialized studies but relatively few general summaries that cover the whole of France. As an example, we can mention the studies carried out at the sites of Grosse Tour de Bourges (Monnet 1999) and Blandy les Tours (Coste 2006). Marie-Pierre Ruas notes the relative importance of bread wheat and peas at several medieval sites in the south of France (Ruas 1997).

6 The three cooking methods (boiled, fried, roasted) were chosen based on the work by André Leroi-Gourhan (Leroi-Gourhan 1943 and 1945), Claude Levi-Strauss (Levi-Strauss 1964-1971), and followers such as Michel Bats (1988). When boiling and frying, the pots were filled with the liquid (water or fat) up to the shoulder, to correspond to the traces most frequently seen on ceramics of this period (Figure 2A and B). Roasting was carried out using a small amount of water at the bottom of the pot, which eventually evaporated (see Figure 2C).



181

182 Figure 2. Fill of experimental pots. A: Cooking sample P3 in ceramic C8 (dry peas fried in animal fat). B: Cooking
183 Sample F1 in ceramic C6F (wheat being boiled), and measuring the temperature inside the vessel. C: Sample P4
184 (fresh peas) in ceramic C9 prior to being oven roasted.

Dry Peas

cooking pot	lot	cooking time	temperature: Average (Max)	sample	
C6P — boiled	PS1	5min (short)	98°C (98°C)	PS-(b.5)-1 A	∅ [conc]
		20min (medium)	98°C (98°C)	PS-(b.20)-1 A	∅ [conc]
		28min (long)	98°C (98°C)	PS-(b.28)-1 A	∅ [conc]
C7 — fried in vegetable oil	PS2	7min (short)	250°C+* (250°C)	PS-(fv.7)-2 A	∅ [conc]
		13min (medium)	225°C (250°C+*)	PS-(fv.13)-2 A	∅ [conc]
		20 min (long)	196°C (250°C+*)	PS-(fv.20)-2 A	∅ [conc]
C8 — fried in pork fat	PS3	7min (short)	175°C (175°C)	PS-(fa.7)-3 A	∅ [conc]
		13min (medium)	173°C (175°C)	PS-(fa.13)-3 A	∅ [conc]
		20min (long)	172°C (175°C)	PS-(fa.20)-3 A	∅ [conc]
C9 — roasted	PS4	15min (short)	58°C (58°C)	PS-(r15)-4 B	∅ [conc]
		30min (medium)	62°C (66°C)	PS-(r30)-4 B	∅ [conc]
		45 min (long)	67°C (78°C)	PS-(r45)-4 B	∅ [conc]

Fresh Peas

cooking pot	lot	cooking time	temperature: Average (Max)	sample	
C6P — boiled	P1	5min (short)	99°C (99°C)	P-(b.5)-1 A	∅ [conc]
		12min (medium)	98°C (99°C)	P-(b.12)-1 A	∅ [conc]
		20 min (long)	98°C (99°C)	P-(b.20)-1 A	∅ [conc]
C7 — fried in vegetable oil	P2	7min (short)	205°C	P-(fv.7)-2 A	∅ [conc]
		13min (medium)	205°C	P-(fv.13)-2 A	∅ [conc]
		20 min (long)	205°C	P-(fv.20)-2 A	∅ [conc]
C8 — fried in pork fat	P3	7min (short)	185°C (185°C)	P-(fa.7)-3 A	∅ [conc]
		13min (medium)	170°C (185°C)	P-(fa.13)-3 A	∅ [conc]
		20 min (long)	164°C ((185°C)	P-(fa.20)-3 A	∅ [conc]
C9 — roasted	P4	15min (short)	103°C (103°C)	P-(r15)-4 A	∅ [conc]
		30min (medium)	94°C (103°C)	P-(r30)-4 A	∅ [conc]
		45 min (long)	88°C (103°C)	P-(r45)-4 A	∅ [conc]

Bread Wheat

cooking pot	lot	cooking time	temperature: Average (Max)	sample	
C6F — boiled	F1	30min (short)	99°C (99°C)	F-(b.30)-1 A	∅ [conc]
		60min (medium)	95°C (99°C)	F-(b.60)-1 A	∅ [conc]
		125min (long)	94°C (99°C)	F-(b.125)-1 A	∅ [conc]
C7 — fried in vegetable oil	F2	5min (short)	250°C+*	F-(fv.5)-2 A	∅ [conc]
		8min (medium)	250°C+*	F-(fv.8)-2 A	∅ [conc]
		11 min (long)	250°C+*	F-(fv.11)-2 A	∅ [conc]
C8 — fried in pork fat	F3	5min (short)	190°C (190°C)	F-(fa.5)-3 A	∅ [conc]
		10min (medium)	175°C (190°C)	F-(fa.10)-3 A	∅ [conc]
		15min (long)	160°C (190°C)	F-(fa.15)-3 A	∅ [conc]
C9 — roasted	F4	25min (Short)	138°C (138°C)	F-(r25)-4 B	∅ [conc]
		45min (medium)	129°C (138°C)	F-(r45)-4 B	∅ [conc]
		60min (long)	119°C (138°C)	F-(r60)-4 B	∅ [conc]

*Thermometer limit

185

186 Figure 3. Diagram presenting the experimental protocol and the average and maximum temperatures recorded
 187 during each of the cooking experiments on the wheat and peas. The pots C6 to C9 are presented in Figure 4. Each
 188 sample was divided into two; one of these was then gently crushed (conc.), while the other (∅) was left as is.

189 Each experiment had a unique identification number that documented the exact process each plant/animal
 190 sample followed. At every step of the experimental protocol, the samples were photographed, and
 191 temperatures taken at five different points inside the pot: one point was always taken whilst the food was being

192 cooked (see Figure 2B). Each event was registered on individual sheets. Each sample of cooked grain material
 193 was divided into two samples, one of these was lightly crushed between two stones. The cooked products were
 194 then individually placed in plastic bags, sealed (vacuum-packed), labeled, and refrigerated at 1 degree Celsius.
 195 By the end of this procedure, characteristic traces on the ceramics for each cooking technique were recorded. A
 196 total of ten cooking vessels were used during the experimental study; in Figure 4 are shown only the ones used
 197 to cook the wheat and peas. At first glance, some differences between the ceramics that were used to boil, fry,
 198 and roast, are evident.



199
 200 Figure 4. Comparison of experimental cooking vessels showing the different types of cooking and the number of
 201 times they were utilized. Along the vertical axis various views of the exterior and interior, as well as the base, are
 202 presented. Pots C6 to C9 were used to experimentally cook the peas and wheat.

203 Further analysis allowed us to point out determining criteria for each type of preparation. Frying as a cooking
 204 technique is the most striking, as it leaves a thick and homogeneous crust above the fill line on the inner face,
 205 but below this same line on the outer face (Figure 5). In fact, unlike boiling, during which the liquid evaporates

206 quickly, the fat passes through the paste and is deposited as a thin layer/film on the outside of the pot, where it
207 quickly undergoes charring. Boiling (Figure 6) is characterized by a distinctive fill line, caused by a frothy deposit
208 which turns brown or even black under the effect of heat, while its external face is covered with a relatively
209 homogeneous soot, which can appear nebulous. Oven roasting (Figure 7), on the other hand, does not cause
210 soot deposits on the ceramics due to the absence of direct contact with the flame. In this context, the external
211 face appears relatively clean, sometimes consisting of simple grayish layers as a result of a light impregnation of
212 the smoke. On the inside, the marks are localized and correspond to the browned negative imprint of the food
213 in contact with the jar. This latter type of cooking is therefore particularly complex to identify, the few traces
214 that may result being very localized.



215
216 Figure 5. *Experimental ceramic C2 where meat was fried in vegetable oil. Crusts above the fill line on the internal*
217 *face, and below this same line on the external face.*



218
219 Figure 6. *Experimental ceramic C1 where meat was boiled. On the left, the external face of the ceramic is covered*
220 *by a homogenous layer of soot. On the right, a frothy deposit is visible on the internal surface of the ceramic.*

221



222

223 Figure 7. Experimental ceramic C9 where the peas and wheat were roasted. On the left, the external face is
 224 slightly smoky, whereas on the internal surface (photo on the right), the negative imprint of the peas are clearly
 225 visible.

226 These kinds of specific traces, found in one cooking method but absent in the other, were carefully registered so
 227 that they could be subsequently used to study archeological ceramics. These determining criteria are
 228 categorized into three groups: the effects of exposure to heat and direct flame on the surface,
 229 residues/deposits, and the fill line. The different markers are more or less relevant, and to determine the
 230 relevance of these differences, a 6-point scale was devised. For each cooking method, the most characteristic
 231 markers were assigned a greater value than the less relevant ones (Table 1). The result can be expressed as a
 232 percentage of correspondence with the experimental models.

Cooking type	Exposure to fire	pt.	Residue/deposit	pt.	Fill line	pt.
Boiling	- homogeneously blackened	1	- light, gray, foamy, generally found above the fill line - foamy limescale	3	- line blackened/browned, darker above	2
Frying	- dark black crust, especially at the bottom, parts with maximum exposure are white	1.5	- dark black crust at the top. Iridescent looking	1.5	- well-defined limit, black deposit visible at the top (on internal face) while on the bottom (on external face)	3
Roasting	- lightly fumigated exterior, while interior is well marked	3	- brown to pink, stringy, spotty/ in layers	2	- not very visible, low	1

233 Table 1. Scale for assigning the cooking traces as observed on archaeological ceramics.

234 The different markers visible on a set of archeological ceramics were registered on an analysis sheet, and these
235 were used to determine the proportion of each cooking method within a site. There are nevertheless some
236 constraints: first, it only represents a small part of the entire ceramic vessel assemblage of a site, and second,
237 this method is not very efficient on dark or glazed ceramics.

238 This characterization method has already been tested by the first author at several sites in France and
239 Switzerland (see Figure 1). Castle sites include Madeleine Castle in Chevreuse and Orville Castle in Louvres, both
240 located in Île-de-France. Urban sites/contexts include Rouen in Normandy, a cathedral site in Geneva,
241 Switzerland, as well as Montlery and Poissy, both located in Île-de-France. Finally, rural contexts include
242 Aubevoye and Acquigny in Normandy, and Ris Orangis in Île-de-France⁷. A study was also carried out on some
243 complete ceramic vessels from the Vicq necropolis, in Île-de-France. These different studies indicate that more
244 traces can be discerned when we consider complete vessels (Figures 8 and 9), rather than isolated sherds.
245 Indeed, while most of the different cooking markers can be present at the same time, although located in
246 different parts of the vessel, this is rarely the case when isolated sherds are considered. Nevertheless, to study
247 only complete vessels would be to overlook a large majority of the ceramics recovered through excavations. The
248 choice was therefore made to study separately the whole vessels and the sherds, without excluding either.
249 Regardless, the correspondence percentage reveals how relevant the identification can be.

250 Couzan Castle is one of the first sites where this method was applied and is of particular interest as unwashed
251 sherds were also available to be tested for starch grains. Therefore, this site provided both ceramic and starch
252 analysis data that could be compared.

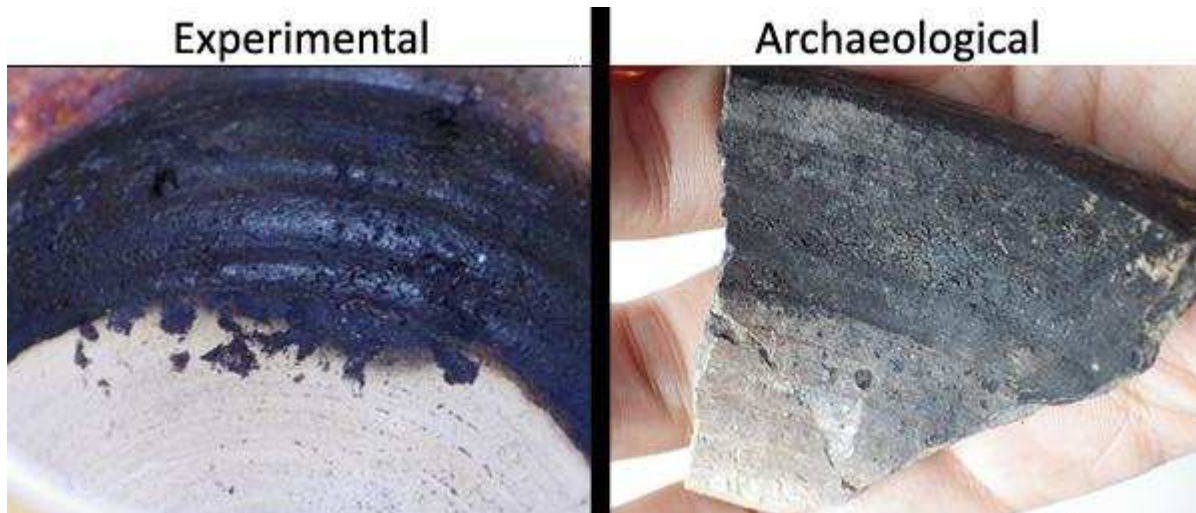
⁷ Studies of material from Poissy and Couzan have already been published in the form of excavation reports: Chantran 2019a, 2019b.



253

254 **Figure 8.** Example of 100% correspondence to the experimental models on a complete vessel from the Vicq
 255 necropolis (C, D on the right), compared to experimental ceramic C1 (A, B, on the left). In red: homogeneous
 256 distribution of the blackened paste on the face exposed to the fire. Orange: gray to pink foamy residues,
 257 predominantly located above the fill line. Beige: white to beige residues, mainly limescale. Gray: blackened fill
 258 line.

259



260

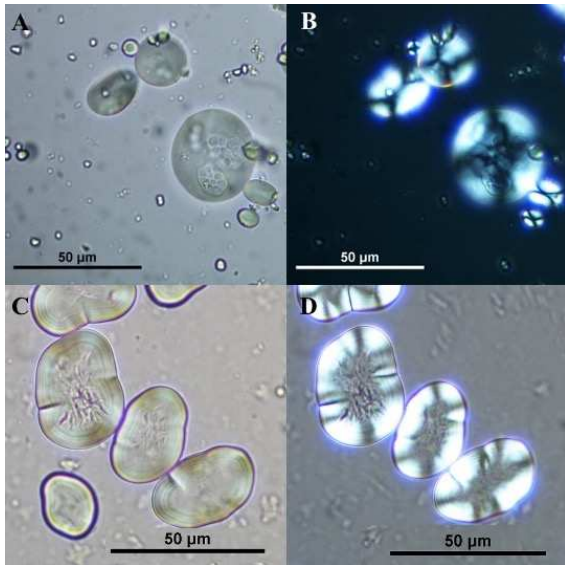
261 Figure 9. *Fried cooking marker: well-defined limit, dark black crust at the top (on internal face), iridescent*
 262 *looking. Left: as seen on experimental vessel C8. Right: as seen on a sherd from the "Rue aux ours" site, Rouen,*
 263 *France (INRAP).*

264 **2.2 Starch grain analysis**

265 The wheat and peas that underwent different cooking techniques were subsequently prepared and studied by
 266 the second author. The reference collection was prepared by cutting in half the cooked peas and wheat grains
 267 from each sample. Once cut, the grains were rubbed against a clean microscope slide. A small drop of a 1:1
 268 glycerin/distilled water solution was added before placing the cover slip. Each slide was then viewed under
 269 plane polarized and cross-polarized light between 100 and 600 X. The starch grains (and resulting masses, also
 270 known as amorphous starch) were all photographed under both plane polarized and cross-polarized light.

271 Raw starch grains of bread wheat are simple, and are bimodal, in that they come in two size classes, large and
 272 small (smaller than 2 μm) grains. The larger grains, which range between 15 and 25 μm in width, are nearly
 273 circular in plane view and lenticular when viewed from the side (Figure 10A-B). Lamellae are seldom visible, but
 274 if present, they tend to be near the center of the grain. Dimples or pits are common on the larger grains, and
 275 often are clustered in only one section of the grain. The extinction cross is radially symmetrical, but in some
 276 cases, the cross can widen towards the ends.

277 Raw starch grains of peas (Figure 10C-D) measure between 15 and 45 μm in length, and are simple, large, and
 278 ovoid to elongate in shape. The outline is often irregular. The larger grains tend to have distinct lamellae, which
 279 are especially visible on the outer edges of the grain. When the grains are viewed sideways, a mesial longitudinal
 280 cleft fissure is visible. The extinction crosses are central, often elongated on the same axis as the fissure.



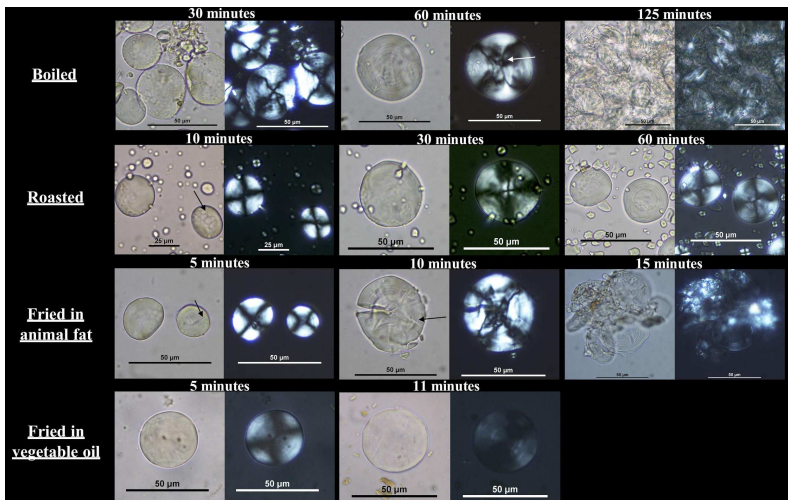
281

282 Figure 10. Native (unmodified) starch grains of bread wheat (A-B) and peas (C-D) seen under plane polarized and
 283 cross-polarized light.

284

285 **2.3 Modification of starch grains as a result of various forms of cooking**

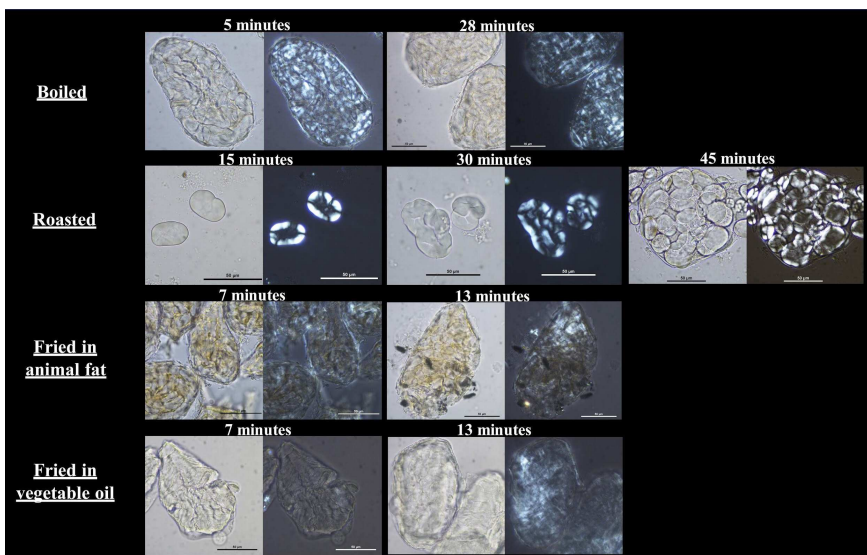
286 Results for each type of cooking— boiling, roasting, and frying in vegetable oil and animal fat— as well as the
 287 times are fully detailed in Supplementary table 1. Below, we provide a summary of these results. We did not find
 288 significant differences between the starch grains recovered from the whole vs. the crushed grains. Evidently the
 289 crushing was not forceful enough to further damage the starch grains, and therefore we do not differentiate
 290 between these categories in our results. After boiling wheat for 30 minutes (Figure 11), the starch grains have
 291 expanded, lamellae become more prominent, but many grains are still identifiable, with pits on the surface still
 292 present. At 60 minutes, gelatinized starch masses begin to form, and many grains can no longer be identified.
 293 Isolated grains are still present but are enlarged, with the extinction cross damaged, and enlargement of the
 294 pits. By 125 minutes, a few isolated starch grains remain, and those that are present are no longer identifiable
 295 as they are visibly damaged (lamellae are very noticeable, and there tends to be the loss of extinction crosses).
 296 Large gelatinized masses are more common, with some containing well defined grains in the center, albeit
 297 lacking an extinction cross. Roasting wheat for 10 minutes does not alter the grains significantly. However,
 298 starting at 20 minutes, the starch grains enlarge as do the pits on the surface, and starch masses begin to
 299 appear. By 30 minutes, the starch grains that are in masses are somewhat still recognizable. By 60 minutes,
 300 starchy masses are very common (extinction crosses faded), isolated grains are still present (some have a faded
 301 extinction cross, with lamellae clearly visible and seem further apart, and surface pits enlarged). Wheat starch
 302 grains were quickly damaged when undergoing frying. For those fried in vegetable oil, by 5 minutes the starch
 303 grains had expanded (some up to 50 µm wide), the lamellae became visible, and no pits were visible. By 11
 304 minutes, the extinction crosses are almost completely faded, the lamellae are almost invisible. For the starch
 305 grains fried in animal fat, faint cracks began to appear after 5 minutes, and between 10 and 15 minutes these
 306 cracks had greatly expanded, becoming almost papery and with faded extinction crosses.



307

308 Figure 11. Modification of starch grains in wheat after boiling, roasting, and frying.

309 Boiling of dry peas was extremely damaging to the starch grains. After 5 minutes, the majority of elements
 310 recovered were amyloplasts⁸ and the grains inside were not identifiable (Figure 12). Rare were the isolated
 311 grains still identifiable. At 28 minutes, while some rare isolated grains were still present, they could no longer be
 312 identified to their species, but could be placed at the family level. The starch grains from the roasted dry peas
 313 were slightly damaged (fissured and sometimes deformed), but recognizable even after 15 minutes. There
 314 doesn't seem to be much size difference at this level. Starch grains inside the amyloplasts could also be
 315 tentatively identified. By 30 minutes, the starch grains begin to expand, and the extinction cross is very
 316 deformed. Even after 45 minutes, some of the starch grains could be identified, as they retained their shape and
 317 relative size. Frying was extremely damaging: by 13 minutes of frying in either animal fat or vegetable oil did not
 318 leave any traces of identifiable grains, only amyloplasts. This damage seems to have begun even before 7
 319 minutes had passed, as amyloplasts with melted grains were already present.



320

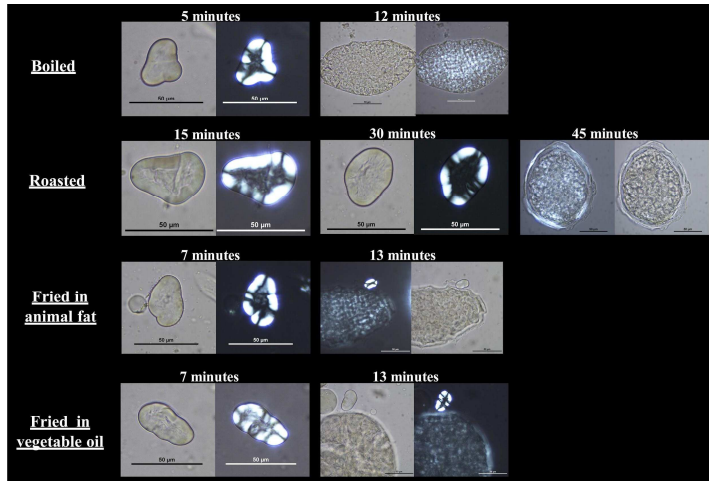
321 Figure 12. Modifications of starch grains in dry peas after boiling, roasting, and frying.

322

323 The fresh peas were quickly damaged when boiled: at 12 minutes, amyloplasts with unidentifiable starch grains

⁸ Plastids (organelles) that store and synthesize the starch

324 were common (Figure 13). Isolated grains were rare, although in some cases could still be identified. Roasting
325 for 15 minutes left behind very damaged amyloplasts, and in some cases, some isolated grains were fractured at
326 the edges. At 30 minutes, some isolated starch grains are still identifiable, although some are clearly damaged
327 with exploded hila and extinction crosses that have faded. By 45 minutes the starch grains were unidentifiable
328 as they all exhibited damage to their extinction crosses. Frying the fresh peas in either type of fat resulted in the
329 starch grains being in some cases still identifiable after 13 minutes (although amyloplasts were the most
330 common element).



331

332 Figure 13. *Modifications of starch grains in fresh peas after boiling, roasting, and frying.*

333

334 3. MATERIALS AND METHODS

335

336 Couzan Castle rises above the village of Sail-sous-Couzan, in the Loire department, France (Figure 1).
337 Excavations, led by Christophe Mathevot (Mathevot 2019), revealed not only the presence of a kitchen used
338 during the last three centuries of the Middle Ages (13th-15th centuries), but also other kitchen contexts used in
339 earlier phases of the Middle Ages (8th-11th centuries). This context was ideal in that the material unearthed
340 covered a long period, thus allowing for the understanding of how cooking techniques evolved through time.
341 The ceramic study focused on occupation contexts that could be linked to cooking practices. In fact, cooking
342 areas or middens with the remains of kitchen activities were very common.

343

344

345

346 3.1 Selection of the sherds/ stratigraphic units

347 The use-wear analysis was carried out on sherds from several stratigraphic units at the site of Couzan to
348 determine possible variations in culinary practices over time (Table 2). The contexts selected for this analysis
349 were chosen because of their clear link with culinary activities.

350

351

N°SU/ Excavation Unit	Context	Date
20903	Excavation unit linked to the Carolingian hearth in zone 2	before VIII - X centuries
40803	Midden, filling of pit	A.D. 993 - 1032
40688	Latrine occupation phase	XII - XIII centuries
20760	Abandonment of dwelling L79	after A.D. 1279 - before A.D. 1335
40610	Filling of pit	Mid-XIV – mid-XV centuries
40400 and 40402	Kitchen occupation phase	XVth century

353 Table 2. Contexts and dates of the stratigraphic units from which the selected ceramics were recovered prior to
354 their use-wear analysis.

355

356

357 While the ceramic corpus recovered in the stratigraphic units dating to the Early Middle Ages (8th-11th
358 centuries AD) is represented by a significant number of sherds, the assemblages consisted for the most part of
359 dark paste ceramics, which prevented an accurate examination of the traces left behind by the different types of
360 cooking.

361 3.2 Use-wear analysis of sherds from Couzan

362 The sherds from these stratigraphic units were then further sorted for use-wear analysis based on the presence
363 of visible firing residues. The percentages of correspondence to the experimental traces are obviously reduced,
364 the scale no longer being able to be established on all the points, but only on the part represented by the
365 residues and the fill limits. Only 19 sherds with visible traces linked to possible cooking activities could be
366 retained for the analysis and only 15 were characterized. No characterization at 50 % or more correspondence
367 with experimental models could be carried out. Gaps in the results for the Early Middle Ages prompted the
368 priority of analyzing samples from this period using other methods - notably through the analysis of starch
369 grains, which we present in this paper.

370 If the characterizations of the sherds dated to the Early Middle Ages are subject to caution, the fact remains that
371 the number of sherds with traces identified as resulting from frying is surprisingly high. It remains to be
372 determined whether this particularly high frequency is due to a real significant use of fat during cooking, or
373 whether this over-representation is in fact due to the presence of dark pastes and surface coatings.
374 Nevertheless, a comparison with other comparable contexts leads us to consider, to our surprise, that frying was
375 a common cooking technique during this period.

376 The most recent contexts (15th century), for which the use-wear analysis was not subject to the same biases,
377 gave results that are generally comparable to the three main types of cooking evoked in Medieval recipe
378 collections such as *Viandier* or *Du Faitz de Cuisine*. Boiling is the most common cooking technique, with a
379 number of sherds also showing traces linked to the use of fat. In the latter case, foods could have been boiled
380 using a certain amount of fat. Traces similar to those obtained through experimental frying represent between
381 about a quarter and a third of the characterizations. However, in the 12th and 13th centuries, traces of boiling
382 are more common.

383 Weak frying markers are regularly present, which increases the proportion of traces of this type of cooking when
384 the traces corresponding between 10 % and 25 % to the experimental models are taken into account. This trend
385 consisting of weaker frying markers compared to those that indicate boiling has been observed in the majority
386 of the ceramics on which this type of use-wear study has been carried out. The reason for this is that contrary to
387 other types of cooking the location and appearance of the markers associated with boiling are more diversified,
388 and distributed over a larger part of the original ceramic vessel. Such markers are therefore more visible and
389 identifiable on various parts of the original vessel (even on individual sherds), and in turn often results in higher
390 correspondence rates. On the other hand, if we consider frying for example, its three markers are very localized
391 in that they are generally found around the fill line. This implies that a sherd from another part of the same
392 vessel (i.e., used for frying), would therefore lack characteristic markers leading to lower correspondence
393 percentages.

394 The possible overrepresentation of frying as a cooking technique in these stratigraphic levels dated to the Early
395 Middle Ages in Couzan deserves additional analyses, in particular through physico-chemical tests. Such tests
396 could determine the presence of lipids that may have been absorbed into the ceramic paste, and could confirm
397 or reject the use of fat during cooking. In fact, the analyses carried out on the Early Middle Age Ile de France
398 corpus (which, to date, consists of relatively few examples and therefore is not very representative) has so far
399 shown different results, with a large dominance of boiling as a cooking technique. It could therefore be a
400 regional specificity or a specific practice, linked to the context. It was also not possible to estimate whether
401 these frying traces were more likely the result of using vegetable oil or animal fat. Once again, lipid residue
402 analysis may aid to further clarify this.

403 **3.3 Methodology for the extraction of starch grains from archaeological samples**

404 During the 2018 field season, seven unwashed ceramic sherds from five separate stratigraphic units⁹ from
405 Couzan Castle were selected for starch grain analysis (Figure 14). The objective was to analyze the starch grains
406 trapped in the inner surfaces of these ceramic sherds. These sherds, located in levels dated to the Early Middle
407 Ages, and in or near a midden where numerous other culinary remains were also found, were collected with the
408 aim of minimizing the risk of pollution. To do so, clean gloves were used and the sherds were placed directly in
409 a new Ziplock bag.

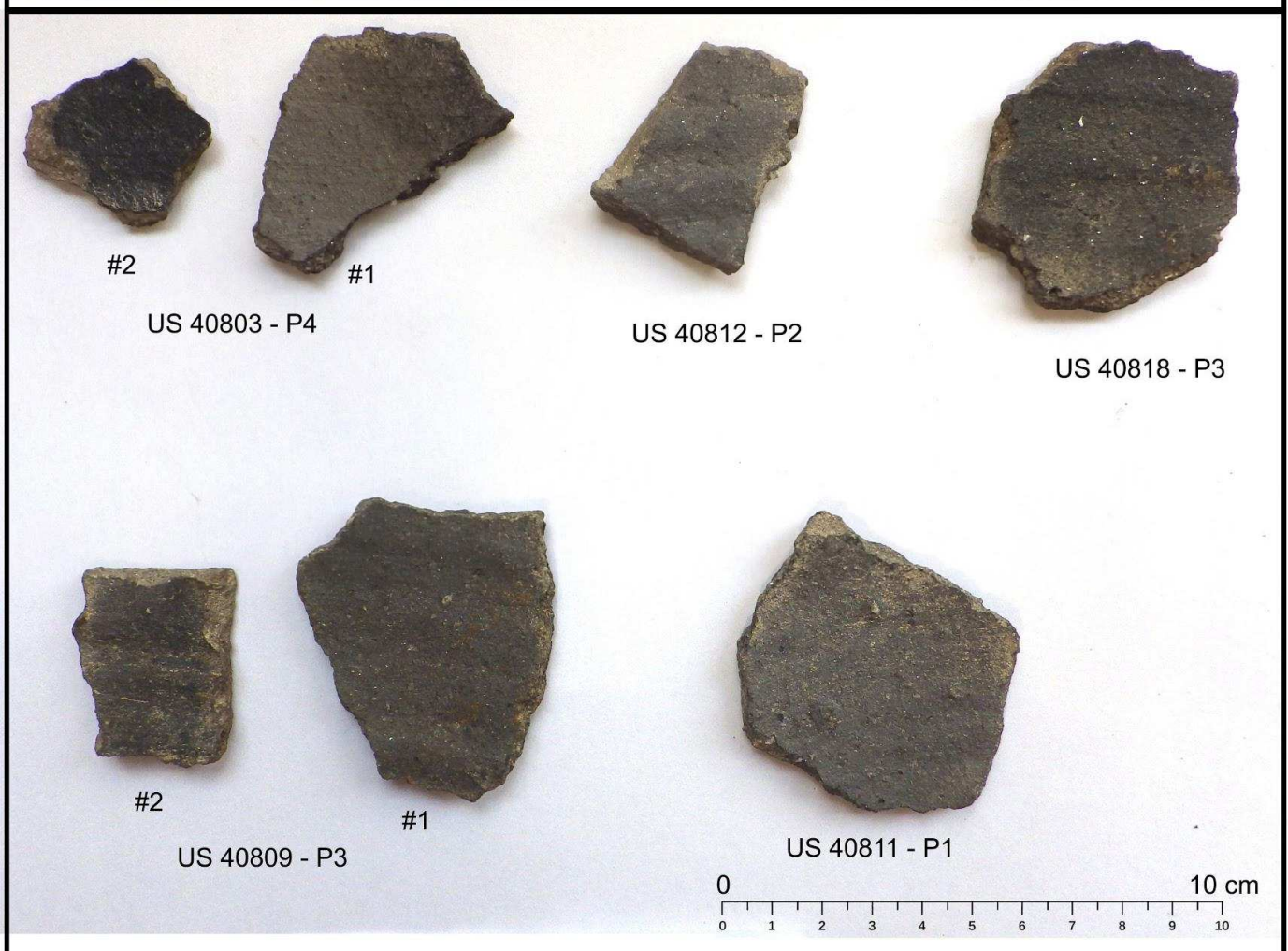
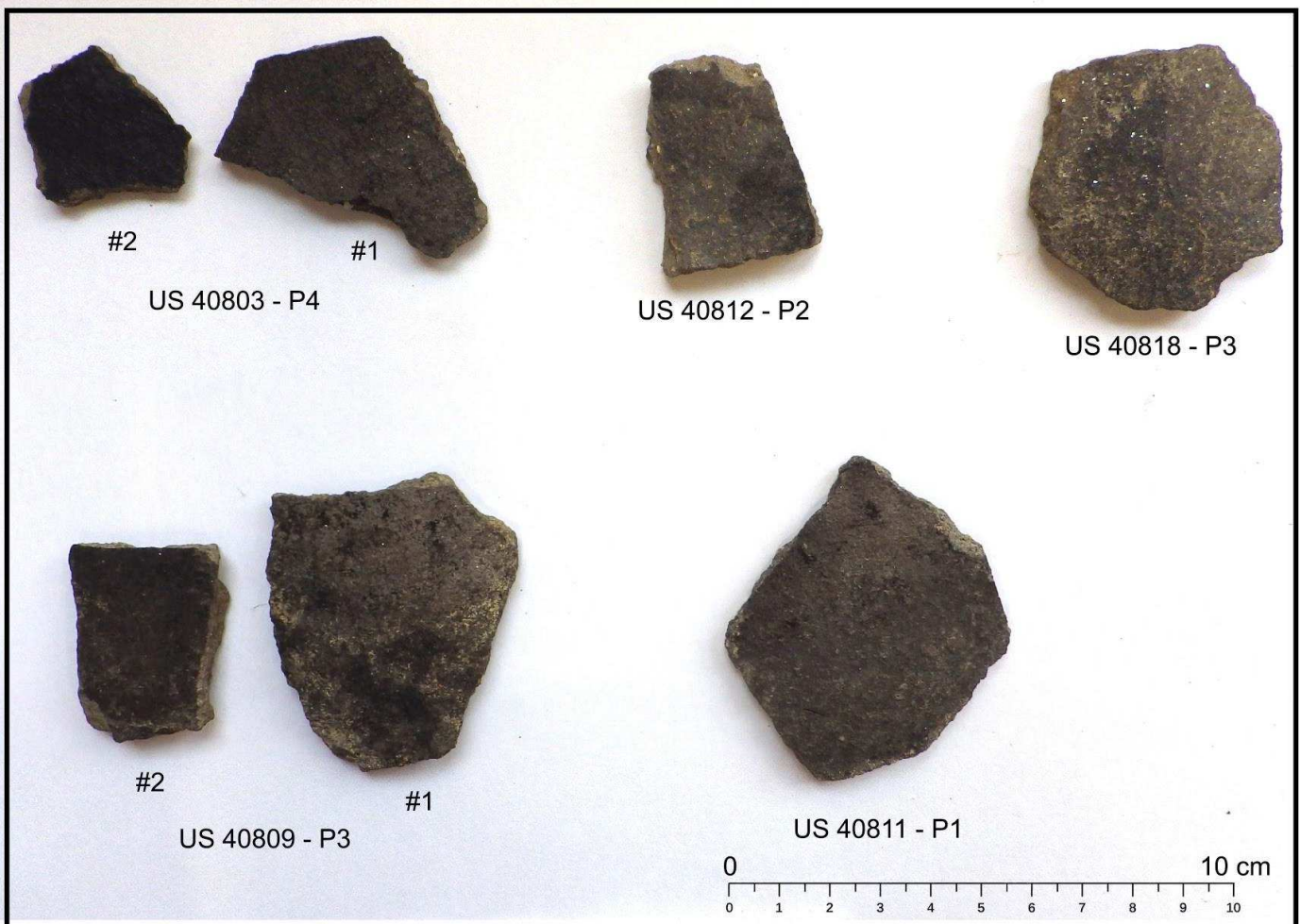
410 The inner surfaces of the sherds were washed with new clean toothbrushes (single use) and distilled water, and
411 the collected samples were placed in previously sterilized containers. It is important to note that the procedure
412 of washing the sherds with a toothbrush did not alter the traces on the ceramics. The samples were then
413 processed in the palynology laboratory (ArScAn UMR 7041) at the MSH Mondes in Nanterre, France. In the
414 laboratory, the protocol for extracting starch grains follows the one presented elsewhere (Cagnato and Ponce
415 2017). In short, different chemicals are used to clean the sample and isolate the starch: ethylene diamine
416 tetraacetic acid (EDTA), which dissolves limescale, and hydrogen peroxide which is used to destroy organic
417 particles as well as deflocculate clay. Finally, sodium polytungstate, with a specific gravity of 1.7 g / ml, is added
418 and is used to separate the starch grains from the sediment. Once the samples are rinsed, a couple of drops are
419 put on glass slides with a drop of glycerin and water (1:1) solution and sealed with a coverslip. The slides are

9 The sherds came from the following units: US 40809-P3 (2 sherds), US 40803-P4 (2 sherds), US 40811-P2 (1 sherd), US 40818-P3 (1 sherd), and US 40812-P1 (1 sherd)

420 analyzed with a polarizing microscope (x100-600), and the starch grains are counted, measured, and
421 photographed in both plane polarized and cross-polarized light.

422

423



425 Figure 14. Sherds from Couzan Castle tested for starch grains: external faces (top), internal faces (bottom).

426

427 **4. RESULTS**

428

429 **4.1 Use-wear results of the ceramic sherds selected for starch grain analysis**

430

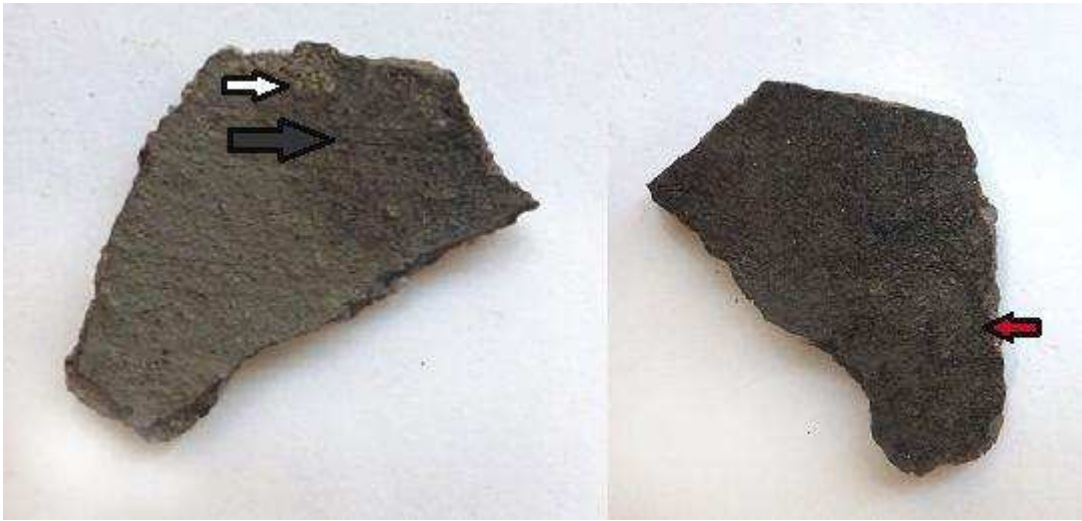
431 These seven sherds belonging to dark paste vessels (voluntarily darkened during their manufacture), are among
432 the types for which use-wear analysis is more complicated. Indeed, this darker paste rarely allows to see some
433 characteristic markers, such as soot deposits and traces indicating contact with fire. However, most sherds
434 showed traces, probably culinary in nature, which were analyzed only after the extraction of the starch grains
435 (Table 3). One of the sherds (40803-P4-#1, figure 15) bears marks of boiling with 33% correspondence to
436 experimental models, two others (40811-P2, figure 16, and 40809-P3-#1, figure 17) have 17% correspondence
437 with traces of boiling, while three others (40818-P3, 40809-P3-#2 and 40812-P1) cannot be clearly linked to a
438 model, obtaining only 8% correspondence with the experimental traces. Finally, one sherd (40803-P4-#2), shows
439 a slightly iridescent, blackened, smooth, and homogeneous surface, which could correspond to a thick fatty
440 deposit. However, it could also be the result of a voluntary surface treatment, applied during the manufacture
441 of the ceramic vessel. Setting aside the particular case of this latter example, most of the sherds bear potential
442 weak marks for the use of fat during cooking, with the exception of 40811-P2 and 10818-P3. Some of the vessels
443 seem to have been used for mixed types of cooking (e.g., boiling in the presence of fat), in particular those from
444 US 40809 (P3- #1 and #2). This analysis clearly shows the problem caused by the dark pastes. As few markers
445 can be seen/identified, the correspondence rates with the experimental models remain low and the
446 interpretations uncertain. The results obtained through the starch grain analysis can nevertheless supplement
447 these use-wear observations.

448

Id.	boiled	fried	roasted
40809-P3-#2	8%	8%	0%
40809-P3-#1	17%	8%	0%
40803-P4-#2	0%	0%	0%
40803-P4-#1	33%	3%	0%
40811-P2	17%	0%	0%
40812-P1	8%	3%	0%
40818-P3	8%	0%	0%

449 Table 3. *Percentage of correspondence to the experimental models on the sherds from Couzan Castle selected for*
450 *starch grain analysis. Values indicated in bold are those high enough to characterize a certain type of cooking.*

451



452

453 Figure 15. *Sherd P4 #1: left, internal face: blackened and continuous fill line (gray arrow), slight foamy gray effect*
454 *(beige arrow). Right, external face: homogenous blackening presenting a foamy aspect which could have been*
455 *the result of an overflow (red arrow).*



456

457 Figure 16. *Sherd 40911-P2, external face: Foamy-looking light overflow residues or dripping (arrow),*
458 *homogenous blackening.*



459

460 Figure 17. Foamy overflow traces on the external face. Left on experimental ceramic C1, right, on sherd P3 #1
461 from US 40809 from the site of Couzan.

462

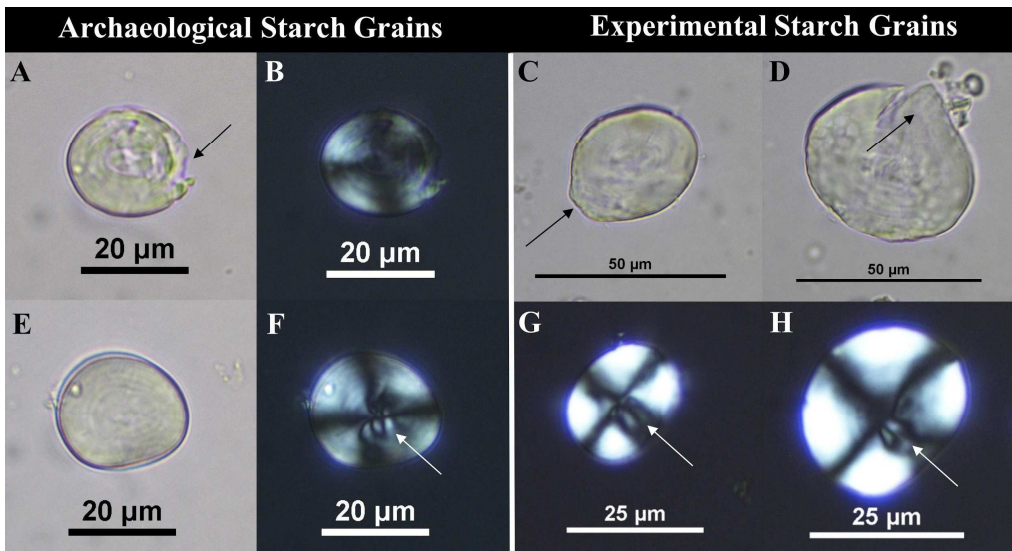
463 4.2 Results of the starch grain study

464 A total of 205 starch grains were recovered in the seven archaeological samples from Couzan Castle. The
465 sherd from US 40803 # 2 had the highest number of grains ($n = 55$), while the sample from US 40812 had the
466 least ($n = 9$). Starch grains belonging to cereals such as wheat (*Triticum* sp.) and barley (*Hordeum* sp.), along with
467 millets (*Panicum miliaceum* L., and *Setaria* cf. *italica*), species in the Fabaceae family, and unidentified
468 underground storage organs (e.g., tubers, roots, and rhizomes) were recovered. Numerous starch grains were
469 placed in the *Cerealialia* category: wheat and barley starch grains, already relatively similar when raw and
470 unaltered, become even trickier to distinguish when damaged. The results of this study are detailed in Cagnato
471 (2019b) and therefore will not be further discussed here. For purposes of this article we focus solely on the taxa
472 for which we have a reference collection: cereals (wheat and barley¹⁰) and peas (in the Fabaceae family). Cereals
473 were commonly recovered in the archaeological samples, while only three possible Fabaceae family starch
474 grains were found. Thus, in this particular article we focus our attention to identifying how cereals were cooked
475 at Couzan Castle.

476 **US 40803 Sherd #1:** 41 starch grains were recovered in this sample; 17 of these showed clear evidence of
477 damages. Three of these belonged to wheat, while one was placed in the *Cerealialia* category. Four masses of
478 starch were also recovered. Based on the starch grains recovered, two modes of cooking were identified:
479 roasting ($n=3$), and either frying or roasting was seen on one starch grain (Figure 18).

480

¹⁰ While barley was not experimentally cooked, we consider that given its strong morphological similarities with wheat we could include these two categories. However, further experimental work will be necessary to determine whether barley really can be lumped together with wheat when considering morphological changes due to cooking.

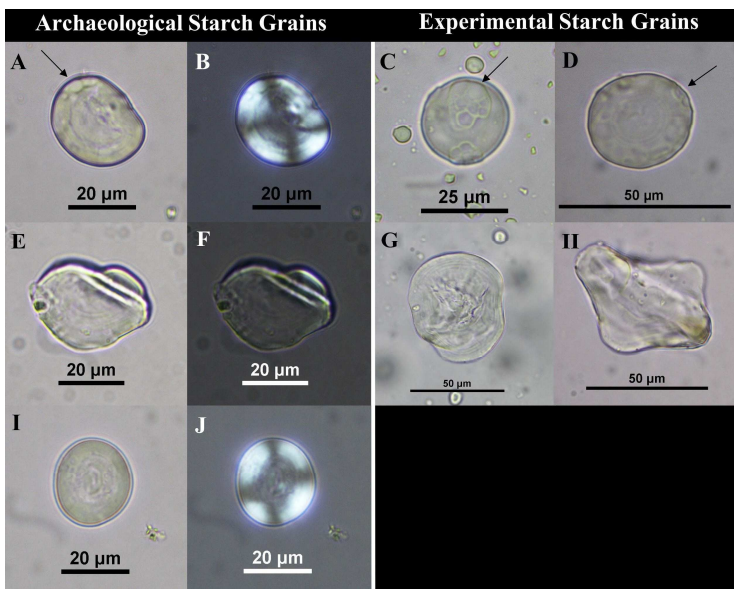


481

482 Figure 18. Archaeological starch grains from sherd 40803 #1. A-B: Roasted wheat, C-D: experimentally roasted
 483 wheat for 10 minutes (C) and 45 minutes (D). Arrows indicate similar melting on the edges of the starch grains. E-
 484 F: Fried or roasted wheat, G-H: experimentally roasted wheat for 20 minutes (G) and fried in animal fat for 5
 485 minutes (H). Arrows indicate similar damage at the hilum.

486

487 **US 40803 Sherd #2:** 55 starch grains were recovered, with 17 of these exhibiting damages. Wheat starch grains
 488 were found (n=8), along with barley (n=2), and 11 grains placed in the *Cerealia* category. Three grains were
 489 placed in the Fabaceae category. Six starch masses were recovered, including one likely belonging to cereals.
 490 The prevalent type of damage on the cereal seems to suggest that roasting took place (n=13). Two starch grains
 491 seem to have been possibly fried, while it was not possible to characterize the remaining six (Figure 19).



492

493 Figure 19. Archaeological starch grains from sherd 40803 #2. A-B: Roasted wheat starch grain. C-D:
 494 experimentally roasted wheat for 25 minutes (C) and 45 minutes (D). Arrows show the melted cupules. E-F:
 495 Fried starch grain (animal?), G-H: experimentally fried wheat in animal fat for 5 minutes (G) and 15 minutes (H).
 496 I-J: Wheat/cereal, modification not identified.

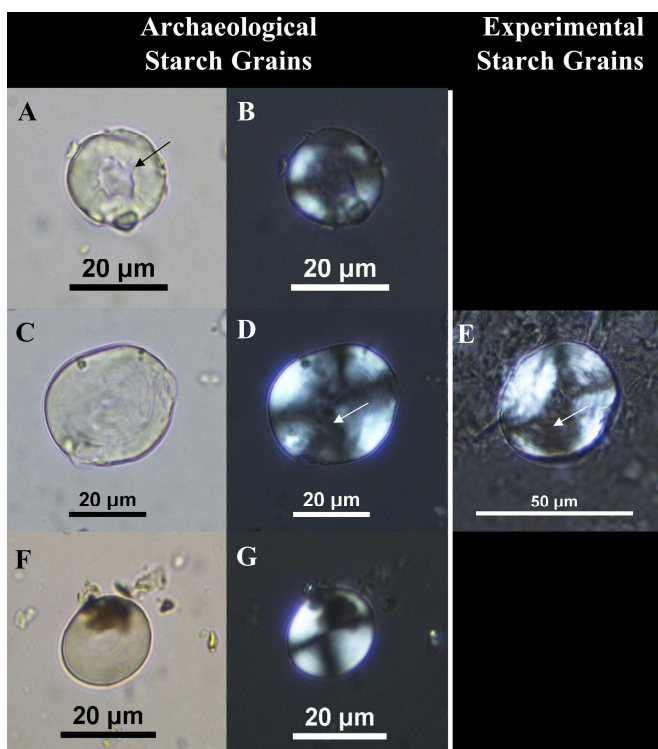
497

498 **US 40809 Sherd #1:** 27 starch grains were recovered, with a large majority of these exhibiting damages (n = 13).
 499 Only one potential cereal starch grain (i.e. *Cerealia*) was recovered in this sample. Three starchy masses were
 500 also found. The cereal starch grain displayed a circular depression in its center (Figure 20). This type of damage
 501 has not been observed in our experimental work, but similar modifications have been noted on plant material
 502 that has undergone thermal treatment (Lippi et al. 2015).

503

504 **US 40809 Sherd #2:** 15 starch grains were recovered, with 5 placed in the unidentifiable category. Wheat (n=2)
 505 and barley (n=1) starch grains were recovered, along with one in the *Cerealia* category. Two starchy masses
 506 were also found. Three starch grains recovered in this sample seem to have been exposed to boiling, while one
 507 does not seem damaged in any noticeable way (Figure 20).

508



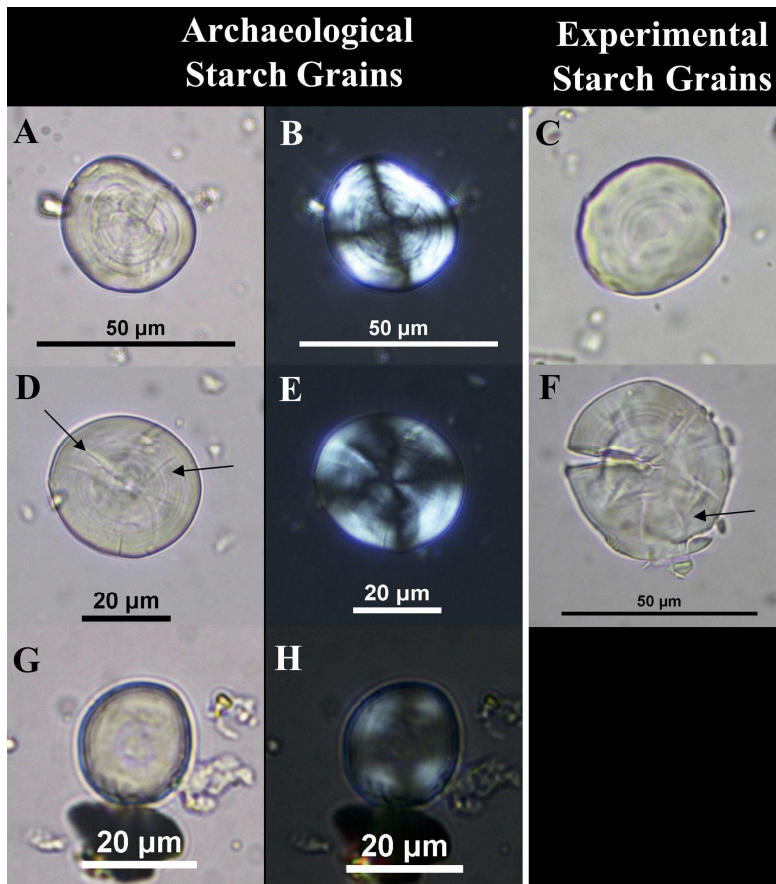
509

510 Figure 20. Archaeological starch grains from sherd 40809 #1 (A-B) and #2 (C-D, F-G). A-B: Wheat/cereal,
 511 modification not identified. Arrow points to exploded hilum. C-D: boiled wheat, E: Experimentally boiled wheat
 512 (125 minutes). Arrows point to damaged extinction cross. F-G: Raw (unmodified) wheat starch grain from
 513 author's reference collection.

514

515 **US 40811:** A total of 35 starch grains were recovered. Out of these, nine were too damaged to identify further.
 516 One starch grain in particular displayed a specific type of damage/alteration, while others were broken in half. In
 517 terms of the cereals, one was identified as wheat, two as belonging to barley, and 8 were placed in the *Cerealia*
 518 category. Seven starchy masses were recovered. In this sample (Figure 21), the cereal starch grains indicate the
 519 following types of cooking: roasting (n=5), boiling (n=3), frying (n=1), and indeterminate (n=2).

520

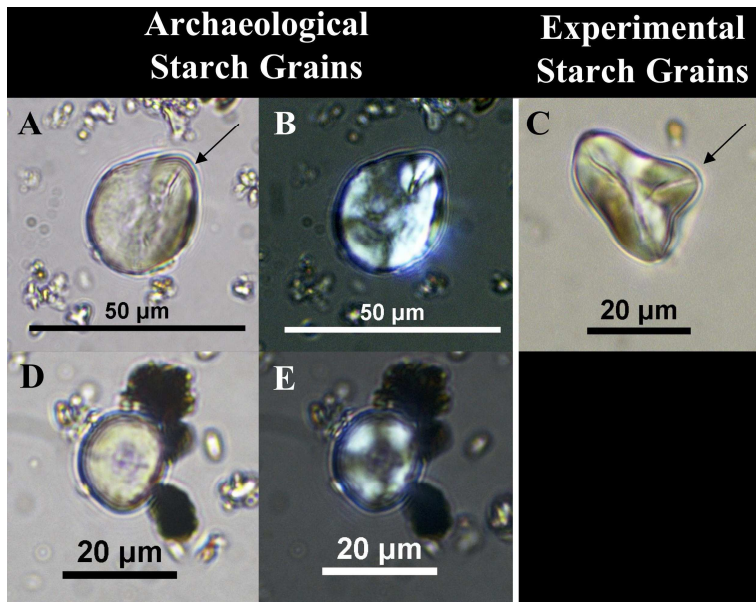


521

522 Figure 21. Archaeological starch grains from sherd 40811. A-B: Roasted wheat, C: Experimentally roasted wheat
 523 (60 minutes). D-E: Fried in animal fat, F: Experimentally fried wheat in animal fat (10 minutes). Arrows point to
 524 cracks on the surface of the starch grain. G-H: Cereal (cf. wheat), modification not identified.

525

526 **US 40812:** A total of nine starch grains were recovered, including four that remain unidentified. Two *Cerealia*
 527 starch grains were recovered, with one displaying clear evidence of having been ground, however it was not
 528 possible to further determine whether the damage was also tied to cooking. It was not impossible to determine
 529 whether the second starch grain had been processed in any way (Figure 22).



530

531 Figure 22. Archaeological starch grains recovered from sherd 40812. A-B: Damaged grain (indicated by arrow),
 532 potentially the result of grinding prior to cooking. This type of damage is similar to that seen in ground wheat
 533 starch grains (see Cagnato et al. accepted); C, grain shown sideways with the arrow indicating protrusion. D-E:
 534 Wheat/cereal, modification not identified.

535

536 **US 40818:** This sample yielded 23 starch grains, including four that were too damaged to identify. No starch
 537 grains identified as belonging to cereals were recovered in this particular sample.

538

539 **5. DISCUSSION**

540

541 **5.1 Contributions to the study of diet at Couzan Castle**

542 Although this is a preliminary study, the results obtained and presented indicate the usefulness in using
 543 multidisciplinary approaches. This is especially true for Couzan Castle, where use-wear analysis was limited by
 544 the important number of dark paste ceramics in Early Medieval contexts. The use of starch grain analysis
 545 therefore permitted us to expand our knowledge on cooking methods used during this period at this particular
 546 site. Our data indicate that roasting, boiling, and frying were techniques used by the cooks at the castle. These
 547 conclusions were clearly strengthened by our combined approach.

548 For example, while cooking techniques are difficult to determine on dark paste ceramics, starch grains are not
 549 affected by this particular factor. Experimental work has shown that roasting tends to preserve the starch grains
 550 the longest, compared to frying, which is the most damaging type of cooking (i.e., the grains are modified in a
 551 shorter amount of time). Frying, on the contrary, can generally be easier to detect on ceramics through use-
 552 wear analysis and this was clearly the case at Couzan, where it would seem that fat, either animal or vegetal,
 553 was frequently used during cooking. On the other hand, roasting was also highlighted (for example on sample
 554 40803 #2) through starch grain analysis: this particular type of processing would not have been detected
 555 through use-wear analysis alone.

556 While neither of these methodologies can determine the exact contents of the ceramic vessels or the recipes,
 557 they do indicate that the ceramic vessels would have been used for different types of cooking. In other words,

558 they were not single purpose vessels: a conclusion that could be reached through both the use-wear and the
559 starch grain analyses.

560 5.2 Contributions to experimental studies

561 Our work presents a unique contribution to experimental studies as it was from the start designed with the
562 specific aim to create reference collections for different types of analyses. Moreover, as the cooking conditions
563 were as close to the original ones as possible, these are a unique type of reference collection.

564 Based on our experimental studies, some general observations can be made concerning the modification of
565 starch grains in bread wheat and peas. Wheat that has been roasted up to 60 minutes, will likely still contain
566 recognizable starch grains, and this due to the absence of swelling induced by moisture. However, beyond 60
567 minutes of boiling, it is likely that only amorphous masses of gelatinized starch will be found. Starch grains in dry
568 or fresh peas will rapidly become damaged and unidentifiable once boiled. To our knowledge, our study is the
569 first to document the effects of frying on starch grains: it shows that this type of cooking quickly modifies the
570 starch grains resulting in unidentifiable masses. Therefore, and in order to avoid underestimating this type of
571 cooking method in the archaeological record, it will be important for other types of analyses to be considered
572 (i.e. use-wear analysis). Overall, we found frying wheat to be extremely damaging, and that after 10-11 minutes
573 it is also unlikely that recognizable starch grains would still be recovered. We noticed differences between fresh
574 and dry peas. In the former, after 45 minutes of roasting, starch grains will no longer become identifiable, yet in
575 dry peas, some will still be identifiable after undergoing the same treatment. This faster rate of damage in fresh
576 peas may be tied to their higher moisture content (see Crowther 2012). Differential results will also be obtained
577 depending on whether fresh or dry peas are fried in animal or plant matter: dry peas immediately gelatinize,
578 while after 13 minutes of frying, some starch grains in fresh peas were still visible and possibly identifiable.
579 Finally, yellow clumps or masses were observed when both wheat and peas were cooked in fat, however, it will
580 be necessary to carry out additional tests to determine if this can be a good indicator of this type of cooking
581 when studying archaeological samples.

582 We must also address the limitations of our study, notably the small sample size of the sherds that were
583 analyzed and the small number of starch grains in some of these samples. However, the reality is that in the
584 archaeobotanical record we often have to deal with small quantities of microbotanical remains. We also have to
585 note that in this study, as we only had a reference collection for cooked bread wheat, we decided to lump
586 together the archaeological starch grains belonging to cereals. And while we can see some differences in the
587 starch grains when cooked in different manners, it is often difficult to differentiate properly between wheat that
588 has been boiled and roasted, something that was also noted by Henry et al. (2009). Finally, here we simply
589 discussed the cooking processes, but other types of preparations may have taken place, notably,
590 grinding/milling but also malting/fermenting, which would also affect the morphology of the starch grains
591 (Babot 2003; Wang et al. 2017).

592 Initially, wheat and peas were chosen based on their prevalence in the archaeobotanical record known to date.
593 The starch grain study of the ceramic sherds from Couzan showed that other plants besides cereals and pulses
594 were consumed, and therefore provide new information on Early Medieval diets. However, given that
595 properties that influence the physicochemical properties of plants differ from one taxon to another, it is
596 imperative that further experiments be carried out if we are to further characterize cooking techniques during
597 this period. Notably, experiments involving other cereals such as oats, barley, and rye (*Secale cereale*), along
598 with underground storage organs and millets would serve to better characterize the data from Couzan and
599 other Medieval contexts. Finally, starch grain samples taken directly from the inner surfaces of the experimental
600 ceramics themselves may provide complimentary data to further reconstruct ancient cooking practices.

601 To determine whether this multidisciplinary method works on a larger scale, we will need to apply it to other
602 datasets. Therefore, a similar study has already begun on material from another site, Orville Castle. The results
603 of this study will be published in a forthcoming archeological report (A. Chantran/C. Cagnato).

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605

606 6. CONCLUSION AND FUTURE PERSPECTIVES

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608

609 The experimental work carried out in 2016 at Orville allowed to establish— through the analysis of starch grains
610 and that of cooking traces on ceramics— a reference collection that would allow for the study of cooking
611 methods. The comparison of these stigmata with archaeological material has been conclusive and shows that
612 the different types of study are in fact complementary. While the faunal bones used during the experimental
613 work have not yet been studied, these remain available for future studies. Other experiments must still be
614 carried out, on the one hand to enlarge the number of samples and make it more quantitatively conclusive, but
615 also to test additional types of plants, cooking styles, and ceramic pastes. Indeed, experimental tests have thus
616 far solely been carried out on thin, light-colored pastes. Mixed types of cooking, where fats and water are
617 combined, or even using dairy products (milk, cream), could for example be added to the range of future
618 cooking experiments.

619 Our study is a reflection of the often emphasized necessity to work with other disciplines (cf. García-Granero
620 2020; Vieugué et al. 2008) but also that the applications of experimental archeology can be multiple and
621 complementary. To this end, it is important to consider, while setting up the experimental protocol, the
622 different ways in which the obtained data can contribute to reading the archaeological record. It is in this spirit
623 that the experimental work carried out in 2016 was established, by rigorously using plants, animal bones, and
624 ceramic vessels that could subsequently provide suitable materials for archaeobotanists, zooarchaeologists, and
625 ceramicists respectively. This type of initiative is only possible through ongoing dialogue between specialists,
626 which we strongly believe should be encouraged.

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