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‘*si la nécessité des affaires ne nous
forçait pas à nous lever de table, ou si le besoin
du sommeil ne venait pas s’interposer, la durée
des repas serait à peu près indéfinie*’

Jean Anthelme Brillat-Savarin, Physiologie du goût

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1. Introduction

The concept of food can be defined from a myriad of points of view. To begin with, two main, very differentiated stages can be mentioned, the food before the human intake, and after it. Numerous disciplines (e.g. biology, physics, chemistry, archaeology, sociology, economy, …) focus on understanding the implications at different levels underneath each of those stages.

In general terms, and following the definition offered by the Oxford Languages Dictionary, '*food*' is '*any nutritious substance that people or animals eat or drink, or that the plants absorb in order to maintain life and growth*'. However, this definition presents big conundrums when we apply it to humans. Indeed, whereas mostly all of the products that humans call 'food' would perfectly fit in the Oxford Languages' description, there is plenty of other products that are, on the contrary, harmful to 'life and growth' by themselves. On this regard, interestingly many scholars have considered the consumption of alcoholic drinks one of the most important moments in the process of 'humanization' of the *Homo sp*. (McKenna, 1999), but also other products that we consume assiduously, such as specific mushrooms or certain spices, are hazardous for our organism when consumed in high amounts. Besides these products, which are harmful by nature, other foods have become unsafe for human consumption without the application of a previous culinary treatment due to the means of production (for example, the characteristic *salmonella* that is generally found in raw chickens, due to the intensive production) (Smyth & Watson, 1987).

Overall, the concept '*food*' is complex due to its ambiguous binominal character. Indeed, it involves an obvious biological factor (merely nutrition), however it rapidly constitutes a cultural axis when it comes to taste, knowledge of the seasonal availability of products, food management (immediate consumption, preservation, fermentation, reutilization, or discard) or cooking techniques, just to cite some aspects. The latter aspect is key when trying to assess on what food means for us, humans, because our cultural selection has somewhat hidden some of our biological needs (Beaudry & Metheny, 2015, pp. 199–201), and consequently our choice for food has slowly become the complexity of our diets. Indeed, we can agree that food and foodways (also diets) are central to cultural practice, social organization, and a range of intersecting identities and belief systems (Beaudry & Metheny, 2015, pp. 10–11), and hence, by analysing their development by the communities from the past, we can get a closer approach to their *modus vivendi* and, finally, reconstruct some of the social dynamics performed by those societies in the past.

1.1.Archaeology of Food

Whereas food is one of the most central aspects in the study of any form of living, its role as an important field of study in Archaeology has been delayed until very recently. Indeed, the studies on diets and foodways did not start to become popular until the 70s. On this regard, plant and animal remains have been since the 70s the most commonly studied proxies and they have informed on the ingredients used by a specific society during a certain period of time. Furthermore, they also give information about food production, trade and storage practices. The results that derive from botanical and faunal records enables highlighting potential social and economic dynamics such as, for example, how wheat cultivation spread from Fertile Crescent to Europe (Standage, 2010, pp. 3-16). By comparing plant and animal consumption trends over time, it is also possible, for example, to identify food taboos and preferences.

With the advent of the 90s, the archaeology of food added a new way to approach the consumption of food in the past. The study of plant microremains and molecules preserved in pottery vessels provided information about long-invisible ingredients (e.g. milk) and cooking techniques (e.g. boiling). This type of analyses enabled answering questions such as 'how was an ancient beer brewed?' (Wang et al., 2016) or 'what was an ancient curry composed of?' (Lawler, 2012). These type of analyses enable discriminating different food compositions and identifying concrete dishes in archaeological contexts.

In the last decade, new advances on the Archaeology of Food have been made. Archaeologists have realized that carbonized remains of prepared meals are also preserved in the archaeological contexts. Charred food remains can be found in a wide range of archaeological contexts – for example potsherds, oven surfaces, midden deposits, or fireplaces– (González Carretero, Wollstonecroft, & Fuller, 2017; Valamoti et al., 2019). The study of charred food remains provides information at three different levels. First, they offer the possibility for the identification of the numerous ingredients being used during food preparation; the structure of the remains allows for the identification of the cooking techniques applied to the ingredients; and when combined, they allow us to characterize the final food products elaborated in the past. However, they can only be applied to a few, and very specific archaeological contexts, thus they inform more about special finds, rather than bringing up a more general knowledge on ancient food preparation.

The outcomes of all these decades of research are allowing a more accurate approach to past human diets, and a better understanding of how ancient societies did operate within their environments. Moreover, scholars have also examined symbolic aspects of food and foodways (Ray & Thomas, 2003; Russell, 2002) and other studies have focused on how food symbology contributes to the roles it plays in different social arenas. Relationships between food, community organization and community identity have been widely studied (Twiss, 2007). Hence, it seems clear that the Archaeology of Food is definitely providing, for the first time in human history, the possibility to tackle a number of research topics that link food – and food choice – with social relations. Indeed, the results brought by such a long-term research are relevant to explore some big questions such as gender inequality, symbolic meaning of concrete foodstuffs (Hayden, 1995), and food preferences among certain populations (Ducasse & Regouby, 2018; Mair et al., 2008) throughout time.

However, one of the most remarkable issues of the Archaeology of Food research is that the actual process of cooking and all the activities therein (smashing, crushing, cutting, hashing, hammering, flattening or fileting, just to mention some of them), are oversimplified or, in most of the cases, completely denied. Indeed, this position towards the research of past foodways has led to the production of reports in the form of endless lists of animals and plants taxa being found in the archaeological contexts, but very often not linked to any process or activity. Certainly, the nowadays focus of the general research seems to have been more dedicated to improve the accuracy of the already discovered methods and the creation of new ones that could be applied to other, new case studies (for example to approach the study to non-pottery hunter-gatherers (Boethius, 2016; Craig, 2021)), while the understanding of the dynamics and processes within food foraging, production, preparation, or consumption seems to be outside the focus.

Overall, the vision of the human past diets offered so far by the Archaeology of Food research has been limited to a range of inanimate food packages that obstructs the consideration and study of the myriad ways in which a certain single foodstuff can possibly be prepared and, then turned into a vast range of diverse products (each of them potentially embedding great differences in taste, aspect, and nutritional properties). Therefore, losing considerable amounts of information about the culture of the societies of the past. However, it is true that diet defines species and cultures, and that gastronomy is an essential aspect of individual and group identity (Sibal, 2018), thus the research on the Archaeology of Food should cross the threshold into this dark room known as the study of cuisine, and the aspects and factors therein (or Gastronomy).

1.2.Cuisine

The present research on the Archaeology of Food employs lots of tools to explore past diets, including studies of food remains such as bones and pottery crusts, stable nitrogen and carbon analyses, and even dental microwear, just to mention some of the most commonly used. However, many do not consider cuisine, nor any of the dynamic processes and activities therein. But what is cuisine? how many types of cuisine are there? And, more important, how can it be a key factor of study to obtain more accurate approaches of the societies of the past, hence why is it valuable for archaeology? The research on the Archaeology of Food might be greatly benefited from the understanding of the recent development of Gastronomy and Food science.

From a gastronomical point of view, cuisine was first practised by the early *Homo* species (Bullipedia, 2019b, p. 304). Obviously, previous hominids had to feed themselves, but at that time, food can only be understood from its biological dimension, hence, being that '*nutritious substance that people or animals eat or drink[…]*'. This first and extended stage of cuisine, normally protagonised by *Homo habilis* and *Homo erectus*, is considered as so due to the introduction of the *elaborations* to the whole spectrum of food, hence creating a division between a) non-elaborated products (raw foods, such as fruits, herbs, etc); b) pre-elaborations (a sort of interphase between the raw products and the final product, such as a ground paste to be added to a roots salad); and c) elaborated products (consisting in the final products that were ready to be eaten) (Bullipedia, 2019b, p. 311). This concepts are important because they allow us to assess more accurately on all the elaborations, techniques or preparations involving different human groups at a very different chronologies, which is key for the development of Archaeology science.

Concerning the types of cuisine existing in human history and in the present, this is an extended and still very debated topic in the gastronomic sphere, because the limits between the types of cuisine are non-fixed and poorly understood. Therefore, this is not a topic that I will discuss within this work. Nonetheless, an overall, very general, yet interesting differentiation in terms of types of cuisine can be made: cuisine without fire and cuisine with fire (Bullipedia, 2019b, p. 311). The consideration of the existence of cuisine beyond the domination of fire is also a generally denied aspect by archaeologists, although it certainly represents the most extensive period of our history. Indeed, the elaborations without fire are still just as present as the ones with fire in our daily lives nowadays, therefore the Archaeology of Food would greatly benefit from a closer look to them. From another perspective, the division between fire/non-fire cuisine is key because it allows to the addition of the third axis to the study of cuisine applied to any human group: a) natural resources; b) type of tools developed by the group; and c) absence or presence of artificial energy resources (such as fire) (Bullipedia, 2019b).

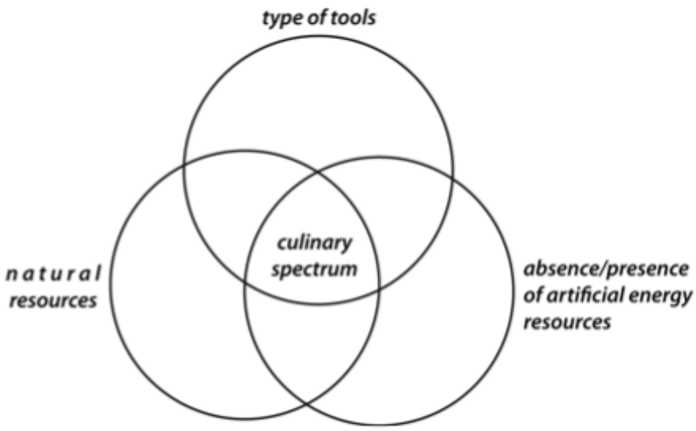


Figure 1. Model suggested by Bullipedia on the culinary spectrum available for any given human group through time.

The role that cuisine and Gastronomy play nowadays is worth to be taken into consideration because it is increasingly being embedded to the divulgation of human culture. Interestingly, Gastronomy and Food Science are bringing food to the forefront of the more general academic study (Beaudry & Metheny, 2015, p. 11). With regards to this cultural branch of Gastronomy, it is not a coincidence that one of the most relevant journals for this topic (International Journal of Gastronomy and Food Science) is including archaeologists and historians as a curators to their teams. Moreover, the increasing amount of *haute cuisine* restaurants (e.g. Central restaurant, Mugaritz, Aponiente, Dos Pebrots, Noor, etc) that are eager to incorporate archaeologists to their R+D teams on the one hand, and the rising appearance of Gastronomic projects (e.g. ElBulli Foundation, Alicia't, etc) requiring archaeologists in their staff on the other, manifests that the food industry already '[…] *acknowledges food centrality to our daily lives and affirms the need to understand the choices that humans make and have made about food, diet and subsistence, and why they make the choices they do*' (Beaudry & Metheny, 2015, p. 11).

Moreover, the scenario described for the present Gastronomy is reinforced by a strong public fascination with food and cuisine, which is, in turn, demanding the food industry to answer to more and more complex questions about the food we intake, why do we intake it, and what other options – in terms of diets – could have ever been developed by previous societies. On this regard, food industry has collaborated with archaeologists, anthropologists and historians with the purpose of getting to better understand the complexity of the processes involving the human evolution. Specially the ones related with food choice (Jones, 2007; Standage, 2010), fermentation (Del Noval & Prado, 2018; Katz, 2015; Mouritsen et al., 2017; Redzepi & Zilber, 2018) and what has been called *paleodiets* (Arranz-Otaegui et al., 2016; Turner et al., 2018). In recent years, some researchers and chefs have seen the opportunity to merge the two disciplines, leading to the development of numerous projects, among them, a special mention needs to be made to the elaboration of the first encyclopaedia completely merging gastronomy and the archaeology of food (Bullipedia, 2019a), although this is an ongoing project, still under development. In fact, many restaurants and chefs have highlighted the history of cuisine and connection to the past, therefore developing other projects, some of the most interesting ones are introduced hereafter.

Figure 2. Sapiens, a course introduced in Mugaritz's 2016 season. Source: mugaritz.com.

In the United States, The Cooking Lab team has developed an interesting approach to link archaeology and gastronomy (Myhrvold & Migoya, 2017). The principle aim was to inform modern bakers to know about the origins, history and fundamentals of bread. For this purpose they released an entire volume focused on bread and established collaboration with archaeologists, anthropologists and historians. There are few case studies introduced in the volume. First, based on the archaeological data, they tracked the origins of cereal processing at some point about 100,000 years ago in Mozambique (Mercader, 2009) – whereas they argued it cannot be considered bread, they suggested that it should be considered one of the first steps into the bread pathway. They have also conveyed experimental studies to investigate how the famous bread of Pompeii (79 a.C) could have been prepared and cooked.

Almost at the same time, during the 2016's season in Spain, the renowned restaurant Mugaritz introduced a concept where classic cutlery was excluded from the culinary experience. The aim was to make a trip back to our most primitive human roots and reconnect with the experience of eating using those parts of the body that are directly correlated with our senses: our hands, nose, eyes and mouth. Indeed, the only cutlery that was kept for the occasion was a handmade flint silex knife, which was used as an element to reinforce the aforementioned link between past and present (Luis-Aduriz, 2019; Regol, 2016). To achieve this aim, Mugaritz initiated a collaboration with experimental archaeologists that had previously studied the *chaines opératoires* – all the processes that involve the elaboration of a product (tool, foodstuff, structure, etc) (Leroi-Gourhan, 1965) – and were able to reproduce them in an innovative context. Combining both archaeological and gastronomical knowledge, a completely new culinary experience was successfully achieved, suitable for audiences not familiar to archaeology.

Another of the most relevant restaurants in Spain is the three-Michelin-star Aponiente, based in Puerto de Santa María, Cadiz. Aponiente's R+D division is looking at the Mediterranean history and applying fishing and cooking techniques from the past into the avant-garde culinary experience. Some of their most relevant concepts – the *almadraba* experience and storytelling, or the elaboration of *garum* – came from a deep bibliographical research in the Archaeology of Food (Pérez-Lloréns, 2019a; E. G. Vargas, 2006; E. G. Vargas et al., 2014; G. E. Vargas & Florido del Corral, 2010). Indeed, the restaurant's aim of contributing to the academia has brought them to collaborate with numerous researchers and communicate the results through their own gastronomical activity (Pérez-Lloréns, 2019b).

Some of these activities would not have been possible without the collaboration of archaeologists and in particular the development of the Archaeology of Food. This is important to be mentioned because, whereas archaeology is being increasingly considered within the new gastronomical projects, it seems that the consideration of cuisine in archaeology has been somewhat limited. As mentioned before, dietary reconstruction is often limited to a list of ingredients instead of more technical '*recipes*'.

A few, quite recent, archaeological studies, nonetheless, are starting to consider the application of cooking methods in the assemblages that they assess. Among others, the quest for fermentation and its implications in the delayed-return strategies (Binford, 1980; Woodburn, 1980) of the past human hunter-gatherer societies is certainly remarkable. Indeed, despite its key implications in the human foraging dynamics and survival strategies (Speth, 2017), very little attention has been paid from archaeology to the actual understanding of how did the ancient societies stored their foods (Boethius, 2016; Craig, 2021; Milner, 2009). While this few cited works are still in the very early stages of merging Archaeology and Gastronomy, they represent perfect examples of the pathway that is worth to be followed in order to increase our knowledge about past societies, but also the relevance of this bridge from a divulgation point of view.

Overall, the study of the culinary processes applied by past societies remain somewhat restricted because cooking and processing, especially of the wild foods that were eaten for the majority of our evolutionary history, leave few traces. Moreover, for the greater part of our history, humans did not have pots, or other complex tools which we can analyse. However, the very few, recent studies on the topic demonstrate that, if the correct questions are made, and the precise methods applied, very research pathways can be opened and it is science, and humanity, at the end of the day, who beneficiates from it. On this regard, one of the most plausible solutions to study the cooking methods applied to wild plants is presented in the following section.

1.3. Data collected for this thesis

To find archaeological traces of ancient culinary elaborations is, as it has been introduced so far, a very challenging issue in the Archaeology of Food research. While there is hope for numerous techniques to emerge and be proven as effective, one possible solution to this issue is the analysis of starch grains. Due to their unique properties, the analysis of starches offers information of the plant assemblage used by past societies, but it also can provide some indication of the processing methods. Indeed, starch grains have been used in archaeology to approach the plant assemblage (García-Granero et al., 2015) of different societies and therefore track the spread of certain important crops (Boyd et al., 2008; Dickau et al., 2007; Zarrillo et al., 2018; Zarrillo & Kooyman, 2006), but more precisely they have also been used to provide more insights on the food preparations of numerous societies (Lu et al., 2005, 2014), specially when these analyses are applied to cooking pots or other cookware tools (García-Granero et al., 2017, 2018, 2022). Furthermore, starch grains analyses have brought very interesting outcomes on diets and early evidence of certain elaborations, such as grinding (Henry et al., 2014). More information about the numerous outcomes obtained from starch grains research through the last few decades can be found in Barton and Torrence (2015).

Additionally, several researchers have documented that starch grains change shape in distinctive and identifiable manner when cooked using different methods (Del Pilar Babot, 2003; Del Pilar Babot & Apella, 2003; Henry et al., 2009; Messner & Schindler, 2010). This research has provided a unique window into processing methods used in the past, however most of the studies undertaken so far have focused on domesticated plants, hence only providing information about a small range of human subsistence assemblage. The knowledge about the exploitation and elaboration of wild plants in past human chronologies, remains, therefore, poorly understood because a) scholars have very often tended to undervalue the potential cooking methods developed by hunter-gatherer societies and consequently focused more on sedentary societies, which are believed to have developed 'more complex' (and therefore interesting) cooking techniques, however this relate is starting to switch very recently (Speth, 2017); b) wild plants are normally high in fibres and sugars, but not necessarily in starch, hence their study becomes more difficult. This is the reason why this thesis will focus on wild plants, in order to provide a starting point from which further research can be continued. The specific problematic and aim of this thesis will be more thoroughly explained in the following section.

2. Problematic

The study of botanical microremains in archaeology is a mature, well understood research which produces key reliable information at different taxonomic levels of specific elaboration or consumption of food from archaeological contexts. Specifically, starch grains in archaeology are a record of plant use. When this is applied to cooking or food management contexts, very promising results can be obtained on diets, food preparation and cultural foodways. Moreover, owing to its durability, archaeological starch provides some of the earliest evidence for the role of plant in human evolution, as well as artefact function and gender-related dynamics (Beaudry & Metheny, 2015, p. 503).

Nonetheless, although archaeology have provided an increasing number of evidences of raw-food obtention, food elaboration, and final consumption, there is apparently a gap in between the archaeological evidences and the dynamics underlying them. In other words, although scholars are providing a stream of information about past human diets, archaeologists are not being able to translate them into real human activities. With the help of the gastronomical knowledge gathered in previous studies, and combining them with present archaeological ones, I aim to tackle this gap by providing more information on how do a selected range of wild plants behave under multiple basic culinary elaborations. All in all, in this thesis, I plan to explore how starches from wild plants that were known to be consumed in the past become modified during cooking. These data will contribute to the understanding of how the different culinary elaborations affect wild plant starches and, therefore, help us be better able to explore our past cooking elaborations, choices and, potentially give us an approach on the all-times human culinary arts.

3. Methodology

A total of 4 species of wild plants have been collected and processed. Depending on the specie, a different part of the plant was collected (whether nuts or roots), as only the starchy parts of each species were interesting for this study. Three individual plants were taken to build every sample. For example, three individual chestnuts were ground and boiled together, then one single sample tube stored the mix and, finally one slide was mounted and analysed (from now on, the term 'sample' will refer to the final sample tube from which the microscopes slides will be mounted to be analysed). Hence, 63 individual plant parts have been collected in total for starch grain analyses, a summary of the information on the collected part of each of the plants, and the culinary processes applied to each plant can be found in Table 1.

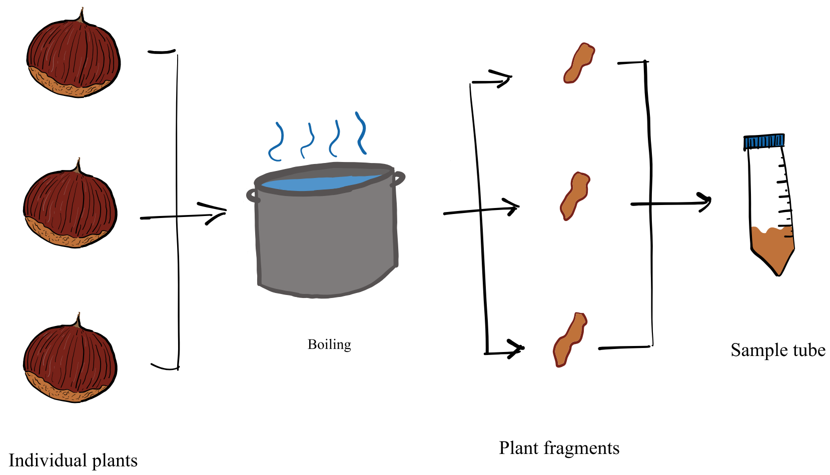


Figure 3. Sketch summarising the procedure followed to make each sample.

These plant species were chosen for a) having a high presence of starch; b) being available during the period when this research was undertaken; and also c) having seen a long history of use by diverse human communities in the past. On the latter evaluated aspect, a brief introduction to the types of plants that are going to be analysed in this thesis, worths to be made.

First, nuts are important because they can serve as an additional source of protein in the diet or as a dietary staple, depending on their availability and abundance (Beaudry & Metheny, 2015, p. 364), hunter-gatherer societies were more likely to rely on nuts, although agrarian societies did also make use of them in their diets. Most of the nut remains found in archaeological contexts that we know so far are preserved by charring, waterlogged nut remains, pollen and starch grains (Beaudry & Metheny, 2015, p. 364).

Specifically, acorns (*Quercus spp.*) are known from both archaeological and ethnographic evidence to have been a dietary staple in many areas of the world such as North America and Japan (Beaudry & Metheny, 2015, p. 364). Moreover, acorns also may have been used as food in Europe, however the evidence for is still poorly understood and not strong enough to make such claim (Beaudry & Metheny, 2015, p. 364). Besides, there is strong evidence to suggest that chestnuts were selected as staple foods in, for example, the Middle Jomon period in Japan (Kawashima, 2016).

Second, several of the world's most important food plants are cultivated for edible starch-rich underground storage organs (Beaudry & Metheny, 2015, p. 464), however, prior cultivation and also as a complementary food source, the roots of wild plants are also used for its high nutritional values. Indeed, many roots provide higher return rates than cereals in terms of carbohydrate returns per expenditure of effort for cultivation and processing prior to consumption (Beaudry & Metheny, 2015, p. 465), therefore making this type of food source one of the staples for through history. Indeed, it has been suggested that tubers were closely linked to the gathering of wild plants, which still played an important role at the onset of the Neolithic (Klooss et al., 2016). Concerning the plant selection for the roots, the presence of lesser celandine (*Ficaria verna*) has been found in Neolithic archaeological contexts in Germany and Denmark (Klooss et al., 2016).

Table 1. Summary of the plant species used and the culinary methods applied.

Common name	**Latin name**	**Part**	Raw	Boiled				Roasted / Popped	Ground & Boiled			Ground & Baked	**n of plants**
				5'	10'	20'	30'		1'	2'	5'		
Horseradish	*Armoracia rusticana*	Rhizome	X		X			X					9
Chestnut	*Castanea sativa*	Nut	X		X	X	X	X	X	X		X	24
Lesser celandine	*Ficaria verna*	Tuber	X	X									6
Chestnut	*Quercus robut*	Nut	X		X	X		X	X	X	X	X	24
Total													**63**

Concerning the place and period of the year in which the plants were collected, whereas the nuts (both chestnut and acorn), were collected nearby Pola de Siero (Asturias, Northern Spain) during the first half of November; the horseradish was picked in Leiden (South Holland, The Netherlands) during the last half of November; moreover, the lesser celandine was gathered in Amsterdam (North Holland, The Netherlands) by mid-February. All the plants were hand-picked from places where it was known they were growing 'spontaneously', or at least, where they were, by no means, planted with domestic exploitation purposes. On this regard, it is worth mentioning the difficulty of finding completely wild plants in Europe, due to the lack of completely 'virgin' areas where crops or lands would have never been manipulated. In addition, a bit of gastronomical criteria has been added to the final selection of the assemblage: these wild plants were selected partly because they are increasingly popular, especially as part of the new concepts of gastronomy at high-end restaurants (Redzepi & Zilber, 2018). This therefore allows this thesis to provide valuable information for the two disciplines previously considered: Archaeology and Gastronomy.

Prior to the cooking processes, a reference collection of the native starches from these wild plants was made. The four plant taxa from the reference collection were examined under transmitted brightfield and cross polarized light at 400x magnification using a Zeiss AxioSkop.A1 microscope. Photos were taken using the attached AxioCam MR greyscale camera controlled by AxioVision SE64 Rel. 4.9.1. These reference images provide the baseline of native starch morphology against which the processed starches were compared.

3.1. Preventing sample contamination

Due to the plant assemblage used for this research comes from modern taxa, the protocols for avoiding contamination are much less strict than the ones applied for sampling the actual archaeological assemblage. In this regard, the presence of specific starch grains from the selected processed plant exceeds the potential contamination of other starch grains. Therefore, as long as the taxa and the applied cooking process that were being sampled were known, the sample contamination prevention criteria was simplified to carefully cleaning every tool and surface before working with each of the different wild plants.

3.2.Description of the culinary techniques applied

Not all of the culinary techniques have been applied to all of the selected wild plants (see Table 1). The criteria for applying certain cooking processes to each of the botanic taxa mainly relies on a thorough review of both the gastronomical and anthropological literature. Although the cooking processes described hereafter were elaborated based on the proposed methodology published by Henry et al (2009), slight changes have been applied in order to meet both archaeological and gastronomic preferences. Furthermore, the cooking processes were performed in a controlled laboratory setting using modern tools (e.g., a temperature-controlled heating plate, mortar and pestle, scale, etc), rather than trying to replicate ancient processing techniques (e.g., open fire, grindstones). The goal of this project was to explore the effects of particular physico-chemical processes on the morphology of starches, not to see how actual 'ancient' processing techniques might alter the foods. Therefore, a controlled laboratory setting as the one offered by the Faculty of Archaeology of the Leiden University, allowed us to control every aspect of the cooking procedures, such as weight, temperature, times, etc.

3.2.1. Boiling

Recent comparisons between experimentally heated stones and archaeologically recovered fire-cracked rock from shallow-basin hearths at a cave site in South Africa suggest cooking stones of some type were in use by 72,000 years ago (Beaudry & Metheny, 2015, p. 182). Interestingly, hot rocks can retain heat longer than burning fuel, therefore they enable fuel conservation and extend the cooking time (Beaudry & Metheny, 2015, p. 182). Other complex wet- and moist-heat facilities that require cooking stones, including earth ovens with rock heating elements and possibly stone-boiling pits, date to 35,000 years ago worldwide, except for North America, which date to 10,500 years ago (Beaudry & Metheny, 2015, p. 182).

From a culinary point of view, boiling is a classic method for cooking food quickly (Myhrvold et al., 2011, p. 63). The very simplicity of boiling a pot of water makes it a useful cooking strategy for many foods. Some products may only need a quick blanching or short boiling time, whereas others need to boil a bit longer in order to soften their tissue (for example big vegetables, specially roots, but also legumes and, of course, meat). Also, boiling cushions food in water and maintains a constant, relatively low temperature, so it may seem to be a gentle way to cool food than, for example, roasting or baking. Moreover, water transmits heat so much more efficiently than air that it can raise the food temperature rapidly, therefore allowing to many different elaborations depending on how much time a food is being boiled (Myhrvold et al., 2011, p. 63). On this regard, boiling owes its speed to the outstanding ability of water in motion to conduct heat. Here, the 'in motion' part is crucial, because the turbulence lifts the hottest water up to the surface, drags colder water down toward the bottom of the pot, and therefore accelerates the transfer of heat (Myhrvold et al., 2011, p. 64).

Concerning to the performed methodology, I boiled 3 individual plant parts (whether nuts or roots) in a pot with 1 litre of water for a total period of one hour, yet different samples were taken at different time periods. Each plant was boiled at a time, and the water was changed and the pot cleaned before starting cooking any new plant taxa. Some little fragments from the very core of each individual plant were combined into a sample tube, therefore one unique sample from each plant species was obtained per each period of time.

The whole plant organ (nut or root) was boiled in order to prevent a possible bias in the results due to an extended overcooking of the sample, and a better control of the cooking times. When food is cut into smaller pieces, the exposure to heat and the cooking environment is multiplied (i.e., cutting an onion in *bronoise* is a method that allows for a faster cooking as the surface that is exposed to heat is multiplied by 6) (Myhrvold et al., 2011). At the beginning, a division of cooking periods by 10, 20, 30, and one hour were established for all the analysed species. The decision to establish this periods was made based on modern cooking recipes and in order to make sure that the whole plant reached the same temperature in all parts (from the surface to the core). In this regard, it seemed reasonable because both of the nuts take long time to be fully cooked, and horseradish can perfectly hold one hour of cooking time without getting significantly overcooked. However, after a first microscope analysis, all samples that were cooked further than 30 minutes were discarded because the starches were completely obliterated, hence impossible to obtain any type of information.

3.2.2. Grinding before processing

Grinding, or milling is a process that breaks solid material into smaller pieces. It is, indeed, one of mankind's greatest technological inventions, as it allowed to transform raw-foods into a myriad of new, more complex food products. Milling stones such as saddle querns and rotary querns and, later, millstones have played a vital role in food processing (Beaudry & Metheny, 2015, p. 344).

A rich ethnographic record suggests that acorns were ground or crushed into a flour, besides that stone mortars and pestles, used to grind acorns and other seeds, are sometimes found on archaeological sites. Whereas in historical chronologies acorns have been perceived in many cultures as food for the poor or as famine food, other cultures see them as a valuable food source (Beaudry & Metheny, 2015, p. 364).

Due to the literature resources and following basic culinary knowledge, only chestnuts and acorns were selected for grinding. Following the same steps as mentioned previously, three individual plants of each taxa (three nuts and three acorns) were ground down to medium powder with mortar and pestle, then each of them was collected for further procedure, as it is detailed hereafter.

- *Grinding, then boiling*

This is the first of the combined procedures applied to the plants. In this regard, only chestnuts and acorns were selected for this procedure. To do so, 25 mg of medium-powder ground sample (obtained from grinding three individual plants) was added to 50 mg water in a 100 ml glass test tube and gently stirred; then, the mix was boiled for three different periods of time: 1, 2, and 5. At the beginning, other periods (5 and 10 minutes) were established based on the available literature of similar research made on cooked domestic cereal grains. However, the starches from the wild plants analysed in this study highly damaged very soon, hence the durations needed to be adjusted.

Immediately after boiling the mix in the tubes, they were cooled down in cold water with ice cubes. This step was added to the methodology that was found previously in the literature as a way to better control the cooking durations and, therefore, obtain more accurate results. With regards to this process, one unique sample was taken from each tube (i.e. each cooking duration) and each plant species.

- *Grinding, then baking*

In kitchen parlance, the verbs *to bake* and *to roast* have similar, yet not exactly synonymous, meaning (Myhrvold et al., 2011, p. 101). Bake is normally applied for bread, or dough-like foods; whereas roasting is used for any other foodstuffs. Although both of them normally happen in an oven nowadays, the origins of these words reveal how the cooking methods used to differ from each other. Certainly, the verb *to roast* comes from the Old French word *rostir*, meaning to cook something before a fire; while the verb *to bake* comes from the Germanic workd *baka*, which interestingly meant drying something out by warming it inside of an oven (Myhrvold et al., 2011, p. 101). This method has long been used for other-than-food products such as pottery, or mudbricks. This is actually why some ceramists refer to the process of cooking pottery as *baking*. Actually, drying is still mostly what oven baking does to food. Indeed, as the oven transfers heat to the food, moisture from the food evaporates into the air as water vapor. This leads to three stages of 'drying' the food when cooking it in an oven (Myhrvold et al., 2011, p. 106): a) the temperature at the surface of the food quickly rises from its starting point, but then stalls and remains until the surface dries substantially; b) after the initial period, the temperature increases again, but more slowly than before, when enough water evaporates from the food, the humidity in the oven increases appreciably; c) then, evaporation flings water from the food into the air, but water is just as quickly replenished by capillary action and diffusion, which drive juices to the surface from deeper within the moist interior, during this stage, thus, the core gradually begins to dry (Myhrvold et al., 2011, p. 107).

Acorns and chestnuts were selected for this procedure. Although the literature is plenty of ethnographical examples of using acorns for making bread-like preparations or even for adding them to numerous types of dough (Thurmond, 2006), chestnuts does not seem to be that common to be used in this way.

To undertake this process, 50 mg of medium-ground powder were mixed with 50 mg of water for some 30 seconds to form some sort of a paste with a bread-dough-like consistency. Then, the mix was placed on a silicon foil in an oven tray and baked at 200ºC until dried, which took about 4 minutes and 35 seconds. The resulting *galette* was coarsely broken into pieces finally and transferred to the sample plastic tube.

3.2.3. Roasting

Roasting is a dry heat cooking method (Beaudry & Metheny, 2015, p. 44) that uses radiated heat to elevate the temperature of the surface of the foods (Myhrvold et al., 2011, p. 28). Desired chemical and structural changes occur during dry-heat cooking, wherein raw-food moisture is adequate for hydrolysis (Beaudry & Metheny, 2015, p. 180). Dry heat from surface hearths is perhaps the most common method of cooking both animal and plant foods, although site-formation processes often render such features archaeologically obscure (Beaudry & Metheny, 2015, p. 181). Evidence from deposits in caves and rockshelters in Israel (ca. 790,000 years ago) and South Africa (ca. 1M-1.7M years ago) showed unambiguous hearths in shallow basins, usually containing burned bone and various plant materials, strongly suggest that dry cooking was well established by 400,000 years ago in the Middle East, Africa and Europe (Beaudry & Metheny, 2015, p. 182).

Open fires disperse heat directly into the atmosphere and are suited for fast, dry-heat cooking with flames or above, on, or in hot coals (Beaudry & Metheny, 2015, p. 183). Hearths also provide heat for other cooking methods that are not going to be assessed in this section.

This process has been divided into the roasting of tubers and the roasting of nuts because they involve different end goals. On the one hand, the aim of roasting tubers might be making them tastier, softer and more edible. This idea was actually fostered by the publication research published by Klooss et al., in which lesser celandine roots were found charred in the archaeological record (2016). On the other hand, the main purpose of roasting nuts is to make the removal of the shell an easier activity (Mithen et al., 2001). All in all, the time and temperature applied for each process is, therefore, completely different.

- *Tubers*

The whole tuber was roasted for the same reasons as for the boiling process (if smaller parts of the plant are roasted, it is possible to incur into a bias due to the increased exposure of heating surface). An electric oven settled at 185ºC was used for roasting tubers for 30 minutes. This process was triplicated for each taxa, then a piece of each individual plant was transferred to a tube, hence making one unique sample from each plant species.

- *Nuts*

The shells were coarsely scored with a knife before placing them in an electric oven grill settled at 200ºC. Using an oven grill allowed us to better control the time and the temperature applied to roasting these products as well as allowing the air to flow through the foods, which improves the actual roasting while prevents the boiling within the nut shells. In terms of time, the nuts were roasted until they 'popped' which started happening at some 8 minutes after they were pushed into the oven.

3.3. Microscope slides mounting and starch analyses

After each of the cooking processes were applied, the each individual plant taxa was sampled by cutting a little piece from its very core. The extracted little pieces were mixed with the other individual plants of the same species, cooking process and cooking duration in a sample tube. In order to be analysed, different little cooked plant pieces from the sample tube were transferred into a microscope slide, then 20 µl of glycerine and 20 µl of water were added to it and gently stirred with the aid of a precision pipette. After that, a cover glass was placed on the sample and carefully pressed to avoid bubbles. The use of glycerin solution (a non-permanent mounting mean) allows to turn the starch over during the microscopic scan, which consequently provides a 3D vision of the grains, this is a useful resource when trying to assess the morphology of the starch grains.

The sample was then scanned under a transmitted brightfield and cross polarized light at 400x magnification under a Zeiss AxioSkop.A1. The pictures of the starch grains were taken with an attached AxioCam MR greyscale camera controlled by AxioVision SE64 Rel. 4.9.1, both under polarized light and under transmitted light, at 400x magnifications. At least five images were taken for each slide sample. The characteristic features of the starch grains were described according to the International Codex of Starch Nomenclature (ICSN, 2011) preestablished parameters.

3.4. Statistical analyses and FAIR research

In the aim to produce open-access data to facilitate the spread of the information as well as the critical evaluation of it, R Studio 2021.09.2+382 open-access software has been used to produce all the statistical analyses presented in this work. In this regard, both the code written and the database produced to undertake this study will be available for any scholar who will aim to consult, test and improve it. In addition, the photos of the starch grains taken with the microscope will also be published in the DANS (Data Archiving and Networked Services) Easy repository to offer a sustainable archiving and open-access to the outcomes of this research.

With regards to the statistical analyses performed in R Studio, first a visualization of the data is provided, in the form of histograms and boxplots. In order to achieve a deeper understanding of the data, a Shapiro-Wilk test is performed on the distribution of the measurements of each plant's native starch grains. This test is used to determine whether a variable is normally distributed or not. In other words, it will provide us with a strong level of confidence whether if we can confirm that only one type of starch grains is present in the sample or if there are more than one, based on the measures taken from the granules (µm). In order to test if the starch grains change after the application of a cooking method, a Kruskal-Wallis test of the mean sizes between cooking methods is used. This test is used to understand whether if differences exist between two or more groups in a nonparametric distribution, hence the use of this test is accurate as it will provide a strong level of confidence to evidence whether if starch grains change after cooking or not, based on the measurements taken from the granules (µm).

4. Descriptive analyses (starch morphology)

4.1. Introduction

In the sections below, I provide a detailed written description of the morphologies of the starches from the four examined wild plants. I first present the raw (or native) starches, and then the appearance of the starches after each of the cooking method applied. Moreover, these changes in the morphology are illustrated by the pictures taken with the microscope's software. These form the basis of the comparison between cooking methods.

4.2. *Armoracia rusticana* (Horseradish)

4.2.1. Raw / Native starch description

Many small starch are present in this root piece. They are often simple and some are arranged compounds of three or four component granules, but also bigger accumulations of more than 20-30 granules are present. The measure of the grains ranges from some 7 to 13µm. The grains are irregular shaped: often spherical, ovoid and sometimes bell-shaped. When isolated and attached to small accumulations, the grains tend to be more spherical and ovoid, when the accumulations are bigger, the grains tend to be ovoid and bell-shaped. The hilum is very small and sometimes indistinct, it becomes however clearly visible in the larger grains. The surface can range from sometimes smooth to more often rough. Crosses are fairly distinct, centric and symmetric. Lamellae are not present.

4.2.2. Boiled whole description

Horseradish were boiled whole for three different durations (10, 20, 30 minutes), however, due to the rapid de-naturalisation of the grains and the impossibility to describe any other change in its morphology after 10 minutes boiling, only this duration has been chosen in this work.

- 10 minutes: the starch grains seems to have been aggregated, however they are extremely blurred and, therefore, the descriptive analysis becomes difficult. The whole structure of the grains has been become denatured, and the characteristic features that were present in the raw description are not present anymore. Moreover, the hilum and the crosses are completely absent as well. Their dimensions, however, seem to have swelled to some 46 to 81µm.

4.2.3. Roasted description

The roasted grains, as well as for the boiled process, presented a high damage in their morphology. The grains have swelled to 55-100µm and, due to this expansion, they seem to have lost their shape – which has turned into an amorphous one – and surface – which presents a very rough and damaged texture. The different characteristic features, such as the hilum and the crosses have been completely disappeared.

4.3. *Castanea sativa* (Chestnut)

4.3.1. Raw / Native starch description

Most of the starch grains seem simple and very few compounds have been found. Two different types of grains have been detected:

- *Small grains*: On the one hand, small grains present a length of 4-10µm, and they have a smooth, irregular – almost bell-shaped – surface. The hilum is not visible. The small grains are non-lamellated and the crosses are clearly distinct, symmetric, and centric. The arms of the crosses are medium sized, clean-cut and slightly curved or also straight.
- *Large grains*: On the other hand, the large grains present an irregular, angular shape, measuring some 13-25µm in length, and presenting an asymmetric cross. The hilum is still not distinguishable in this type of grains. Lamellae are present but certainly blurred. The asymmetric crosses, however are clearly distinct and non-centred, allowing for a short arms on one side and larger, curved ones on the other.

4.3.2. Boiled whole description

Chestnuts were boiled whole for three different durations (10, 20, 30 minutes). The structure becomes increasingly disturbed as the cooking time increases. Indeed, as a broad description, it can be said that the texture of the chestnut starch grains appear to leak inner substances progressively during this process. There are considerable differences among the cooking times:

- *10 minutes (small grains)*: Most of the small grains seem to have disappeared, and those that are still present, are embedded into the larger ones. The surface of the smaller grains has become blurred and morphological traits are no longer distinguishable. A very blurred cross can rarely be distinguished in very few cases.
- *10 minutes (large grains)*: aggregations of large starch grains and groups of starches appear. The most remarkable feature at this moment of the process is that the starch grains have already lost the cross; moreover, lamellae are no longer distinguishable. The texture becomes rough and the shape undefined. The average size of the grains seemed to increase to 36-77µm.
- *20 minutes (small grains)*: At this moment of the process, the small grains seem to have completely disappeared.

- *20 minutes (large grains)*: The aggregation of the large grains continues and all the grains are compactedly attached to each other. The texture of the grains is still rough and the shape is irregular, but there are still clear, if irregular, boundaries among the granules. Again, the average size of the grains seemed to have swelled to 37-80μm.
- *30 minutes (large grains)*: the aggregation of the large grains becomes broken at this stage of the process, and the starches seem to start disaggregating from each other. Their shape has become, very often, more elongated than before, although there is still presence of irregularly round grains. The texture is rough and very damaged, but the grains kept the '*wholeness*'.

4.3.3. Ground & Baked description

Overall, the grains that have been ground and then baked are very damaged. However, two observations can be provided:

- *Small grains*: At this moment of the process, the small grains seem to have completely disappeared.
- *Large grains*: Large grains present a really blurred texture and an irregular shape. Moreover, the hilum and the cross, as well as the lamellae, are no longer distinguishable in this process. All the large grains seem to be hardly attached, almost completely embedded, forming a sort of amorphous mass of accumulation of starches. The size of these grains ranges between 34-77μm.

4.3.4. Ground & Boiled description

Chestnuts were ground and then boiled for two different durations (1 and 2 minutes). Roughly, what can be seen in the pictures is that the starch grain's structure becomes broken and slowly loses their characteristic features. However, a more thorough description is provided hereafter:

- *1 minute (small grains)*: many small grain starches appears individually and unattached to each other. Whereas these small grains conserved the texture and, sometimes, even their shape is preserved; they are very often broken in diverse amount of pieces. Their cross has become more blurred, but is still distinguishable. Some small grains seem to have been popped up. Their size ranged from 7-18 μm.
- *1 minute (large grains)*: On the other hand, larger grains tend to attach to each other and form groups. Their surface is seriously damaged, with a blurred,

irregular shape. The size of the grains seemed to have increased to 33-36µm. The hilum and lamellae, as well as the crosses, are absent at this stage.

- *2 minutes (small grains)*: some small grains continue to be present individually, however they are more often broken into different parts. They have mostly lost their crosses and the texture is very often melted down and almost disappeared. Their size ranges from 8-30µm.
- *2 minutes (large grains)*: On the contrary, large grains have almost completely lost their surface and they are leaking due to disruption or fragmentation. Their shape is irregular and their size ranges between 29-66µm.

4.3.5. Popped description

Only large starch grains are preserved in this process, which have become attached into big groups. The shape of the grains is irregular and the average size has increased to 34-76µm. The texture of the surface is slightly rough and the grains have lost many of their characteristic features (crosses and lamellae).

4.4. *Ficaria verna* (Lesser Celandine)

4.4.1. Raw / Native starch description

A limited and very scattered presence of grains were present in this category. The visible grains have an ovoidal, discoidal shape, presenting a smooth texture and a significantly blurred cross. A little, centric hilum is present, but lamellae were not distinguishable. Concerning the measure of these grains, they vary between some 8-19µm.

4.4.2. Boiled description

Lesser celandine roots were boiled for different durations as well (5, 10, and 20 minutes). However, descriptions for only 5 minutes are provided because the damage at 10 minutes already produced completely denatured starch grains.

- *5 minutes*: again, the presence of grains was very dispersed through the sample. The dimensions of the boiled grains swelled to between some 31-55µm. With regards to the morphological features, the shape has turned more sub-rounded to oval, the texture has less smooth but far more blurred, and the hilum has increased its dimensions. Finally, the cross is definitively not visible anymore.

4.5. *Quercus spp* (Acorn)

4.5.1. Raw / Native starch description

Two types of grains are present in this category as well, although some of them can be found in simple groups, accumulations and compounds occur very often, and numerous fibers can still be seen.

- *Small grains*: Concerning the small grains, they vary between some 6-12µm in length and present a round, oval shape. Their surface is mostly smooth, with a large, scar-like, transversal hilum. Whereas lamellae are not distinguishable, the small grains present a fairly clear and symmetric cross with short and straight arms.
- *Large grains*: The larger grains present a length between 13-23µm and a more round shape. The surface is certainly grooved, also with a large scar-like hilum. Lamellae are also not distinguishable, however crosses are normally present, they tend to be symmetrical but blurred in the centre, with short and straight arms.

4.5.2. Boiled description

Acorns were also boiled whole for three different durations (10, 20 and 30 minutes) However, descriptions for only 10 and 20 minutes of boiling are provided because the damage at 20 minutes already produced completely de-naturalised starch grains.

- *10 minutes (small grains)*: most of the small grains have been aggregated into big groups and have lost their characteristic features. Whereas their shape has become blurred, their texture is still smooth. Moreover, the hilum has disappeared, but the cross is still visible. The size of the grains ranged between 6-22µm.
- *10 minutes (large grains)*: regarding the larger grains, they seem to have been exploded, and therefore lost their shape and part of its features. Some of them, however, still preserved part of the structure, and the hilum, as well as the lamellae can still be observable. The crosses, nonetheless, they are hardly visible or completely lost in most of the grains. The measure of the large grains ranged between 25-84µm.
- *20 minutes*: only small grains can be observed at this stage of the cooking process. They are, however, extremely damaged and therefore very little description can be offered. All the grains are forming part of bigger, amorphous, accumulations, the surfaces are completely disappeared and only glimpses of the previous shape can be observed in the few grains that kept the features. The texture of these accumulations is smooth, with a few, little chunks of broken grains. Glimpses of crosses can be discerned in the very few grains that preserved the form, but they are lost in the major part of the cases. The other features are completely lost. Their size swelled to 11-118µm, showing a very high standard deviation.

4.5.3. Ground & Baked description

All the starch grains for the ground and then baked process were extremely damaged. The very few starches that could be distinguished presented a very rough texture with an amorphous shape, potentially produced by an collapse of the grain. The cross, hilum and lamellae have disappeared completely. The size of the few grains observed ranged between 40-85µm.

4.5.4. Ground & Boiled description

Acorns were ground & boiled for three different durations (1, 2, and 5 minutes). A difference in the behaviour of the small and the large grains is significant, and might imply a key trait for cooking processes diagnosis. The descriptions of the analyses are presented hereafter:

- *1 minute (small grains)*: the texture of the grains is not completely smooth, however it is clearly not rough. The oval shape is still clear and very few changes in shape can be observed. Whereas the hilum is not visible anymore, the crosses are still observable, although they are starting to become blurred. Their size ranged between 7-17µm.
- *1 minute (large grains)*: these grains are more damaged than the small ones, although most features are still clearly visible. The boundaries of the grains are still observable, but the shapes varies from oval to sub-rounded. The texture is coarse and the hilum has been disappeared. The crosses are still observable, and their size ranged between 14-24µm.
- *2 minutes (small grains)*: although the shape is turned more variable, the texture is maintained and the boundaries are still well defined. Some of them start to present lamellae and the cross is still observable. Their size ranged between 7-16µm.
- *2 minutes (large grains)*: the size seemed to be increased to 17-46µm in the major part of the large grains., but the boundaries have become very blurred, until the point that some grains are hardly observable. Many large grains seemed to be broken at this stage of the cooking process, and most of them have lost the hilum and the cross.
- *5 minutes*: all starch grains, both small and large, have completely blurred and, therefore, no trait is discernible at this stage of the process.

4.5.5. Popped description

Because all the characteristic traits have disappeared, no differences can be made in terms of the size of the starch grain for this cooking process. Only amorphous accumulations of inflated starchy-like grains can be observed, they present a rough texture with lots of chunks from broken starch grains attached to them. All the presence of hilum and crosses have disappeared as well. The size of the grains that could be observed ranged from 46-82μm.

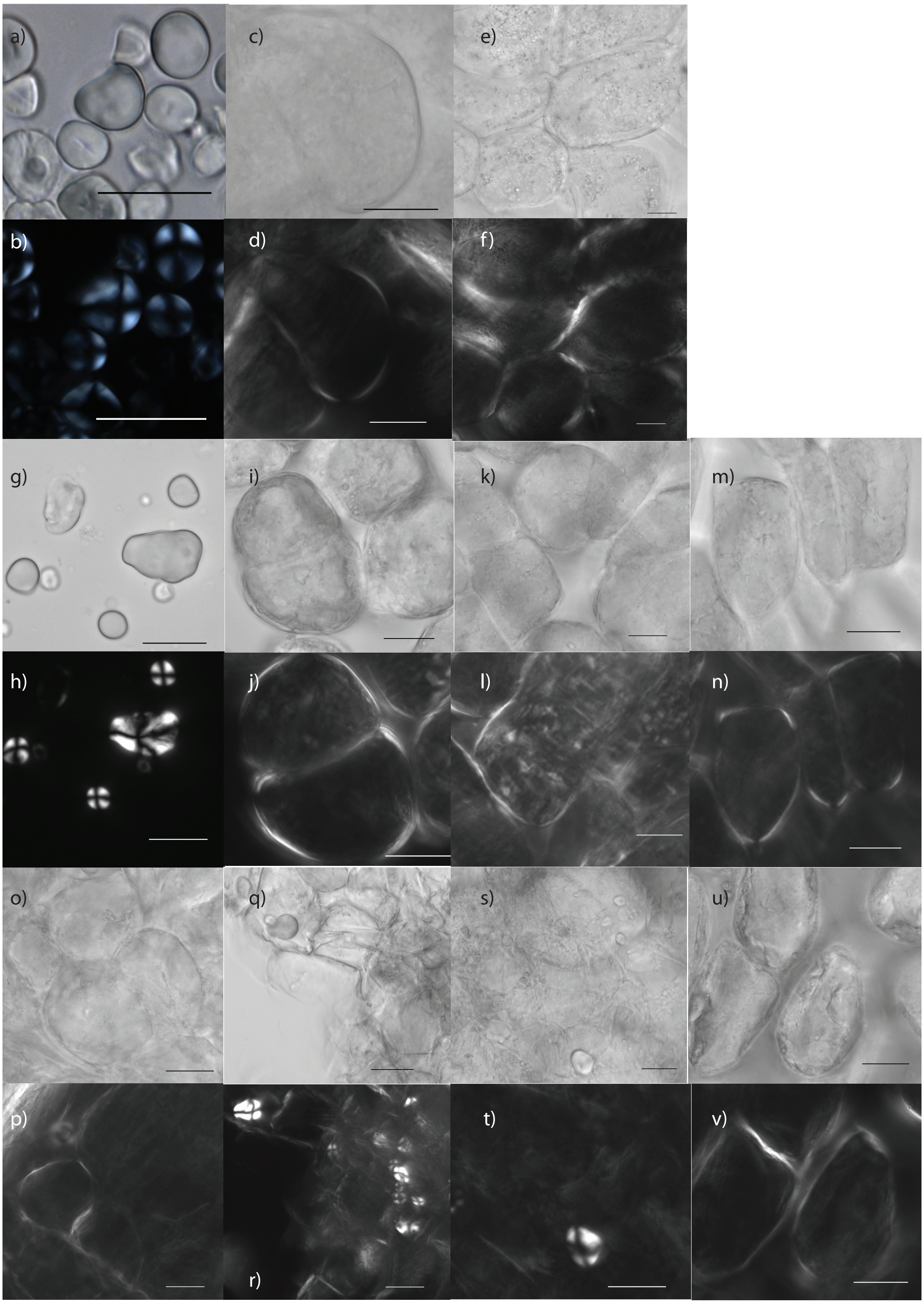


Figure 3. Photographs of the starches under normal and cross-polarized light. All scales represent 20 μm. From top-left to bottom-right: **a)-b)**: Raw horseradish starch; **c)-d)**: Boiled for 10 minutes horseradish starch; **e)-f)**: Roasted horseradish starch; **g)-h)** Raw chestnut starch; **i)-j)**: Boiled for 10 minutes chestnut starch; **k)-l)**: Boiled for 20 minutes chestnut starch; **m)-n)**: Boiled for 30 minutes chestnut starch; **o)-p)**: Ground & baked chestnut starch; **q)-r)**: Ground & boiled for 1 minute chestnut starch; **s)-t)**: Ground & boiled for 2 minutes chestnut starch; **u)-v)**: Popped chestnut starch.

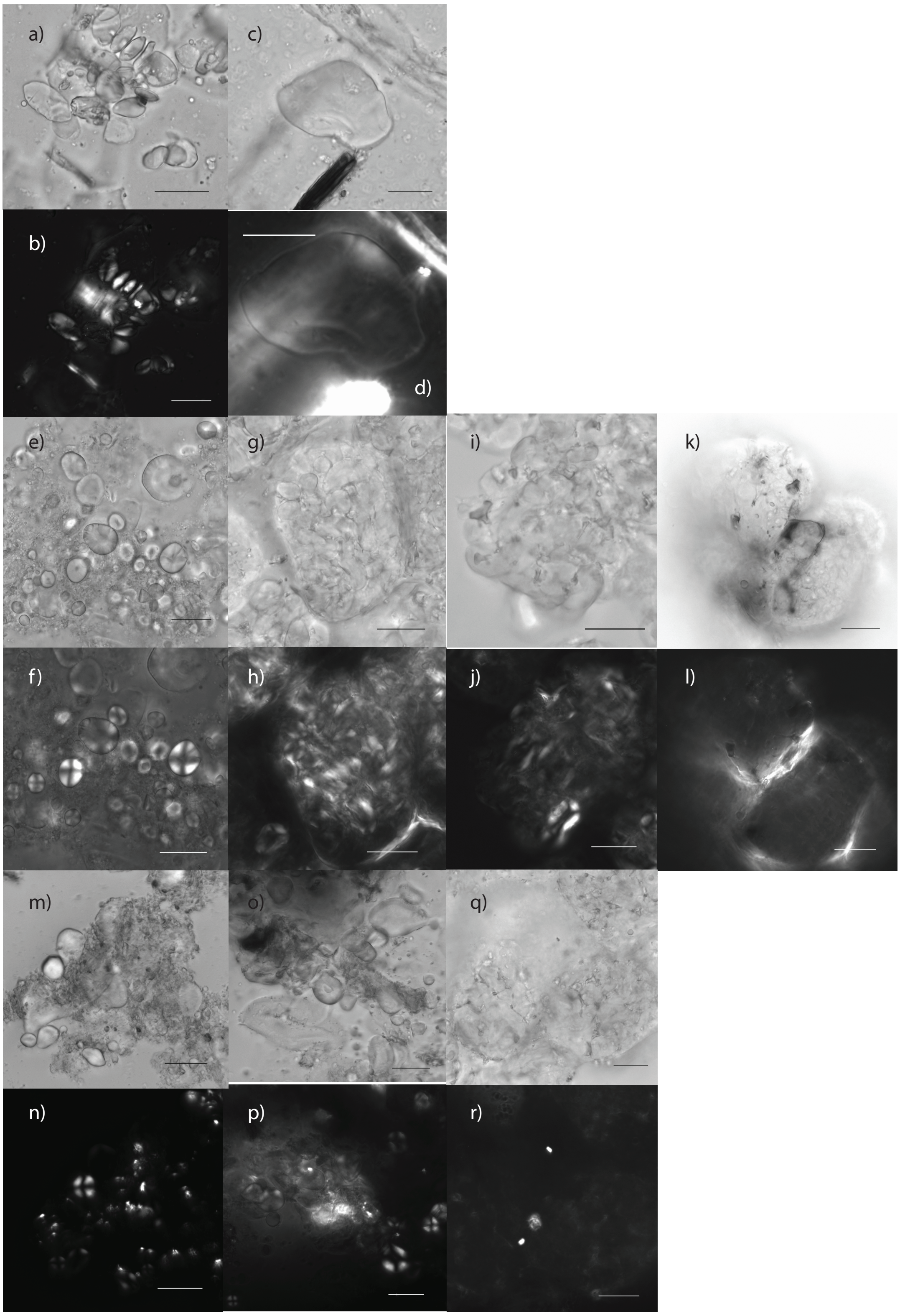


Figure 4. Photographs of the starches under normal and cross-polarized light. All scales represent 20 µm. From top-left to bottom-right: **a)-b)**: Raw lesser celandine starch; **c)-d)** Boiled for 5 minutes lesser celandine starch; **e)-f)** Raw acorn starch; **g)-h)**: Boiled for 10 minutes acorn starch; **i)-j)**: Boiled for 10 minutes acorn starch; **k)-j)**: Ground & baked acorn starch; **m)-n)**: Ground & boiled for 1 minute acorn starch; **o)-p)**: Ground & boiled for 2 minutes acorn starch; **q)-r)**: Popped acorn starch.

5. Statistical analyses (starch measures)

5.1. Introduction

The analyses of the measurements of the starch grains brought numerous outcomes. In the following sections I present the results for the different statistical tests used in the study. As mentioned in the Methodology section, both Shapiro-Wilk and Kruskal-Wallis tests are used alongside with the histograms and boxplots to describe the obtained distributions from the measurements. They are put forward in this section following a classification per plant species as well. A summary of the results is presented in Figures 9 and 10.

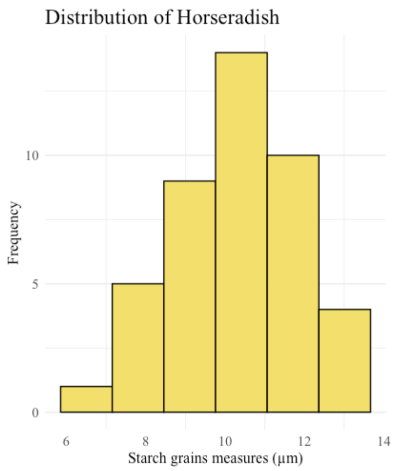
5.2. *Armoracia rusticana* (Horseradish)

5.2.1. Within-species differences

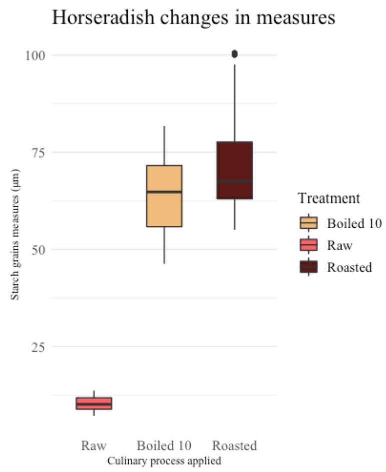
The result of the Shapiro-Wilk test (p-value = 0.3658) applied to the measures taken on raw horseradish suggested that there was only one distribution in the sample, therefore providing statistical confidence to state that we can only find one type of horseradish starch grain. The result retrieved by the test seemed to fit accordingly with the data visualized in the histogram (see Graphic 1), where the distribution is mainly grouped in the range of 7.14-13.65 µm, with only one sample showing a small deviation.

5.2.2. Do the starch grains change with cooking?

Whereas there was no significant statistical (nor qualitative) difference in the native, raw horseradish starch grains, the difference in size after cooking is fairly evident (see Graphic 2). The differences among the different cooking methods applied are also confirmed by the result of the Kruskal-Wallis test (p-value < 2.2e-16). The differences showed in the boxplot suggest that the horseradish starch grains increased in size both when boiled for



Graphic 1. Histogram showing the distribution of the frequency in the *A. rusticana* (Horseradish) measures.



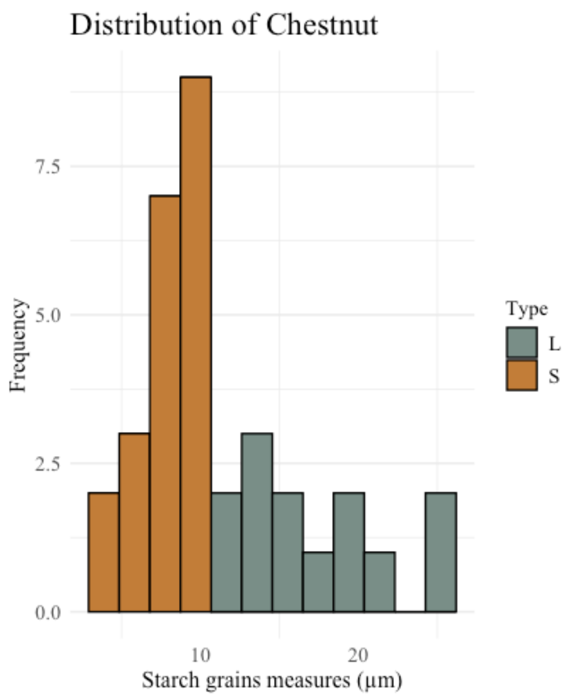
Graphic 2. Boxplot showing the changes in size of the *A. rusticana* (Horseradish) starch grains after cooking.

10 minutes and when roasted. This feature was certainly observed in the descriptive section above.

5.3. *Castanea sativa* (Chestnut)

5.3.1. Within-species differences

The result of the Shapiro-Wilk test (p-value = 0.003093) applied to the measures taken on raw chestnut suggested that there are two different distributions in the sample, as showed by colours in the histogram (see Graphic 3). This result aligns with the description provided in the previous section.

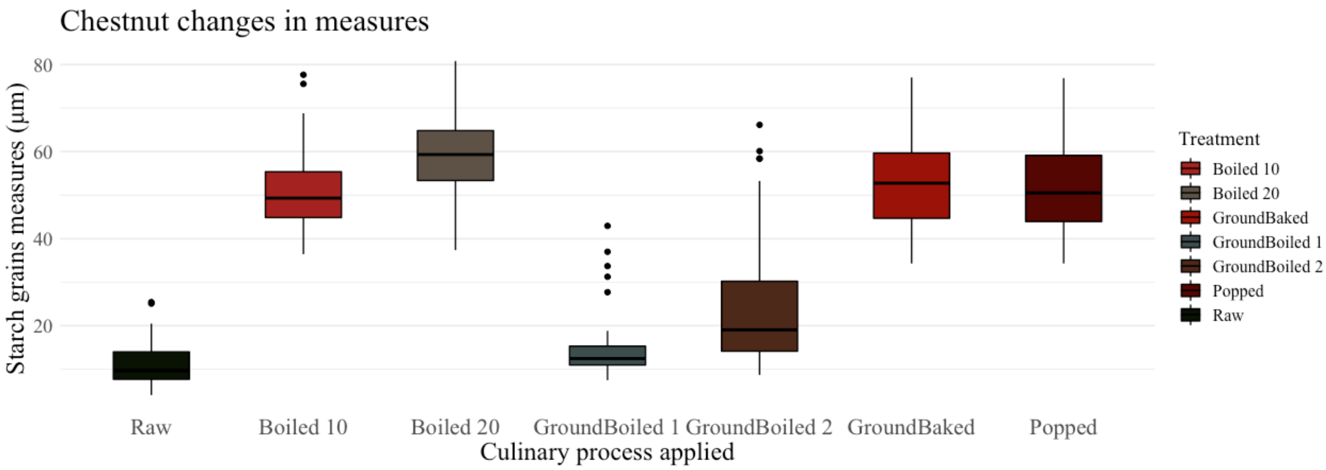


Graphic 3. Histogram showing the distribution of the frequency in the *C. sativa* (Chestnut) measures.

In this regard, two main groups can be distinguished, on the one hand, the 'S' group showing the smaller grains, which ranges from some 4.07-10.27 µm; on the other hand, the 'L' group showing the larger grains, which ranges from some 11.12-25.41 µm.

5.3.2. Do the starch grains change with cooking?

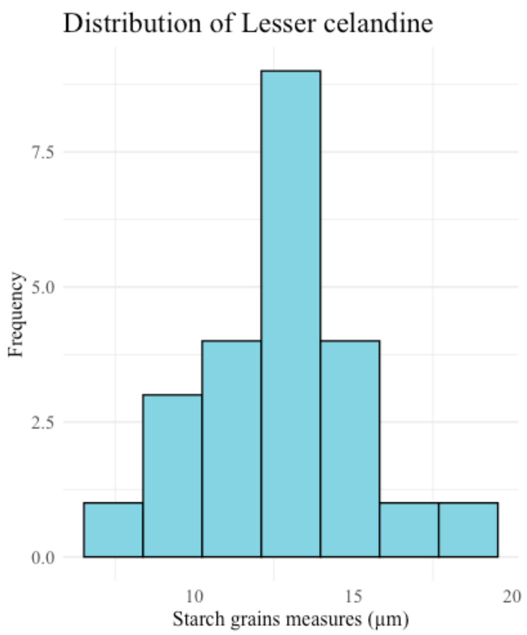
Accordingly with the results commented on the difference in the raw starch grains, the Kruskal-Wallis test showed a clear, significant difference in chestnut's starch grains size after cooking (p-value < 2.2e-16). However, in this case, the boxplot (Graphic 4) does not show any clear, specific variation in the measures after cooking, this is probably due to the high standard deviation values obtained, specifically those obtained for 'boiled 10' (sd = 24.1), 'boiled 20' (sd=21.8), and 'ground and baked' (sd = 16.6).



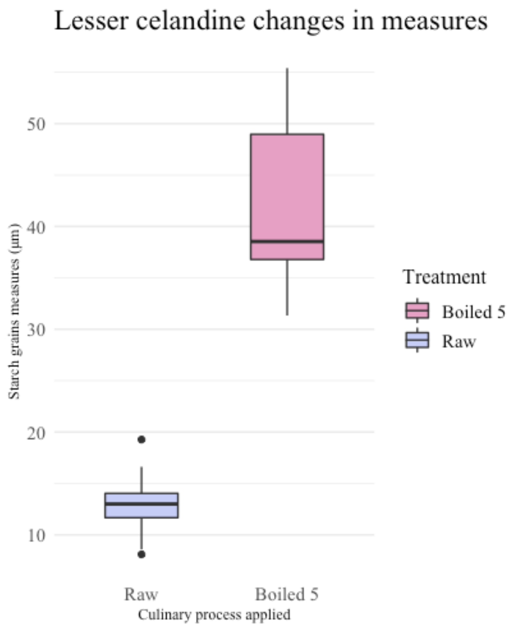
Graphic 4. Boxplot showing the changes in size of the *C. sativa* (Chestnut) starch grains after cooking.

5.4. *Ficaria verna* (Lesser celandine)

5.4.1. Within-species differences



Graphic 5. Histogram showing the distribution of the frequency in the *F. verna* (Lesser Celandine) measures.



Graphic 6. Boxplot showing the changes in size of the *F.verna* (Lesser Celandine) starch grains after cooking.

The Shapiro-Wilk test showed a single, clearly different distribution (p-value = 0.5935). Moreover, when visualizing the data with a histogram (Graphic 5), the result obtained from the Shapiro-Wilk test is clearly confirmed in the distribution ranging between 8.09-19.27 µm.

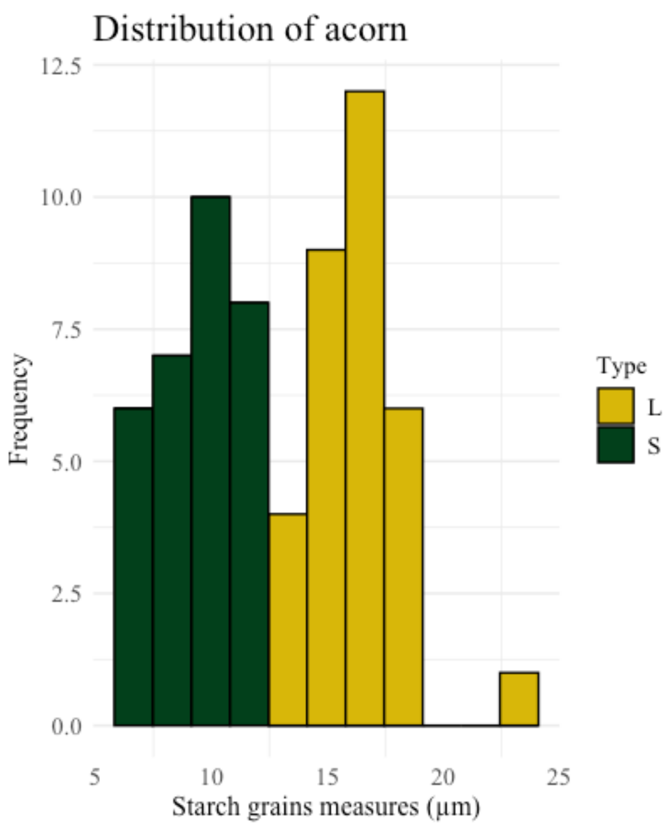
5.4.2. Do the starch grains change with cooking?

As shown by both the Kruskal-Wallis test (p-value = 1.438e-05) and the data visualization in the boxplot (Graphic 6), there is fair proof to suggest that clear, significant differences in the size of lesser celandine starch grains after cooking exist. Moreover, the differences showed by the boxplot reflect the increase in their size when boiling for 5 minutes.

5.5. *Quercus robur* (Acorn)

5.5.1. Within-species differences

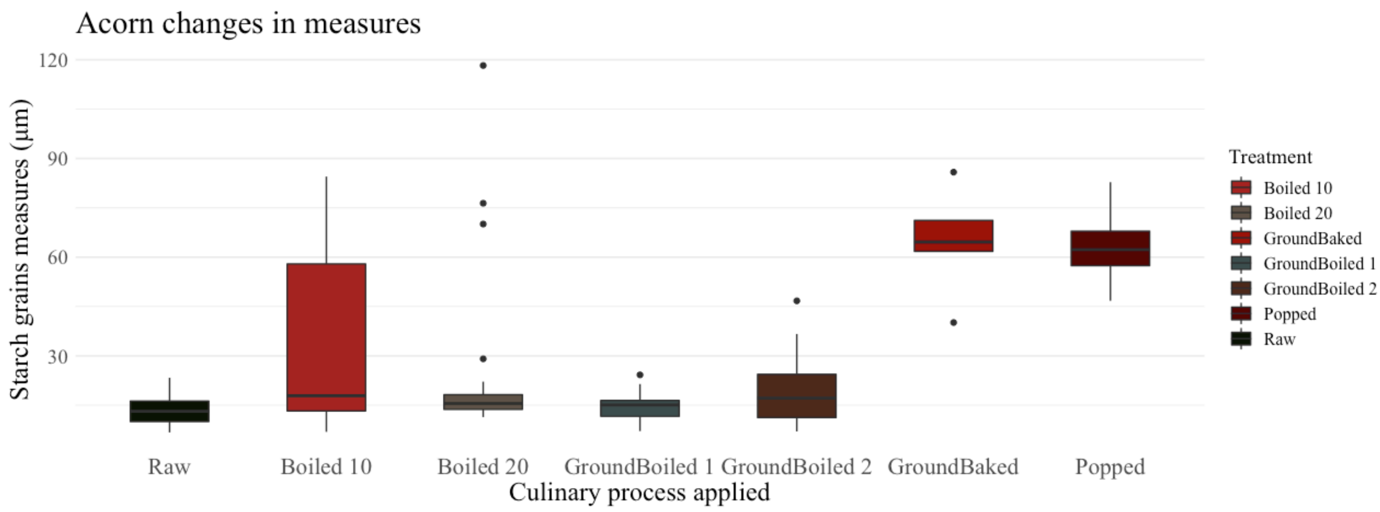
The Shapiro-Wilk test (p-value = 0.02568) showed two different distributions in the sample, as it was evidenced in the qualitative descriptions provided before. Overall, the classification of acorn's starch grain mainly falls into two groups: on the one hand, the 'S' group, showing the smaller grains, which ranges from some 6.71-12.14 µm; on the other hand, the 'L' group showing the larger grains, which ranges from some 13.14-23.33 µm.



Graphic 7. Histogram showing the distribution of the frequency in the Q. robur (Acorn) measures.

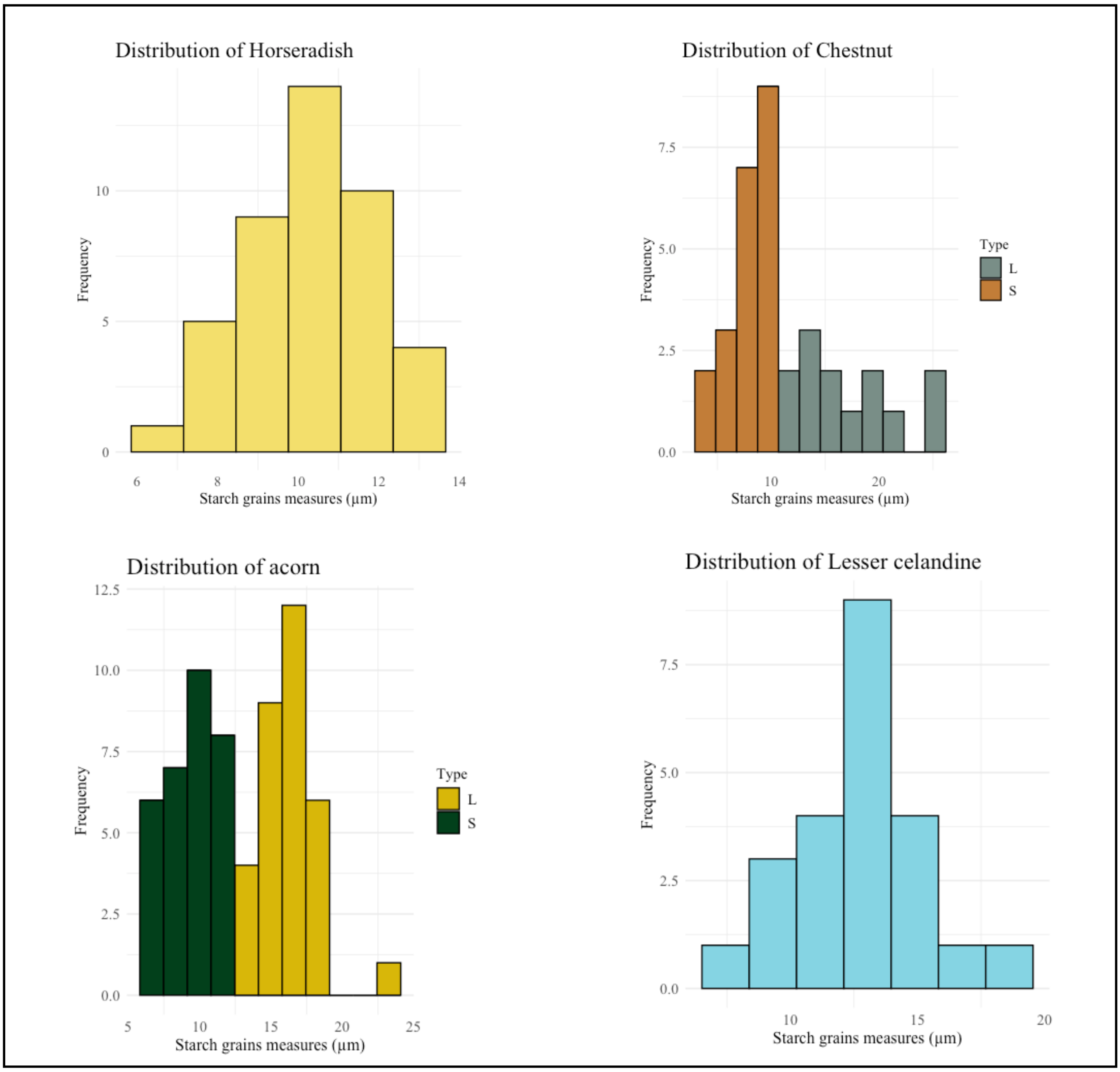
5.5.2. Do the starch grains change with cooking?

Following with the similarities between chestnut and acorn, the same pattern can be observed when applying the Kruskal-Wallis test (p-value = 1.238e-15). Likewise, a significant difference can be observed in acorn's starch grains size after cooking.

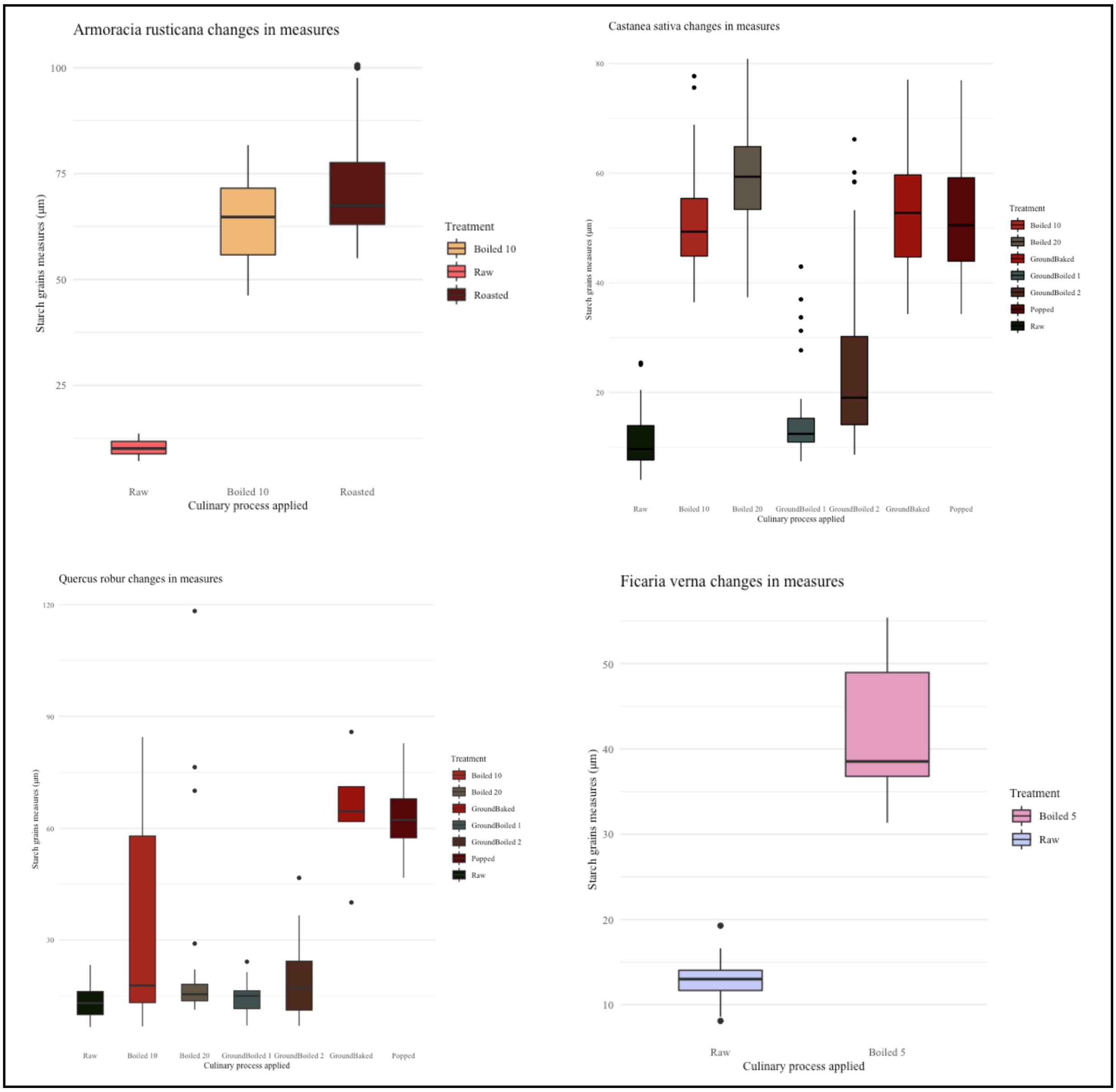


Graphic 8. Boxplot showing the changes in size of the *Q. robur* (Acorn) starch grains after cooking.

Interestingly, three coarse groups can be mentioned by looking at the boxplot (see Graphic 8) : a) the group formed by 'raw'. 'boiled 20', 'ground and boiled 1', and 'ground and boiled 2'; b) the group formed by 'ground and baked', and 'popped'; and finally c) the very wide range of observations in 'boiled 10'.



Graphic 9. Distribution of the sizes before cooking for all the analysed plants summarized together.



Graphic 10. Changes in size after cooking for all the analysed plants summarized together.

6. Discussion

6.1. Introduction

Overall, both the descriptive and statistical analyses have provided a wealth of information towards the understanding of behaviour of the starch grains from wild plants when cooked. While I examined only a few taxa, some interesting outcomes have been obtained that are valuable both for the archaeological research and the improvement of gastronomical experiences. The obtained results are thoroughly discussed in this section.

6.2. Discussion of the results

With regards to the differences between domesticated cereals and wild plants, some remarkable features have been observed. First, wild plant starches seemed to present a higher sensitivity to cooking methods – the damages in their structure were clearly present at earlier durations, some 5 to 30 minutes versus the sometimes 60 minutes observed in the literature (Henry et al., 2009) – than domesticated cereals. Yet, this is a very premature consideration and more research is needed whether to confirm it or not. Nonetheless, until a certain moment of complete obliteration, the grains could be recognized as a starches even if severely damaged. This factor allowed for a good record of the descriptions of the damages observed through the analyses.

Second, perhaps due to the major sensitivity of the wild plants to cooking damage, the identification at a species level remains more difficult than for domesticated cereals. A potential reason for this might be the small reference collections of starchy wild plants and the few archaeological research performed with them to understand their changes or variability from one species to another. Therefore, more research needs also to be done in understanding the way in which specific species change due to the application of diverse culinary processes. Archaeometry applied to the images and deeper qualitative analyses could well shed more light on this aspect.

From an analytical perspective, it can be easily observed that starch grains tend to swell when any cooking method is applied to them. This is an expected result as it is already mentioned in the food science bibliography (BeMiller & Whistler, 2009, pp. 320–323), however, as long as the published results always referred to domesticated starchy plants, the same behaviour in wild plants needed to be evaluated and demonstrated empirically. Moreover, unless the swelling trend seems to be a basic when looking at cooking damage, differences can be detected in the type of the damage in relation with the cooking process applied.

Following the food science sources, two different classifications can be done: cooking with high-moisture environment (i.e. boiling) and cooking with low-moisture environment (i.e. roasting) (BeMiller & Whistler, 2009, pp. 310–359). Following this premise, the overall differences observed in the chapters 5 and 6 suggest that when the whole starchy sources are cooked in a high-moisture environment, they tend to swell just as they do when cooked in a low-moisture environment. Nonetheless, whereas the starches cooked in a high-moisture environment tend to keep a smooth-like texture, the ones that are cooked in a low-moisture environment tend to swell and loose the smoothness of their texture, turning into a more rough, sometimes melted and sheared surface.

Interestingly, when the plants were mechanically processed (i.e. ground) and then either boiled (high-moisture environment) or baked (low-moisture environment), the former granules do not show such a big swelling, perhaps due to the obliteration of the largest granules, which therefore compromised the distribution of the data; whereas the latter showed a more dramatic swelling, similarly to what was observed for the whole plants. Considering this premise, it can consequently be suggested that mechanical processes tend to induce more damage in large starches than in small ones. Therefore, this is a strong key feature to bear in mind when analysing the archaeological use of starchy wild plants. In other words, it can be suggested that whereas small grains presented more sensitivity to certain cooking processes (i.e. boiling), they seemed to be more resistant to the processes that involved mechanic activities, such as grinding (as can be seen in the grinding and boiling, and in the grinding and baking categories).

Moreover, it can be inferred that there is a significant difference in the behaviour among the roots (horseradish and lesser celandine) and the nuts (chestnuts and acorns). Whereas the former are more sensitive to the application of cooking methods and the damage of their starches occurs very rapidly and dramatically, the former tends to behave more similarly to how domestic cereal starches do, allowing for long-duration cooking methods. Hence, this is a key aspect to bear in mind when future studies will apply cooking methods to diverse starchy wild plants.

6.3. Future research and further implications of this work

These results offer the opportunity to positively evaluate cooking processes, techniques and elaborations of wild plants in archaeological cooking contexts, nonetheless, further work needs to be done to achieve the aim of reconstructing past cuisine dynamics. First, it is necessary to perform more experimental archaeology, following the methodology described in this thesis, on other starchy wild plants. Moreover, taking more samples on more species of the same *genus* would also be key for the understanding of the high variability of these plants. This is a very important aspect to consider, because the regional variability of wild plants might have implications on the morphology of the starch grains within them.

Second, further on the understanding of the culinary processes and elaborations from the study of starch grains changes in morphology, it is worth mentioning that the outcomes of these analyses provide with the addition of another piece for the puzzle when approaching past foodways and diets. This analyses, indeed, evidenced the possibility to look at the elaboration being applied to the raw food, and hence allowing to build a context in which humans interact with their environment, their equals, and their tools in order to create elaborated food. The implications of this are, therefore, key in the path of developing a greater understanding on cooking and the gastronomical knowledge developed by early *Homo sp.*

Indeed, there are still many uncovered aspects in terms of ancient foodways and paleodiets from the Archaeology of Food which could be greatly benefited from the analyses of starchy wild plants and which have not been covered in this work. In this regard, one of the most denied features past human diets is the consumption of beverages – other than beer, or mead – such as juices or spiced waters and the processes therein. Certainly, the dimension of drinks in human prehistory has been surprisingly unexplored. Did early humans juice the fruits they would forage in the wild? Would they infuse some of the plants they could find around? Is it possible that carbonic fermentation would have been performed even before humans started to brew beer or mead? Does the morphology of starch grains change if the plant has been juiced? Scholars have paid very little attention to any of these aspects so far, however the implications of this dimension can potentially open up a whole world of new intersections between early humans and the way they exploited their environments in the search for food, which would have a direct impact in the study of their diets. Exploring the liquid dimension of food might, hence, be a powerful stream of information about paleodiets, early foodways and, obviously, ancient culinary techniques. In addition to the poorly understood features of human foodways in the past, there is an essential concept that is, only recently, starting to become an interesting topic for scholars: fermentation. As a matter of fact, storage extends the period of time which the resource is actually available (Stopp, 2002). This relation between storage and a long time-span availability of a given foodstuff was introduced by Binford (1978) as a *gain- time* factor, and since then other authors have developed the implications of storing in delayed-return and immediate-return systems (Woodburn, 1980) and the consideration about whether if the delayed-return of resources could be achieved in a diversity of mobility strategies (Ingold, 1987, pp. 201–210). However, and despite its key implications in the human foraging dynamics and survival strategies (Speth, 2017), very little attention has been paid from archaeology to the actual understanding of how did the ancient societies, in general, but foragers in particular did store their foods, preserving their nutrients availability, over long periods of time (Boethius, 2016; Craig, 2021; Milner, 2009). Whereas some recent research has been published on the meat fermentation, very little has focused on the fermentation of plants (excluding beer brewing), and even lesser research has been performed on wild plants. Nonetheless, fermentation and other kinds of preservation might have been potentially developed even at very early chronologies (Shoda, 2021; Speth, 2017). Did peoples in prehistory make *miso*-like fermentations employing chestnuts or acorns? Did they perhaps apply lactic-acid fermentations (such as the one applied for products like *sauerkraut* or *kimchi*) to the wild plants they had available? Did they pickle starchy parts of their plant food? How does the morphology of the starch grains change when they ferment under different conditions? Managing nutritious food availability through all the seasons of the year might have been one of the most important activities for ancient societies and, therefore, the Archaeology of Food researchers should focus more efforts on better understanding the myriad processes therein.

In relation with the consequential next steps to be taken after the research undertaken for this thesis, and with the aim to merge the two areas of interest of this thesis into a more divulgative final outcome, I plan to combine the results of this work with other archaeological research performed on starch grains, both from domesticated and wild plants. Seeking for patterns in the morphology changes might allow to approach culinary traditions related to specific societies from the past and, potentially develop interactive experiences where Archaeology and Gastronomy will be merged in order to convey those culinary traditions. As it has been mention in the introduction, in the last decade, cuisine has increasingly played a central role in the divulgation of human culture, and Archaeology presents a unique window to approach that topic, therefore the Archaeology of Food remains as a key discipline to bridge them, and, as such, one of the most relevant fields of study in Archaeology to spread the knowledge and results of the multiple research projects that are going on.

7. Conclusions

From a methodological point of view, this work has demonstrated that cooking damage can be analysed in starches from wild plants, just as it has been analysed for domesticated starchy plants. However, some slight appreciation in the differences between domesticated and wild plants have been noted in the way that the damage is actually observed.

Interestingly, the demonstration of the applicability of this methodology for wild plants opens wide, new avenues for researchers. For example, it might allow to pass from the mere lists of wild plants published by archaeologists over the last few decades, to a more interconnected scenario of raw products and elaborations which eventually would end up into final products. Moreover, it also opens the possibility to explore on other interesting, yet still poorly explored cooking processes, such as fermentation or the role of drinks in early human groups.

Besides the direct outcomes of the thesis, it is worth to mention that this work has been developed under a FAIR research purposes. This implies that all the information and outcomes of it will be available as an Open Access work. All the inputs, such as the images of the starches, as well as the code used to analyse the dataset of their measures will be uploaded as well. This will allow further research on the analyses of the changes in the morphology of starch grains from wild plants through cooking to be continued by any scholar who might be interested on this topic, and therefore foster the addition of information about cooking wild plants in the past.

From the perspective of Gastronomy and Food science, the importance of the consideration of cuisine and elaborations when studying the *modus vivendi* of any human group, whether in the past or the present, have been remarked. Besides, the methodology and the interpretation of the results have benefited from the influence of Food Science literature, which has increased the academical value of this work. In a nutshell, this thesis will, in the long term, influence the cultural and historical approaches to food and foodways from Gastronomy and Food science.

Abstract

The Archaeology of Food has allowed us to rethink the origins of food products, the ways they were processed as well as the social implications involved in the processing activities. On this regard, microremains analyses – particularly starch grains analyses – provide of a wealth of information for specific, well understood archaeological contexts. Indeed, it is widely accepted that starch grains analyses can identify the processed plant foods at various taxonomic levels, but it has also been suggested that information about the processing methods applied to them can be obtained by looking at the changes in starch grain morphologies. However, whereas the changes in starch grains of some of the 'founder crops' through cooking processes have been already analysed and published, the transformation of the starch grains in wild plants still remains poorly understood. This thesis, therefore, aims to create a collection of reference which will provide valuable information for further research on ancient societies' foodways.

From another perspective, Gastronomy & Food Science disciplines are now more interested than ever before in conveying cultural aspects such as the origins and development of different cooking techniques in human history. Several projects focusing on understanding how the different human communities before us interacted with their food resources have recently taken off. However, the lack of information for several extended periods of time in prehistory on the one hand, and the inherent difficulties that both gastronomes and food science researchers are experiencing when trying to understand the complexity of the archaeological outcomes on the other, is resulting into coarse interpretations and an overgeneralized explanation of the past. On top of that, in the last 20 years, the gastronomic sphere has widely demonstrated its power for creatively promoting and communicating numerous cultural and scientific concepts to people, hence providing of a brand new scenario for archaeology to spread cultural knowledge in new, sometimes more efficient ways.

In this regard, this thesis focuses on the analyses of the changes of starch grains from a selection of diverse starchy wild plants available during the season that this research is undertaken (autumn-winter) through the application of diverse cooking techniques (boiling, grinding, baking). The determination of the processes will be assessed by the merging of archaeological methods and gastronomic knowledge.

Finally, by combining the knowledge acquired through the study of both of them, this thesis will offer some of the guidelines to be undertaken for the development of this research in the future.

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