Heat of the moment

Experimental paleoethnobotany combining starch grain analysis in order to better understand the results of archaeological starch grain analysis in the Caribbean

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Cover image: Griddle and the starch grains within, photo by Anika Hellemons

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CONTENTS

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1 INTRODUCTION

The interaction with, and the usage of, plants has always been deeply embedded in human history (Atkins and Bowler 2001, 1; Messner 2008, 1-2). As either, or both, the preparation and consumption of plant based foods is part of everyone’s daily life, understanding practices surrounding food preparation and diet can help with the closer understanding of the lives of peoples of the past (Messner 2008, 2). To reconstruct the dietary practices of peoples of the past, different parts of the diet and their proxies, such as animal remains, faunal lipids, botanical lipids, isotopes and botanical macro- and microfossils can be analysed. Additionally, historical and ethnographical accounts may prove useful as a basis for these researches. However, as historical accounts are often incomplete or less clear due to the lack or prior knowledge of native plants and their preparation and consumption, these accounts could better be used as a basis for further research (Berman and Pearsall 2008, 184, 193; Crosby 2003, 65-71; Hellemons 2018, 6 15; Makarewicz and Sealy 2015, 151; VanderVeen 2006, 5).

Starch grains are part of the aforementioned indicators of what plants were processed and are considered the only type of botanical microfossil remains which can be directly correlated with both the usage as well as the preparation of plants by humans from the past (Hellemons 2018, 6; Pagán-Jiménez and Oliver 2008, 144; Pagán-Jiménez 2011a, 326). The preparation of food and beverages by, for example, heating, grinding or fermenting starchy plants can damage the starch grains within. This damage can result in the starches being either unidentifiable to species level, or even completely unidentifiable, making it harder to understand which plants were processed. This is a problem that has been encountered in several researches of archaeological remains in the Neotropics, such as Berman and Pearsall (2008); Ciofalo *et al.* (2018, 2019, 2020); Corteletti *et al.* (2015); Hellemons (2018); Mickleburgh and Pagán-Jiménez (2012); Pagán-Jiménez (2011, 2012), and many more. However, not only preparation techniques can damage starches as it has been shown that after artefact deposition, taphonomic processes such as bacterial deterioration also affect the starchy residues (Hutschenreuther *et al.* 2017, 95, 99, 104-105).

Even though the damage on starch grains due to food preparation makes the identification of used plants harder or even impossible, the characteristic traces of the processing techniques can aid in identifying the preparation techniques used (Babot 2006, 66; Ciofalo *et al.* 2018, 309; Gott *et al.* 2006, 35; Hellemons 2018, 25; Mickleburgh and

Pagán-Jiménez 2012, 2469; Pagán-Jiménez *et al.* 2017, 30). Analysing and describing these damage patterns can provide valuable insight in the human plant-interaction and preparation techniques used in the past. However, in order to correctly interpret the damage done by the preparation techniques, one needs to understand which traces are left by which specific process. To understand this, several studies have been conducted aiming to classifying this damage and linking them to specific processes (see for example Henry *et al*. 2009 for the fermentation, grinding and baking Old World crops; Messner and Schindler 2010 for the effect of slicing, drying and heating arrow arum; Mickleburgh and Pagán-Jiménez 2012 for the effect of grinding on maize starches; Pagán-Jiménez 2013 for the effect of fermentation while making maize beer, or *Chicha*; Pagán-Jiménez *et al*. 2017 for the processing and cooking tortillas made of manioc and two varieties of sweet potato). However, most of these experiments were focusing on one aspect of the processing of plants instead of the effect on starch granules by a combination of processes, which might result in an accumulation of damage patterns. Additionally, more experiments were done informally and were never published. They are thus not easily accessible for all researchers analysing starch grains. It could therefore be useful, as also argued by Beck and Torrence (2006), to conduct experiments in less controlled and more realistic environments, preparing 'traditional' foodstuffs while carefully monitoring the changes in the starch granules per step.

1.1 Research aim

The aim of this thesis is to gain a better understanding of damage patterns occurring on starch grains encountered in the archaeological record of the Neotropics, especially the Greater Antilles. This was done by replicating certain preparation techniques and comparing the damage patterns to previously published archaeological starch grain analysis. These preparation techniques include the grating and squeezing of manioc (*Manihot esculenta*) in order to prepare *Pan de Casabe,* as well as boiling, roasting and grinding maize (*Zea mays*).

This thesis will therefore focus on recreating several foodstuffs based on recipes determined by combining both historical sources and ethnographical works describing plant use and food preparation in the Neotropics. The experimental recreation were conducted on ceramic griddles resembling pre-Colonial ceramics from the Caribbean as described in ethnohistoric and ethnographical sources, as well as recovered from the archaeological record. These griddles are no exact replicas, but were made for cooking flatbread, which makes them suitable for cooking.

Through both the analysis of starch grains damaged through the experimental preparation of foodstuffs and the previously published archaeological starch grain analysis, this thesis aims to answers the main research question:

> *To what extent is it possible to identify the cultural processes involved with ancient food preparation in the circum-Caribbean area through recreating these processes and subjecting the residues to starch grain analysis?*

To aid in answering this question, the following sub questions are posed and treated:

1. What damage patterns can be observed per processing technique, and how can these be correlated to the culinary processes involved in preparing food?
2. What are the different damage patterns observed per used starchy plant?
3. How do these damage patterns compare to the archaeological record, and can we identify different food preparation sequences in archaeological samples?

1.2 METHODOLOGY AND APPROACH

Besides conducting experiments based on ethnohistorical, ethnographical and historical sources, previously published archaeological literature will be consulted to compare the results. For this, three case studies from two sites in the Dominican Republic have been chosen. They were selected based on the type of artefacts that were analysed, being clay griddles, cooking pots and shell scrapers, and as the expected recovered starch grains are of the same species as used in the experiments. Both sites were excavated between 2013 and 2016 by a team from Leiden University as part of the ERC-synergy project "NEXUS1492: New World Encounters in a Globalizing World" (Guzzo Falci *et al.* 2020, 183; Hellemons 2018, 8; Hofman and Hoogland 2015, 5; Hofman *et al.* 2018, 203; Keegan and Hofman 2017, 128; Ting *et al.* 2016, 377).

The results of this thesis will be approached with a critical attitude towards the middle-range theory as applied to archaeological research by Lewis Binford, combined with critical approaches of ethnography, ethnoarchaeology and experimental archaeology. The middle-range theory, as used in archaeology, is focused on our interests to presume behaviour from material remains in the archaeological record. (Binford 1981, 29; Pierce 1989, 1-2; Raab and Goodyear 1984, 255). The theory fits well within this thesis as the generalising principles used within the theory to infer behaviour from material traces, are derived from ethnoarchaeology, modern material studies, and experimental archaeology, approaches that are all central to this research (Binford 1981, 22; Raab and Goodyear 1984, 259; Tschauner 1996, 2). However, major flaws can be found in the approach, such as, in fact, the aforementioned generalising principles. These flaws will be discussed later in this thesis.

1.3 Structure of thesis

The **second chapter** of this thesis will provide a background on the archaeology of foodways, discussing its importance in understanding the daily lives of peoples of the past, and briefly highlighting the different types of archaeological research. This will be followed by an introduction on starch grains, their morphology and characteristics in **chapter 3**. This chapter will also discuss previous research into damage patterns.

Chapter 4 will critically discuss the middle-range theory, ethnography, ethnoarchaeology and experimental archaeology and will discuss how this will be applied to this thesis. **The fifth chapter** goes into the materials and methods of this thesis, explaining the experiments and archaeological comparative collection. In **chapter 6** the results will be presented, which will be discussed and concluded in **chapter 7**.

2 ARCHAEOLOGICAL BACKGROUND: FOODWAYS AND EXCAVATIONS

To gain a better understanding of how this research is situated between other archaeological work on both foodways and pre-colonial and Caribbean research, one must first gain a little more insight into what foodways are and what previous research has been conducted. Therefore, this chapter will serve as a background on these two topics. Firstly, this chapter will focus on the archaeology of foodways and the aspects of the lives of peoples of the past it can shed light on. Following this, the previously done archaeological research on two sites in the Dominican Republic will be discussed.

2.1 THE ARCHAEOLOGY OF FOOD

The saying “you are what you eat” has a certain truth in it. Of course, one will not turn into a chicken when consuming one, but the availability of certain food is dependent on our social and cultural status and thus on who we are. As humans and omnivores, we have a range of potential foods to choose from. Through our ability to grow our own crops, cooking and processing certain foods that might otherwise not have been safe for consumption and by combining certain foodstuffs, we expand our options even more. This gives us many choices. (Atkins and Bowler 2001, 1; Twiss 2019, 1; Peres 2017, 421).

However, even though we have all these options and eating is a necessity, we do not choose to eat all the foodstuffs that are available to us. We are restricted by the environments we live in, which will not allow every crop to grow or every animal to survive, but also by our economies, politics, belief systems, and personal preferences (Twiss 2015, 190; Peres 2017, 421; Twiss 2019, 1). This means that understanding foodways of the past, can shed light on both the social and biological lives of peoples of the past (Beaudry 2016, xxix; Ciofalo *et al.* 2019, 1633; Twiss 2019, 1). Because of this, ancient subsistence practices and strategies have already been a topic of research for archaeologists, and anthropologists, for a long time (Twiss 2019, 10-11; VanDerVeen 2016, 1). These studies are consequentially not merely focussed on which plants were gathered in what way, and which animals were prepared, but also on broader and more complicated aspects of culture and the daily lives of people (Ciofalo *et al.* 2019, 1633; VanDerVeen 2016, 1). But what is food, and why is so significant to us?

2.1.1 Food and foodways, a short definition

When considering foodways, a multitude of different ideas might come to mind. The term *foodways* is not a synonym for *food, diet, subsistence* or *subsistence strategies*. It does however, encompass all of these terms. First, let us look at *food*. The Oxford Learners Dictionary defines food as “things that people or animals eat” (www.oxfordlearnersdictionaries.com). Peres (2017) elaborates a bit more and argues that “food in its most basic form is simply plants or animals that are biologically sustaining for humans” (Peres 2017, 422). Both of these definitions are true, but are lacking the social and cultural meaning food has to people, be it individuals or groups of people (Peres 2017, 422). This deeper, layered, meaning will be discussed later.

When combining all the food that either an individual or group eats on a regular basis, one is looking at the *diet* of this group or individual. This diet does not differentiate between daily meals and special meals, often the same types of foods are eaten but prepared in a different way and in different quantities, consumed in different contexts (Peres 2017, 423). The way people get their food, either through hunting, gathering, agriculture, or shopping in the mall, is what makes their *subsistence* or *subsistence strategy*. It is the dominant way in which an individual or group obtains their food (Peres 2017, 423).

As stated before, these terms together, make what we consider foodways. Foodways can be considered as not only the food itself, but also all the activities, economy, norms, contexts, and meanings that surround it. This includes the acquisition, preparation, consumption and disposition of the food and its remains (Bescherer Metheny 2015, 221; Ciofalo *et al.* 2019, 1633; Peres 2017, 423). Foodways are thus not simply part of the basic necessities, but also part of the social and cultural interactions of humans, they “represent the intersection of food and culture” (Bescherer Metheny 2015, 221; Camp 2015, 326).

2.1.2 Food, culture and social lives

When thinking of one’s favourite food, memories of eating it will surface. Often these memories are precious and shared with others. It might be a memory of preparing the food with one’s mother, who is teaching the recipe, a memory of the awful amount of dishes that need to be done after the meal has been eaten, or just a memory of being together. All these actions and memories are associated with meal times, whether it is preparing long before the meal or doing the dishes after, meals bring with them social and cultural experiences (Hastorf 2016, 1, 3; Twiss 2019, 3). The actions leading food preparation can even be considered the *chaîne opératoire* of food (Hastorf 2016, 83). These experiences stay with us, even though the meal itself might have been insignificant, maybe even creating traditions. On the other hand there are meals that are very significant and break with the normal ways of preparing food, such as a Christmas dinner with the family, throwing a party for work, or even going out for dinner with just your significant other (Twiss 2019, 3-4; Peres 2017, 432). These 'feasts', as one might call them, often involve food deemed special such as Christmas pudding, an elaborately prepared steak, or even small party snacks. These feasts are elaborate and do not happen very often, they are different from our daily eating habits. Still, in archaeology, these feasts tended to get more attention than the daily cuisine of peoples of the past (Twiss 2019, 4; Peres 2017, 443).

As stated, understanding foodways of the past can aid in understanding the social lives of the past. This is why it is important to understand the daily foodways, alongside the feasts. It can be argued, for example, that researching daily meals can help with understanding domestic labour (Twiss 2019, 10). As aforementioned, there are many activities surrounding meals that can take up most of one's daily labours. On the other hand, understanding the foodways and specific diets of peoples of the past can help with gaining a better understanding of the culture. Humans are omnivores, yet we choose not to eat everything at our disposal. Of course, the environments we live in (used to) heavily influence what we eat, but our cultural and social lives, as well as our preferences, influence our choices too (Atkins and Bowler 2001, 1; Hastorf 2016, 6-7; Twiss 2015, 190; Twiss 2019, 1, 5). We tend to choose what our culture 'dictates', maybe because we are used to it, or maybe to show our identity or to show ourselves in the best light possible. Nevertheless, a distinction in taste and choices between different social groups and classes do occur and can be considered a part of either personal or group identity (Atkins and Bowler 2001, 1; Ciofalo *et al.* 2019, 1633; Twiss 2015, 190). This again illustrates the strong connections between food, identity and one's social life.

2.2 ARCHAEOLOGICAL RESEARCH INTO FOODWAYS

If foodways are intertwined with the social lives and experiences of peoples of the past, how does one study this? It is of course true that many aspects of meals of the past are not visible anymore. The activities surrounding meals such as gathering the ingredients, stirring the soup, or sharing a meal, are gone. These important social experiences that are part of foodways are impossible to study (Hastorf 2016, 7). Even through experimental research, experiences cannot be replicated, but the actions might become more visible. However, even when the actions are gone, foodways leave traces. The remains of the crops and animals that were consumed are sometimes still present in the archaeological record. The materials used to prepare them can be excavated and analysed for phytoliths, starches or other microremains, as can human remains bearing dental plaque full of starches and stable isotopes (Hastorf 2016, 4, 7, 83-84; Twiss 2019, 1, 16). Next to this, oral histories and ethnographies can help strengthen our interpretations and broaden our horizons on different cooking processes we might not have considered (Twiss 2019, 19). These are only some of the possible ways to research foodways.

In doing these researches, it is important to keep an eye out on the integrity of the data. The sample and its context are really important in both understanding foodways, and ensuring that one is researching the right thing. A feasible link between the activities one wants to research and the data should be present. Twiss (2016) provides an example for this:

> Imagine, for example, an article based on food remains found "in an oven." Were those remains on the floor of the oven, and so plausibly left there at the time the oven went out of service? Or were they floating high up in the soil that filled the oven, and probably just part of the room fill that happened to end up there? The two possibilities have profoundly different interpretive implications (Twiss 2019, 16).

This illustrates the necessity to be careful with, and clear about, the context and interpretations of one's data. Next to this, as there are many ways of researching food, our interpretations are at the strongest when we compare our data (Hastorf 2016, 83-84; Twiss 2019, 19). There are thus many ways to research foodways, all of which are important and should be used together. This thesis specifically focusses on starch grains and their way of telling us how they were prepared, but this is only one aspect of the possible researches that can be done to strengthen our analogies.

However, this plethora of possible data should be handled with care so one does not make the wrong interpretations. As argued before, we are omnivores yet we do not choose to eat everything we can. This means that researchers in the present cannot presume that what they consider food now, was considered food in the past as well, and vice versa. It cannot be assumed that people in the past considered all non-toxic, digestible, and nutritional sources as edible, or that they never considered toxic, non-digestible, food lacking nutrition as food (Twiss 2019, 6-7). Next to this, we are basing our interpretations on either modern accounts, or on indirect evidence such as ethnographic, ethnohistoric, and ethnoarchaeological sources, as well as experimental data to interpret why the remains are as they are (Binford 1981, 22; Raab and Goodyear 1984, 259; Twiss 2019, 19). Interpretations are needed, as otherwise we would just have 'evidence', but no meaning attached to it (a debate on this can be read in chapter 4.0: Methodology).

2.2.1 Ethnohistorical and ethnographical accounts on foodways

As mentioned previously, one way to study the foodways of the past is by consulting written sources on the matter, including ethnographical and ethnohistorical accounts, or 'chronicles' as the European written accounts on the New World are often called. However, these accounts should only serve as a basis, as the historical accounts are often incomplete or imprecise due to a lacks of understanding of native plants and their preparation and consumption. Other issues with these accounts can be the bias of the observer, or changes due to the colonisation of the islands (Berman and Pearsall 2000, 221; Berman and Pearsall 2008, 184, 193; Crosby 2003, 65-71; Hellemons 2018, 6 15; Makarewicz and Sealy 2015, 151; VanderVeen 2006, 5).

Nevertheless, written accounts can still serve as a basis for our understanding of the past and can illuminate the archaeological record. It is therefore still valuable to give an overview of some of the works that are available. Since the arrival of the Europeans to the Americas, descriptions of the 'newfound' land and the way of life of the Indigenous peoples have been abundant: there are around 200 chroniclers which are recognised by modern scholars today. However, only some of these chroniclers wrote about the Caribbean islands, of which an even smaller group was actually present in the Americas. This understandably narrows done the amount of written sources (Churampi Ramírez 2011, 282). However, giving a full record of the available sources is beyond the scope of this thesis, therefore a selection which is used to determine the experiments will be discussed here.

An excerpt of Columbus' diary, copied and summarised by Bartolomé de Las Casas and translated by Clements R. Markham in 1893, is one of the best examples of the somewhat vague descriptions chroniclers could give about the local plant life:

> "They raise on these lands crops of yams, which are small branches, at the foot of which grow roots like carrots, which serve as bread. They powder and knead them, and make them into bread ; then they plant the same branch in another part, which again sends out four or five of the same roots, which are very nutritious, with the taste of chestnuts" (Columbus [1492-3], 99-100).

Here one can see that a description is given, but as there was no knowledge on which plant this was, this is not mentioned. Another mention of native crops can be found in a later passage:

> "They ran hither and thither to bring us bread made of yams, which they call *ajes*, which is very white and good [...]" (Columbus [1492-3], 123)

This time, a name is given to the food. These *ajes* are some sort of yam, and also referred to by de Oviedo in his 'Natural History of the West Indies' (de Oviedo [1526], 98). De Oviedo also explains how maize is eaten both roasted, particularly on the islands, as well as made into bread and either baked or boiled. He also gives an overview on how both maize and manioc are grown, and how *Pan de Casabe* is made. This is also explained by de Acosta [1604] and Schomburgk (1847). Columbus also mentions bread that they call *cazavi* (Columbus [1492-3], 136). That maize was often roasted is supported by Chroniclers as De Acosta [1604], as well as ethnographers and ethnoarchaeologists such as Boomert (2000), Goeje (1906) and Lopez de Gomara [1596]. Flour and bread made from manioc and maize is still being reported in ethnographic work done in Amazonia, such as Howard (2001) and Politis and Alberti (2007).

Besides maize and manioc, reports on aloe, cotton, sweet potatoes, yams, avocado, a variety of fruit trees, pineapples and other now well known plants can be found in several chronicles, including Columbus [1492-3], de Acosta [1604], and de Oviedo [1526]. However, mentions of plants that were imported by the Europeans can also be found in these works, such as mentions of sugar by de Acosta [1604] and Schomburgk (1847). These descriptions show the importance of involving ethnohistorical and ethnographical works, even though some might be vague or including plants that were imported later.

2.2.2 Macrobotanical remains

Starting in the early, the research of botanical macroremains has aided in a better understanding of plant use in the Neotropics. Especially on the topic of arboriculture, it has proven itself more than useful (Ciofalo 2021, 5; Berman and Pearsall 2000, 232-233; Newsom 1993, 30; Newsom and Wing 2004, 120-121). In Caribbean archaeological research, Veloz Maggiolo and Vega (1982) contributed to reports on macroremains by their research on a domestic cave in the Dominican Republic, where Zamia *(Zamia* sp.) and *Clusea rosea* were recorded (Berman and Pearsall 2000, 233; Ciofalo 2021, 5; Newsom 1993, 33). According to Ciofalo (2021), even though their finds have been isolated and the interpretations and validity of the remains have been called dubious, it was a first step in understanding plant use through macroremains. Pollen analysis confirmed Zamia pollen in multiple other sites in the Dominican Republic however (Ciofalo 2021, 5). Next to this, Veloz Maggiolo and Ortega (1976) reported carbonised hard seed coats, possibly from palm seeds, recovered from at least three separate sites in the Dominican Republic.

It is argued that Pearsall's analysis (1983; 1985) on macroremains started full-fledged systematic paleoethnobotanical research in the Caribbean. With her work on the Krum Bay site, on the south shore of Sint Thomas, she demonstrated that the use of flotation greatly enhanced seed and wood recovery. This allowed her to better interpret the findings, concluding that the use of plant resources was not only limited to the coastal zone where the site is located, but that plants from the interior of the island were gathered as well (Pearsall 1989, 291, 348-357). Pearsall additionally researched El Bronce, Puerto Rico (1985), and the Three Dog Site, San Salvador (1989). The latter two only yielded a few seed remains (Newsom 1993, 33). Newsom additionally worked on two sites in Puerto Rico (1988, and 1992). Additionally, Van der Klift (1985) recovered cockspur seeds (*Celtis* sp.) from midden samples taken in Golden Rock, Sint Eustasius, while Cutler (1990) identified avocado (*Persea American*) and yellow sapote (*Pouteria campechina*) in samples from material excavated in 1948 from the Maria de la Cruz cave in Puerto Rico.

Not only seeds and wood samples can tell us more about plant use, but also impressions left on pot sherds, such as the leaf impressions on sherds from Pearls, Grenada (Newsom 1993, 33-34). Research of macrobotanical remains continues in the 21st century, with publications from Berman and Pearsall (2020), among others, on archaeological findings and Hofman *et al.* (2021) on paleoenvironmental data. Next to this, research into the preservation of macrobotanical remains by for example Braadbaart *et al.* (2009), Tryon (2006), and Wright (2003; 2008) were done, and reconstructions paleo-environments were made (Castilla-Beltrán *et al.* 2018, 66-80; VanDerwarker *et al.* 2016, 127-132).

2.2.3 Microbotanical remains

As previously stated, pollen analysis was already used in 1978 showing the presence of Zamia (*Zamia* sp.) and tobacco (*Nicotiana* sp.), as well as maize (*Zea mays*) at the Sanate site in the east part of the Dominican Republic. Pollen of Zamia were also encountered at Rio Jobá, in northern Dominican Republic. The latter was an interesting find as Zamia is currently not known in the northern part of the Dominican Republic, showing that relaying on modern environmental records is not always possible (Ciofalo 2021, 5). Next to this, pollen recovered from the sediments from two sites in the Dominican Republic, El Curro and Puerto Alexander, gave early evidence of maize. The samples were dated around 1550 B.C. (Ciofalo 2021, 6). Both pollen and phytoliths can be used to reconstruct paleoenvironments, besides macrofossils and charcoal, which makes them a very interesting proxy to research (Castilla-Beltrán *et al.* 2018, 66-80; Ciofalo 2021, 6; Pagán-Jiménez *et al.* 2020, 1-13; Siegel *et al.* 2015).

Not only pollen and phytoliths are useful markers for plant use in the Caribbean. Starch grains, especially on tools associated with plant processing, can shed light on which plants were processed. An example is a study by Perry (2004) on tools traditionally associated with manioc (*Manihot esculenta*) processing from the Los Mangos del Parguaza site in Venezuela, including ground stone tools and flakes microlith artifacts. No manioc starch grains were recovered, but instead some of these tools had starch grains from arrowroot (*Maranta* sp.) and ginger (Zingiberaceae) present on them. Next to this, every sample yielded starch grains from maize. This shows that one should not be inferring plant use from artifact type alone, but instead also include microbotanical research (Ciofalo 2021, 6).

Not only can starch grains give us information on maize or manioc, but also crops such as sweet potato (*Ipomea batatas*), achira (*Canna indica*), chili pepper (*Capsicum* sp.), yams (Dioscoreaceae) and beans (Fabaceae) have been recovered from pre-Saladoid contexts. These analysis were done on dental calculus (Chinique de Armas *et al.* 2015, 121-130), but also on lithic, shell and ceramic tools (Pagán-Jiménez 2009, 9-12; Pagán-Jiménez 2011b, 96-99; Pagán-Jiménez *et al.* 2015, 231-244 amongst others). Starch grain research into later periods showed a continuation of these plants, and additionally revealed leren (*Calathea allouia*), palms (Arecaceae), arrowroot (Marantaceae), and cocoyam (*Xanthosoma sagittifolium*) (Hofman *et al.* 2021, 14-17; Pagán-Jiménez 2009, 12-14). Palms, arrowroot and yams have also been recorded across all periods investigated by Dr. Pagán-Jiménez (Pagán-Jiménez 2007, 123-157; Pagán-Jiménez 2009, 12-14; Pagán-

Jiménez 2011b, Pagán-Jiménez 2015b, 396-400; 96-99; Pagán-Jiménez and Oliver 2008, 145-152; Pagán-Jiménez et al. 2015, 231-244).

Starch grains recovered from dental calculus from pre-Saladoid and Ceramic age contexts showed a predominance of maize remains. This was interpreted as evidence for consistent and unconditional use of maize, next to a diversity of other root crops, by Indigenous Peoples of the Caribbean (Ciofalo 2021, 6-7; Mickleburgh and Pagán-Jiménez 2012, 2472, 2476). Additionally, a study on dental calculus from White Marl, Jamaica, yielded a tentative identified cacao (*Theobroma* cacao) starch grain, representing the first finding of precolonial cacao on the Caribbean islands (Mickleburgh *et al.* 2018, 1-6). Late pre-Colonial contexts show a continuation in use of maize, sweet potato, beans, yams, manioc, ginger, chilli pepper, and zamia (Ciofalo *et al.* 2019, 1631-1655; Ciofalo *et al.* 2020, 362-376; Hellemons 2018, 38-57; Rodríguez Suárez and Pagán-Jiménez 2008, 161-164).

2.3 SUMMARY

To summarise why foodways are important to include in archaeological research: it sheds light on the daily lives of the people of the past. Our social lives are intermingled with food, and it is an important part of our day. We gather food, prepare it in different ways, eat it by ourself or with others, and then discard it and clean up our dishes. Although the actions we take to eventually consume the food are gone, their traces remains. Traces archaeologists can study and interpret.

There are many different ways of studying food and foodways, including archaeobotanical research into seeds, but also research into the usage of ceramics and other tools, phytoliths and pollen, or starch grains trapped in dental plaque, and these all have a history in the archaeology of the Caribbean. When comparing the several types of researches, interpretations of the data can lead to interesting finds about food and foodways. They can for example shed light on foods that we now do not consider foods anymore, or the abundant use of crops that were considered limited. This, however, may proof tricky, as we are never sure what peoples of the past deemed to be 'food'.

As with all archaeological research, there are many things to keep in mind when researching ancient foodways. We want to understand a part of the past that we might never fully grasp. However, we can keep researching this vital part of everyone's lives to gain a better understanding.

3 STARCH GRAINS: WHAT ARE THEY AND WHY ARE THEY IMPORTANT?

To understand the worth of this research, one must understand what starch grains are, what their function in the plant is, and what their value in archaeological research is. To put it frankly: starch grains can provide insight in the plant usage of peoples of the past. They can do this, because they are one of the multiple microscopic residues of tubers, roots and seeds of edible plants which can be recovered from different (archaeological) tools. Next to this, the morphology, size, chemical composition, and the basic structure of starch grains are characteristic per species. This means that one could identify them at various taxonomic levels, which can give information on which plants were processed with what tools (Gott *et al.* 2006, 35, 40; Hellemons 2018, 19; Kooyman 2015, 525; Messner 2008, 111; Pagán-Jiménez 2011a, 325). Next to this, modified starches changed by dietary practices such as cooking or grinding can shed light on how the crops were processed with these tools (Hellemons 2018, 24; Pagán-Jiménez 2011a, 325; Pagán-Jiménez and Oliver 2008, 144). This chapter will discuss starch grains in general, diving into the main characteristics, their function within the plant, and previously done research on starch grain damage patterns.

3.1 THE PRODUCTION OF STARCH

The production of starch can be traced back to the process of photosynthesis. During this process, a conversion of the energy of sunlight to a solid form of potential energy takes place in the chloroplasts of the plant. These chloroplast are the green plastids which are to thank for the colour of plants. During photosynthesis, the energy of light starts a sequence of reactions during which water (H_2O) is split into hydrogen (H) and oxygen (O). The hydrogen that came free, fuses with absorbed carbon dioxide dioxide (CO_2). This fusion forms glucose ($C_6H_{12}O_6$) (Gott *et al.* 2006, 35). This glucose, more commonly known as sugar, provides the basic building block for all material the plant requires to live, including protein and fat, and complex carbohydrates such as cellulose and starch. A part of these building blocks are then transported to more specialised organs in the plant, where they are converted in amyloplasts to reserve or storage starch. These storage starches are, as the name suggests, meant for long-time storage (Gott *et al.* 2006, 35; Hellemons 2018, 19; Messner 2008, 111; Shannon *et al.* 2009, 26). When the plant is in need of energy, these starches are converted back into glucose and transported tot he parts of the plants where the energy is required (Gott *et al.* 2006, 35; Messner 2008, 111; Pagán-Jiménez 2011a, 325; Shannon *et al.* 2009, 24, 26).

During the formation of a starch, layers are laid down around the hilum, which is the fixed starting point of a starch grain (see figure 3-1). When growing conditions are normal, one layer is added to the starch grain each day. However, on a day when the rate of photosynthesis is high, small starch grains of indeterminable shape and of around 1 micron in diameter will be formed in the chloroplasts. During the night, these starches – which are called either transitory, temporary or transient starches – are reconverted into glucose and transported to other parts of the plants where they either are used for their energy or converted into storage starches in the amyloplasts (Gott *et al.* 2006, 35; Kooyman 2015, 525; Messner 2008, 111; Shannon *et al.* 2009, 26).

These transitory starches do not have shapes that are species specific, and it has been argued that their shape are simply determined by the space available in the location where they are formed. Due to this, they are unlikely to be assigned to certain plant taxa, while storage starches on the other hand can be identifiable to certain taxonomic levels. Additionally, the biochemical make-up of transitory starches differs from the make-up of storage starches (Gott *et al.* 2006, 35-36; Kooyman 2015, 525; Messner 2008, 111; Shannon *et al.* 2009, 26, 33). This, however, is beyond the scope of this thesis which focusses on identification through studying the morphological characteristics of the starch grains, which will be discussed next.

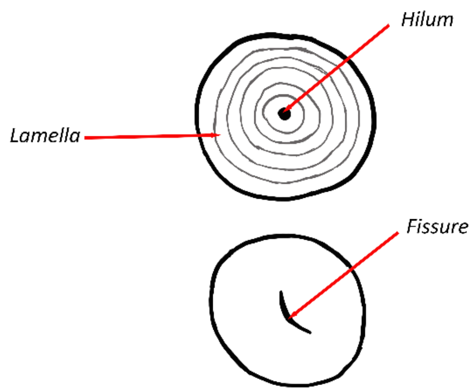

Figure 3-1
Drawing of two starch grains, one showing the hilum and lamellae, or growth rings. The other shows a linear fissure coming from the hilum.
Drawing by: Anika Hellemons

3.2 The morphology of a starch grain

Even though the overall structure of starch grains will exhibit similarities between species and make them recognisable as starches, it is the variations that can make a starch grain diagnostic (Gott *et al.* 2006, 40; Kooyman 2015, 525; Messner 2008, 111). The combination of size, shape and other characteristics of starch grains are often species specific, and will help with identifying the taxon. However, one must keep in mind that starch morphology can also differ, albeit slightly, in cultivars of the species, or the environment the species grows in. The occurrence of mutation in a species can also result in interspecies variation (Gott *et al.* 2006, 40; Pagán-Jiménez 2011a, 325; Shannon *et al.* 2009, 24). The general morphological characteristics of starch grains will be discussed next.

3.2.1 Grain types

During the production of the starch grains in the amyloplasts, either one or more starches can be produced at the same time. This can result in starch grains being either loose and 'on their own, known as simple starches, or they can stick together, which are called compound starches. Simple starches are thus formed in the amyloplasts one at a time and consist of only one component, whereas compound grains are formed simultaneously with two or more other starch grains. These starches are called subgranules and stick together to form a compound starch. It is noteworthy that each of the subgranules still have both a hilum and exhibit a Maltese cross of their own (see Additional diagnostic characteristics). Next to this, it might occur that compound starches will break up into their separate subgranules when milled or ground. This is important to keep in mind when identifying starches that have been processed (Gott *et al.* 2006, 41; Shannon *et al.* 2009, 33).

Some starchy plants will produce compound starch grains, which are later encompassed by a surrounding layer of amorphous starch, which fuse together the subgranules. These semi-compound starches consist of multiple subgranules with their own hila, but have only one surface (Gott *et al.* 2006, 41; Shannon *et al.* 2009, 33).

3.2.2 The shape and size of starch grains

Within the shapes of starches there is a wide variety, which aid in their identification. As abovementioned, the storage location and circumstances of creation of the starches influences both the shape and size. An example are the previously mentioned transitory starches, which often are small and without species specific shapes. Another example can be found in sweet potato (*Ipomea batatas* L.), in which variation in size can be found between the inner tissue, where the starches are generally larger, and the outer tissued adjoining the peel and the peel itself. Additionally, the age of the starch can influence its size, as younger starch grains will be smaller than older ones (Gott *et al.* 2006, 41). In general the size of starch grains varies between 1 micron to 100 microns, with exceptions going up to 175 microns. However, grain sizes are commonly at the lower end of this range. Besides the age of the starch grains, the age of the plant organ influences the size. A young and actively growing or expanding plant organ will contain more young grains than a mature storage organ. The size of the starch grains thus increases with the age of the plant. However, this does not mean that the sizes are ever expanding, as at a certain age this stabilizes. Besides location and age, the nutritional status of the plant also influences the size of the starch grains. A stressed plant produces less carbohydrate and consequently produces fewer, and smaller, starches. An example of this is a plant living under drought conditions, which exhibited less starches, as well as smaller starches, than a plant of the same species living in a more favourable environment (Gott *et al.* 2006, 41-42).

As stated previously, the shapes of starch grains differ between, as well as within, species. Typical shapes include spherical, truncated, oval, elongated, bean-shaped, droplet-shaped, and various polyhedral shapes, as well as irregular forms (Gott *et al.* 2006, 41; Hellemons 2018, 22, 83; Shannon *et al.* 2009, 33). Additionally, some species exhibit two or more distinct grain shapes. Examples of this are cereals in the tribe Triticeae – including wheat (*Triticum* sp.), rye (*Secale cereal*), and barley (*Hordeum vulgare*) – which exhibit lenticular or disc-shaped grains, as well as spherical grains. These two shapes also differ in size, with the lenticular ones being larger than the spherical ones (Gott *et al.* 2006, 41; Shannon *et al.* 2009, 33). Figure 3-2 shows an overview of the shapes encountered in this thesis, as well as some other characteristics of starch grains.

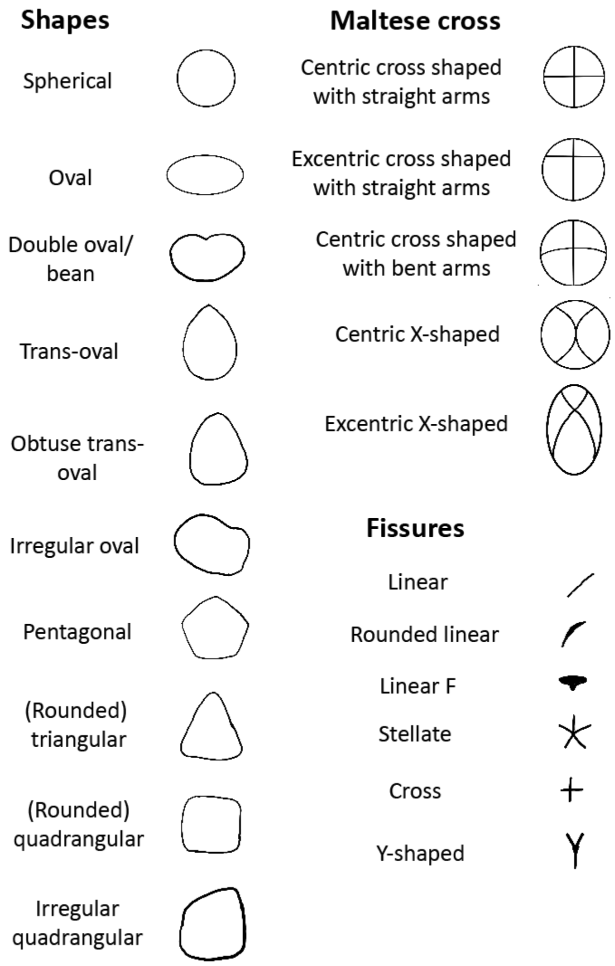

Figure 3-2
Overview of the different shapes encountered in this thesis. Next to this, the different possible Maltese crosses, and a selection of fissures are displayed.
This is merely a selection, for a more complete overview, see Pagán-Jiménez 2007.
Drawing by: Anika Hellemons

3.2.3 Additional diagnostic characteristics

Next to size, shape and grain type, starch grains display different characteristics which can aid in the identification of a species. The first characteristic was already briefly mentioned, namely the *hilum*. This is the centre point from which the starch grain grows, as new layers are formed around it. The hilum can either be in the middle of the grain, and thus centric, or it can be eccentric, meaning that it is located on the outer parts of the grain. In certain species, *fissures* in different forms may stem from the hilum (see figure 3-2). Additionally, the aforementioned growth layers, the *lamellae*, are also one of the diagnostic characters in a starch grain. Not all species distinctly show these layers, and they are also more commonly visible in larger grains. Other characteristics visible on the exterior of the starch grains are striations, ridges, and pores (Gott *et al.* 2006, 40; Hellemons 2018, 23; Messner 2011, 47). In addition, starch grains can exhibit different borders, as well as *pressure facets.* As the name suggests, pressure facets are points on the grains where pressure has been exerted. This resulted in indentations at the edges of the starch grain (Hellemons 2018, 23; Messner 2011, 48).

Another important characteristic of starch grains stems from its birefringent properties, namely the *Maltese cross* (also called an *extinction cross*). When viewing the starch grains under cross-polarised light, this cross becomes visible due to the semicrystalline arrangement of starch molecules, which allows the polarised light to travel at different speeds through the grains (Gott *et al.* 2006, 43). This results in the cross being bright white, against a black background (Gott *et al.* 2006, 43; Hellemons 2018, 23; Yang and Perry 2013, 3172). The cross originates from the hilum and can therefore be eccentric or centric. Next to this, the Maltese cross can either be shaped like a cross, or be more of an X-shape. The arms of the cross can be bent or straight. The combination of these characteristics in the Maltese cross make it diagnostic for certain species (Hellemons 2018, 23; Messner 2011, 48; Yang and Perry 2013, 3172).

3.3 CHARACTERISTICS OF *MANIHOT ESCULENTA* CRANTZ AND *ZEA MAYS* L. STARCH GRAINS

As aforementioned, *Manihot esculenta* Crantz. And *Zea mays* L. have been selected for the use in the main experimental research in this thesis, aiming to create a set of visible damage patterns per processing technique. In order to understand what damage is visible on the starch grains as a result from the experimental cooking, one needs to understand their undamaged forms. This section will discuss several of the characteristics of *Manihot esculenta*, or manioc, and *Zea mays*, or maize based on previous descriptions and samples taken by the author before processing the plants.

3.3.1 Manihot esculenta Crantz

The most common shapes of manioc have been described as being hemispherical, or bell-shaped (Ciofalo *et al.* 2019, 1648; Ciofalo *et al.* 2020, 372; Duncan *et al.* 2009, 13204-13205; Mickleburgh and Pagán-Jiménez 2012, 2491; Pagán-Jiménez 2007, 220; Pagán-Jiménez 2011, 337; Pagán-Jiménez 2015a, 68; Pagán-Jiménez *et al.* 2016, 153; Piperno 2006, 51). However, spherical, triangular, and oval starch grains have been observed as well (Duncan *et al.* 2009, 13204-13205; Pagán-Jiménez 2007, 220; Pagán-Jiménez 2015a, 68; Pagán-Jiménez *et al.* 2016, 153). The size of the starch grains have been reported to lay between 5 and 20 µm (Mickleburgh and Pagán-Jiménez 2012, 2491; Pagán-Jiménez 2007, 220; Pagán-Jiménez 2011a, 327), 6 to 28 µm (Piperno 2006, 57) and even 6.7 to 37.3 µm (Pagán-Jiménez 2015a, 68; Pagán-Jiménez *et al.* 2016, 146). The mean of these ranges, however, lies commonly between 13 and 17 µm (Mickleburgh and Pagán-Jiménez 2012, 2491; Pagán-Jiménez 2007, 220; Pagán-Jiménez 2011a, 327; Pagán-Jiménez 2015a, 68; Pagán-Jiménez *et al.* 2016, 146; Piperno 2006, 57). These ranges have been documented through studying modern reference collections of cultivated *Manihot esculenta* Crantz and will therefore not be direct reflection of the crop in the past. This can already be noted when comparing the ranges to the sizes of wild species of *Manihot* (see for example Piperno 2006 for an overview of size in different *Manihot* species). However, a study by Perry (2004) on desiccated modern and archaeological starch grains shows that date and starch grain size are not correlated per se, and both smaller and bigger grains can be found in modern versus archaeological contexts (Perry 2004, 340-342). The sizes of manioc are therefore variable between domesticated and wild variants, as well as between modern and archaeological context.

Next to size and shape, fissures, pressure facets and the Maltese cross can serve as identifiers. In *Manihot esculenta*, stellate, cross-shaped or linear fissures, as well as Y- and T-shaped fissures have been be registered (Ciofalo *et al.* 2019, 1648, 1650; Ciofalo *et al.* 2020, 372, 374; Duncan *et al.* 2009, 13203, 13205; Mickleburgh and Pagán-Jiménez 2012, 2491; Pagán-Jiménez 2007, 221; Pagán-Jiménez 2011a, 337; Pagán-Jiménez 2015a, 68; Pagán-Jiménez *et al.* 2016, 153; Piperno 2006, 54-57).

Noteworthy is that even though stellate fissures are not the most common fissure – 30% of the fissures in Piperno's (2006) research were stellate, while merely 1.6% of the fissures in Pagán-Jiménez's (2007) research were stellate – they are considered to be diagnostic for *Manihot esculenta* on bell-shaped starch grains (Ciofalo *et al.* 2019, 1648; Ciofalo *et al.* 2020, 372; Pagán-Jiménez 2007, 221; Pagán-Jiménez 2011a, 337; Pagán-Jiménez 2015a, 68; Piperno 2006, 54). Recorded pressure facets are often concave or rounded and located at the basal part of the starch (Duncan *et al.* 2009, 13203; Mickleburgh and Pagán-Jiménez 2012, 2491; Pagán-Jiménez 2015a, 68; Piperno 2006, 53-54, 58). The Maltese crosses observed in *Manihot escultenta* starch grains are commonly centric crosses with straight arms. However, eccentric X-shaped crosses, or cross shaped ones with wavy arms have been observed as well (Ciofalo *et al.* 2020, 372; Pagán-Jiménez 2015a, 68; Pagán-Jiménez *et al.* 2016, 153). Lamellae are not distinctively present in manioc starch grains (Ciofalo *et al.* 2020, 372; Pagán-Jiménez *et al.* 2016, 153).

When identifying starch grains, a combination of these characteristics can make a starch grain identifiable as *Manihot esculenta*. However, one should note again that there is some variability within the species and, only between archaeological and modern crops but also between wild and domesticated varieties.

3.3.2 Zea mays L.

As with *Manihot esculenta*, *Zea mays*, or maize, starch grains can take different shapes. The shapes have been described as spherical to oval, spherical to polygonal, truncated, pentagonal or even quadrangular (Ciofalo *et al.* 2019, 1647; Ciofalo *et al.* 2020, 372; Mickleburgh and Pagán-Jiménez 2012, 2493; Pagán-Jimenez 2007, 240-254; Pagán-Jimenez 2011, 339; Pagán-Jiménez 2015a, 102-179; Pagán-Jiménez *et al.* 2016, 150; Pearsall *et al.* 2004, 430). The starch grains thus have a wide range of shapes, which are also variable per race. For an extensive overview of different races and their characteristics see Pagán-Jimenez (2007 and 2015). A variety of sizes has also been recorded for maize. The recorded ranges range from 1 to 28 µm (Pagán-Jiménez 2007, 240-254; Pagán-Jiménez 2011a, 329, Pagán-Jiménez *et al.* 2016, 146), 2 to 28 µm (Mickleburgh and Pagán-Jiménez 2012, 2493), 4 to 24 µm (Pearsall *et al.* 2004, 431), and 2.61 to 29.67 µm (Pagán-Jiménez 2015a, 102-179). Their means lay between 8 to 19 µm, of course with variations per race (Mickleburgh and Pagán-Jiménez 2012, 2493; Pagán-Jiménez 2007, 240-254; Pagán-Jimenez 2011, 339; Pagán-Jiménez 2015a, 102-179; Pagán-Jiménez *et al.* 2016, 150; Pearsall *et al.* 2004, 431).

Documented fissures in maize starch grains include, radial fissures, linear fissures, Y- and T-shaped fissures, as well as triangular shapes. The Y- and T-shaped fissures are especially common in starch grains from dried kernels, or races that are generally harder or have a harder endosperm, such as the flint variant (Ciofalo *et al.* 2019, 1647; Mickleburgh and Pagán-Jiménez 2012, 2493; Pagán-Jiménez 2007, 240-254; Pagán-Jiménez 2015a, 102-179; Pagán-Jiménez *et al.* 2016, 150; Pearsall *et al.* 2004, 430-432). The edges of the grain can display multiple pressure facets (Mickleburgh and Pagán-Jiménez 2012, 2493; Pagán-Jiménez *et al.* 2016, 150; Pearsall *et al.* 2004, 430). Another characteristic of maize starch grains is the extinction cross, which has been described as either an eccentric, or sometimes centric, cross with straight arms. Eccentric crosses with wavy arms also have been documented in several races, but seem to be less common (Pagán-Jiménez 2015a, 102-179). What is also very characteristic of maize starch grains, is the presence of a double border (Ciofalo *et al.* 2019, 1647; Ciofalo *et al.* 2020, 372; Mickleburgh and Pagán-Jiménez 2012, 2493; Pagán-Jiménez 2007, 240-254; Pagán-Jiménez 2015a, 102-179; Pagán-Jiménez *et al.* 2016, 150; Pearsall *et al.* 2004, 341). Lamellae are generally not present (Mickleburgh and Pagán-Jiménez 2012, 2493; Pagán-Jiménez 2007, 240-254; Pagán-Jiménez *et al.* 2016, 150).

3.4 PREVIOUS RESEARCH INTO INDUCED DAMAGE PATTERNS

Several researches have been done understand the damage starch grains endure during cooking processes. To put this thesis in a broader perspective and understand its results, it is good to also take into account previously done studies. This part of the chapter will therefore discuss some studies that are relevant to the experiments done in this thesis. To identify the damage, shape, size, fissures, the Maltese cross, and damage patterns will be discussed. Damage done through grinding, and baking or toasting, will be discussed per species. Boiling will be discussed based on studies done on several species of grain not native to the Americas.

3.4.1 Damage through grinding, grating or pounding

Experiments done on both maize (*Zea mays*) and manioc (*Manihot esculenta*) to see how damage caused by grinding and grating manifest on starch grains have been done by Babot (2003), Chandler-Ezell *et al.* (2006), Mickleburgh and Pagán-Jiménez (2012) and Pagán-Jiménez (2015), amongst others. Chandler-Ezell *et al.* ground dried maize kernels, while Mickleburgh and Pagán-Jiménez soaked three of the four kernel types they used for an hour prior to the grinding (Chandler-Ezell *et al.* 2006, 109; Mickleburgh and Pagán-Jiménez 2012, 2480). The four kernel types used by Mickleburgh and Pagán-Jiménez were ground in a liquid environment – 2 millilitres of distilled water – for five minutes. In the research of Chandler-Ezell *et al.*, the kernels were ground for 10 minutes (Chandler-Ezell *et al.* 2006, 109-110; Mickleburgh and Pagán-Jiménez 2012, 2480).

As for the manioc, Pagán-Jiménez states that after washing and peeling the manioc, it was grated with a metal grater until a fine mass was created (Pagán-Jiménez *et al.* 2017, 32). Chandler-Ezell *et al.* reports to have pounded manioc for five minutes before analysing the samples (Chandler-Ezell *et al.* 2006, 109-110).

3.4.1.1 Changes in Zea mays due to grinding

3.4.1.1.1 Shape

A variety of shapes was detected after the grinding, including irregular oval and polygonal shapes, but also spherical to round oval. It was noted that intensive grinding of the kernels can influence the homogeneity of starch grain shapes instead of creating a greater variety (Babot 2003, 76; Mickleburgh and Pagán-Jiménez 2012, 2480). Mickleburgh and Pagán-Jiménez note that the amount of spherical to oval starch grains in comparison to irregular oval and polygonal shapes did seem to have increased (Mickleburgh and Pagán-Jiménez 2012, 2480).

3.4.1.1.2 Size

Mickleburgh and Pagán-Jiménez (2012) documented size ranges above the normal range in three of the four types of kernels. They note a correlation between the hardness of the kernel and the enlargement of the starch grains due to grinding, as the harder kernels showed a higher size range. They note that the harder the kernel is, the bigger the enlargement of the starch grains due to intense grinding (Mickleburgh and Pagán-Jiménez 2012, 2482). Babot (2003) on the other hand noticed a scarcity of large grains, but a homogeneity in the sizes overall (Babot 2003, 76).

3.4.1.1.3 Maltese cross

Several starch grains were reported to have lost their Maltese crosses completely, while others were damaged. The reported damage includes lowered birefringence overall, and changes in the shape and cohesion of the cross (Babot 2003, 77; Chandler-Ezell *et al.* 2006, 110).

3.4.1.1.4 Other damage patterns

3.4.1.1.4.1 Fissures:

Mickleburgh and Pagán-Jiménez (2012) note that even though fissures are a naturally produced characteristic in starch grains, they can also appear due to grinding. Again, a correlation between the hardness of the kernel and the amount of fissures can be detected: harder kernels seemed to have more fissures. Radial fissures were the most common (Mickleburg and Pagán-Jiménez 2012, 2483). Babot (2003) also noted fissures, such as 'a hole, line or star' (Babot 2003, 76). Additionally, Chandler-Ezell *et al.* (2006) noted the occurrence of wider and larger fissures after the grinding.

3.4.1.1.4.2 Central depression

Among the damage reported were darkened centres, or "folds" around the hilum area (Babot 2003, 76; Chandler-Ezell *et al.* 2006, 110; Mickleburgh and Pagán-Jiménez 2012, 2485). Mickleburgh and Pagán-Jiménez called them central depressions and note that they can either be 1) small to medium size, regularly found in the hilum area; or 2) large central depressions extending to the edge of the grains. They also again note a correlation between kernel hardness and the occurrence of these central depressions (Mickleburgh and Pagán-Jiménez 2012, 2485).

3.4.1.1.4.3 Bright ring around the hilum

Another feature documented in ground starch grains is a bright ring around the hilum. Mickleburgh and Pagán-Jiménez again note a correlation between kernel hardness and the occurrence of bright rings, with harder kernels showing a bright ring more often (Mickleburgh and Pagán-Jiménez 2012, 2486). However, none of the other sources mention this type of damage. It would therefore be interesting to see if this appears in the experiments done for this thesis.

3.4.1.1.4.4 *Surface cracks and fracturing*

It was noted by Babot (2003) and Chandler-Ezell *et al.* (2006) that after grinding, some starch grains showed cracks in the surface, or were fractured and incomplete. Babot also reports starch grains looking 'empty' and flat (Babot 2003, 76, 78; Chandler-Ezell *et al.* 2006, 110).

3.4.1.1.4.5 *Roughened surface*

Lastly, a roughened or dented surface was noticed in several starch grains by Babot (2003), Chandler-Ezell *et al.* (2006) and Mickleburgh and Pagán-Jiménez (2012) (Babot 2003, 76; Chandler-Ezel *et al.* 2006, 110; Mickleburgh and Pagán-Jiménez 2012, 2484).

3.4.1.2 Changes in Manihot esculenta due to grinding, grating and pounding

3.4.1.2.1 Shape

After grinding the cassava to a fine mass, Pagán-Jiménez *et al.* (2017) reported no changes in the shape of the starch grains. The shapes that were documented are truncated or flared forms with two, three or four pressure facets, or oval starch grains with five or six pressure facets (Pagán-Jiménez 2015a, 14). After pounding the starches, Chandler-Ezell *et al.* found that compound starch grains had split to separate subgranules (Chandler-Ezell *et al.* 2006, 110).

3.4.1.2.2 Size

When looking at the size range of the starch grains, no alteration due to grating in the starch grains was detected and stayed within the typical range of 6 to 30 µm (Pagán-Jiménez *et al.* 2017, 35). The pounded starch grains also showed no change in size (Chandler-Ezell 2006, 109-110).

3.4.1.2.3 Maltese cross

Pagán-Jiménez *et al.* (2017) does not comment on the Maltese cross, even though it could be a diagnostic feature. He did note that there were no morphometrical alterations due to the grating of the tubers, so this could be why the Maltese cross is not addressed. After pounding the manioc, Chandler-Ezell *et al.* report that starch grains with enlarged fissures in the area of the hilum often lost their Maltese cross. However, in some cases the damage to the hilum area was not as extensive and the Maltese cross was still visible. Additionally, some starch grains with cracked surfaces also still displayed the Maltese cross (Chandler-Ezell *et al.* 2006, 110).

3.4.1.2.4 Other damage:

3.4.1.2.4.1 Fissures

According to Pagán-Jiménez, no alterations to the starch grains due to grating could be observed (Pagán-Jiménez *et al.* 2017, 35). Chandler-Ezell *et al.* however, note enlarged fissures after pounding the manioc. The fissures described are circular to stellate (Chandler-Ezell *et al.* 2006, 109-110). Next to stellate fissures, Y-shaped and asymmetric were documented in the grates mass (Pagán-Jiménez *et al.* 2017, 35).

3.4.1.2.4.2 Surface cracks and fracturing

Chandler-Ezell *et al.* (2006), report surface cracks and fracturing of the surface of the starch grains (Chandler-Ezell *et al.* 2006, 110). Pagán-Jiménez *et al.* (2017) reported no such damage after grating the tubers (Pagán-Jiménez *et al.* 2017, 35).

3.4.1.3 Grating, grinding and pounding damage overall:

In both the maize and the cassava starch grains, no drastic change in the shape could be observed. In case of maize some sort of homogenization of the starch grains, suggesting at least some sort of change. In case of grinding the maize, a change in size was documented. This was not the case with pounding or grating the cassava. Both maize and cassava reportedly showed the occurrence of more, larger, and deeper fissures in the hilum area after grinding and pounding. Grating the cassava did not specifically modify the fissures. Both maize and cassava had starch grains with and without Maltese crosses after grinding and pounding, they also both has cracks around their surface or complete splitting of the grains. Again, no such thing was documented after the grating of the cassava. As for other damage patterns, only maize showed a roughened surface, central depressions and a bright ring around the hilum. Even though the manner of processing and altering the starch grains was not the same, some similarities can be seen, even between two species, which is interesting for studying mechanical damage.

3.4.2 Damage through baking, roasting and toasting

To understand the damage heat does to starch grains, particularly heat in combination with little to no moisture, experiments on maize (*Zea mays*) and manioc (*Manihot esculenta*) were conducted by Babot (2003), Chandler-Ezell *et al.* (2006), and Pagán-Jiménez *et al.* (2017). Experiments by Henry *et al.* (2009) on 10 domesticated 'Old World' plant species, including four legumes and six from the Poaceae family including wheat (*Triticum aestivum*), barley (*Hordeum vulgare*), and oats (*Avena sterilis*) amongst others, were also included to gain more insight into the possible mechanical damage occurring (Henry *et al.* 2009, 916).

In the experiments done by Henry *et al.* 2009, the grains were first ground, then mixed with sufficient water to form a paste resembling dough, and then baked at 200 C until the paste dried and became brittle. This took about 5 to 10 minutes, depending on the particular species (Henry *et al.* 2009, 917). In the experiments done by Pagán-Jiménez *et al.* (2017), the manioc was first grated to a fine mass. Following this, the manioc was squeezed to release the juice from it and placed in an oven with a temperature of 27 C for 16 hours to dry. When dry, the manioc rolls were crumbled and spread over a clay plate to bake. The temperature of the cooking surface reached 160 C during the baking of the cassava bread, which took one minute and 35 seconds. The cassava bread was also fully carbonized in four minutes. Samples were taken after fully cooking the cassava bread and after carbonization (Pagán-Jiménez *et al.* 2017, 36-37). Chandler-Ezell *et al.* toasted and oven-roasted manioc roots, as well as toasting and oven-roasting maize (Chandler-Ezell *et al.* 2006, 110). Lastly, Babot (2003) roasted maize kernels in an container placed in hot ashes to avoid charring (Babot 2003. 72).

3.4.2.1 Changes in Zea mays due to roasting and toasting

3.4.2.1.1 Shape

No information on shape and possible alterations was given in the sources. However, it is mentioned that unaltered starch grains have been documented (Babot 2003, 73; Chandler-Ezell *et al.* 2006, 110)

3.4.2.1.2 Size

No information on size and possible alterations was given in the sources. However, it is mentioned that unaltered starch grains have been documented (Babot 2003, 73; Chandler-Ezell *et al.* 2006, 110)

3.4.2.1.3 Maltese cross

Some unaltered starch grains showing their Maltese cross remained after roasting maize. Starch grains with both partial or deformed crosses were also reported. The grains that were gelatinised however, lost all birefringent properties (Babot 2003, 73; Chandler-Ezell *et al.* 2006, 110). After toasting the kernels, most of the starches, even when seeming unaltered, lost their Maltese crosses. However, some crosses still remained (Chandler-Ezell *et al.* 2006, 110).

3.4.2.1.4 Other damage patterns

3.4.2.1.4.1 Gelatinisation

Roasting maize resulted in both gelatinised and unaltered starch grains (Babot 2003, 73; Chandler-Ezell *et al.* 2006, 110). Gelatinisation is a process of alteration in the bonds that keep the starch grain structure together. When these bonds are altered, the starch grains turn into a viscous and amorphous mass, which is nonreversible. Gelatinised starch grains lose their characteristics, including size, shape and Maltese cross (Gott *et al.* 2006 44; Pagán-Jiménez *et al.* 2017, 36).

3.4.2.1.4.2 Central depressions

Babot (2003) notes the most typical or important feature of starch grains from roasted maize kernels is the appearance of clear rounded, stellate or irregular projections at the hilum. These projections appear as dark centres when seen under both normal and polarised light (Babot 2003, 73). In this thesis, this damage will be considered as a central depression.

3.4.2.2 Changes in Manihot esculenta due to baking, roasting and toasting

3.4.2.2.1 Shape

No information on shape and possible alterations was given in the sources. However, it is mentioned that unaltered starch grains have been documented (Chandler-Ezell 2006, 110; Pagán-Jiménez *et al.* 2017, 36-37).

3.4.2.2.2 Size

Pagán-Jiménez *et al.* (2017) report a change in starch grain size in the case of the carbonised cassava bread. They are described as larger than the unaltered starch grains (Pagán-Jiménez *et al.* 2017, 37-38).

3.4.2.2.3 Maltese cross

Oven-roasting manioc roots resulted in only gelatinised starch grains, which do not posses birefringent properties. As it is also mentioned that some unaltered starches remained after toasting and baking, some Maltese crosses would still be present (Chandler-Ezell 2006, 110; Pagán-Jiménez *et al.* 2017 36-38).

3.4.2.2.4 Other damage patters:

3.4.2.2.4.1 Gelatinisation

Among the damage reported is gelatinised damage. Pagán-Jiménez *et al.* (2017) reports gelatinised starch grains in both the normally baked and the carbonised cassava bread. However, in the case of the carbonised cassava bread, the amount of gelatinised starch grains was significantly higher. However not all grains were gelatinised and unaltered grains remained (Pagán-Jiménez *et al.* 2017, 36-38). Chandler-Ezell *et al.* (2006) also reported gelatinised starch grains in the oven-roasted manioc roots, they did not report any undamaged starch grains. When toasting the manioc however, a mix of unaltered and gelatinised starches could be observed (Chandler-Ezell 2006, 110).

3.4.2.2.4.2 Folded or wrinkled surface

Pagán-Jiménez *et al.* (2017) reports starch grains that are between undamaged and gelatinised forms, display other damage as well, including folded or wrinkled surfaces (Pagán-Jiménez *et al.* 2017, 35).

3.4.2.2.4.3 Central depressions

Some starch grains with shadows in the centre of the starch were registered as well. These were said to be either restricted or extending to the edge of the grain (Pagán-Jiménez *et al.* 2017, 36) In this thesis, this damage will be considered central depressions.

3.4.2.3 Changes in 'Old World' plant species due to baking

The species used in the research by Henry *et al.* (2009) are: *Triticum aestivumi* L. (hard red winter wheat), *Hordeum vulga*re L. (barley), *Avena sterilis* L. (oats), *Panicum miliaceum* L. (white proso millet), *Sorghum bicolor* (L.) Moench (sorghum), *Oryza sativa* L. (rice), *Lens culinaris* Medik. (lentil), *Pisum sativum* L. (green pea), *Cicer arietinum* L. (chick pea, garbanzo), and *Vigna radiata* (L.) R. Wilczek (mung bean).

3.4.2.3.1 Shape

Some species seemed to have retained their original shapes, including rice. Other species have a mix of gelatinised and undamaged starch grains, so one can assume that the shapes of the latter are still more or less intact. It has also been noted that starch grains of oats become elongated ovals (Henry *et al.* 2009, 917-918).

3.4.2.3.2 Size

It has been noted that all species display swollen starch grains after baking them (Henry *et al.* 2009, 918). Their size thus has increased.

3.4.2.3.3 Maltese cross

When heated, some species including wheat and barley, lost their Maltese crosses completely. Rice, however, keeps its Maltese cross fairly long (Henry *et al.* 2009, 918).

3.4.2.3.4 Other damage patterns

3.4.2.3.4.1 Fissures

Sorghum displays radial striations or fissures after heating, while the starch grains from the legume family (lentil, green pea, chick pea, and mung bean) lost their longitudinal cleft fissure (Henry *et al.* 2009, 918).

3.4.2.3.4.2 Gelatinisation

It is noted that both wheat and barley showed gelatinised starch grains after heating. Additionally it is shown that after heating the starch grains long enough, all samples will show gelatinised starch grains (Henry *et al.* 2009, 918-920).

3.4.2.3.4.3 Disappearance and appearance of lamellae

Wheat and barley reportedly lost their lamellae when heated. Lentils however, seemed to gain more distinct lamellae after being baked (Henry *et al.* 2009, 918).

3.4.2.3.4.4 Central depressions

In wheat and barley, but also sorghum, folds, shadows and large depressed circles were observed in the centre. Additionally, millet starch grains showed a darkening around the hilum (Henry *et al.* 2009, 917-918).

3.4.2.4 Damage through baking, toasting and roasting overall:

No clear information is given on the size, shape and fissures in the case of manioc and maize. However, it was stated multiple times that undamaged starches remained next to fully gelatinised starch grains. Their shape and size are arguable also unaltered. In the case of the ten 'Old World' species, it was mentioned that some species retained their shapes. They also mention swelling and the appearance of new fissures, with the disappearance of characteristic fissures.

All the baked, toasted and roasted starch grains showed gelatinisation to some degree. This appears to be a common damage when heating starch grains. Next to this, all experiments mention folds, shadows or large depressed circles in the region of the hilum, which in this thesis will be placed under central depressions. Manioc starch grains baked as cassava bread displayed more folds in the surface, as well as wrinkled. This was not noted in any other experiments. This is also the case with the appearance and disappearance of clear lamellae, this was only documented in wheat and barley, who lost theirs, and lentils who gained distinct lamellae. This illustrates how different species respond differently to heating in environments with low humidity.

3.4.3 Damage through boiling

To understand what damage starch grains get by heating them in a humid environment, boiling them, experiments have been done on manioc roots and ten 'Old World' crops (Chandler-Ezell *et al.* 2006, 110; Henry *et al.* 2009, 916-918). The Old World crops were both ground and boiled whole for one, five, ten and thirty minutes. It is not mentioned how long the manioc was boiled (Chandler-Ezell *et al.* 2006, 110). Experiments with boiling maize at a temperature for 46 °C for nine hours were conducted by Pagán-Jiménez (2013). However, this experiment was part of brewing Chicha and the grains were subjected to other types of induced damage before boiling (Pagán-Jiménez 2013, 3-6). This study was therefore not used to describe possible characteristics of boiling.

3.4.3.1 Damage to Manihot esculenta through boiling

3.4.3.1.1 Shape

Chandler-Ezell *et al.* (2006) state that when boiling the manioc roots, all starch grains were gelatinised. No unaltered starch grains remained (Chandler-Ezell *et al.* 2006, 110). This means that their original shapes cannot be documented anymore.

3.4.3.1.2 Size

Due to the complete gelatinisation of the starch grains in the manioc roots, no information can be given on their size (Chandler-Ezell *et al.* 2006, 110).

3.4.3.1.3 Maltese cross

After the complete gelatinisation of the starch grains in the manioc root, no birefringent properties remain (Chandler-Ezell *et al.* 2006, 110).

3.4.3.1.4 Other damage

3.4.3.1.4.1 Gelatinisation:

After boiling the manioc roots, all starch grains were gelatinised. No undamaged or partial gelatinised starch grains remained (Chandler-Ezell *et al.* 2006, 110).

3.4.3.2 Changes in 'Old World' plant species due to boiling

3.4.3.2.1 Shape

Rice starch grains kept their shape even after 30 minutes of boiling. The starch grains of oats became elongated and swollen ovals. Gelatinised starch grains which have lost all their shape were documented next to seemingly undamaged starch grains (Henry *et al.* 2009, 918).

3.4.3.2.2 Size

Many of the species showed swelling and thus an increase in size. Next to this, gelatinised starch grains were documented, which have an altered size and shape. Undamaged starch grains were also still present, which do not have an altered size (Henry *et al.* 2009, 918).

3.4.3.2.3 Maltese cross

It was reported that most of the species lost most of their birefringent properties due to the boiling. The some of the starch grains of oats, however, kept showing their Maltese crosses even after being boiled for 30 minutes (Henry *et al.* 2009, 918).

3.4.3.2.4 Other damage

3.4.3.2.4.1 Fissures

After boiling the starch grains from the legume family, their characteristic longitudinal cleft fissure was lost. No other starch grains gained or lost fissures (Henry *et al.* 2009, 918).

3.4.3.2.4.2 *Folds and wrinkled surface*

The starch grains from the legume family displayed a folded surface, which gave them the appearance of 'chewed bubblegum'. This type of damage was not reported in any other of the starch grains (Henry *et al.* 2009, 918).

3.4.3.2.4.3 *Central depression*

Barley, wheat, millet, and sorghum all displayed folds, shadows, or dark depressions around the hilum area after boiling. This was not registered in the starch grains from the legume family, nor in rice (Henry *et al.* 2009, 918).

3.4.3.2.4.4 *The appearance and disappearance of lamellae*

After boiling the wheat and barley samples, they developed clearly visible lamellae, which disappeared after boiling them longer. Sorghum also developed more visible lamellae after cooking. None of the other starch grains gained or lost lamellae (Henry *et al.* 2009, 917-918).

3.4.3.3 *Overall damage from boiling*

Both the boiled manioc and the ten domesticated 'Old World' crops showed gelatinisation, which influences the shape and size of the starch grains. Rice however, did keep its angularity even after 30 minutes of boiling. This is the same case with the Maltese cross. Some starch grains did still display their crosses, especially in rice, however the gelatinised starch grains did not display any birefringent properties anymore. It was reported by Chandler-Ezell *et al.* (2006) that only gelatinised starch grains remained after boiling the manioc. Unfortunately this means that nothing can be said about other possible damages that the starch grains took between the stages of being undamaged and fully gelatinised. The other ten species did show a variety of damage though, including a wrinkled surface, central depressions and the loss of fissures.

4 METHODOLOGY

This chapter will combine key aspects of middle-range theory with ethnography and create a relevant theoretical framework for this thesis. Starting of with an overview of middle-range theory and how it came into archaeology. It will also go into the relevance of both middle-range theory and ethnography, and experimental archaeology today and in this thesis, highlighting how it will be used.

4.1 MIDDLE-RANGE THEORY: BRIDGE BETWEEN THE PAST AND THE PRESENT?

In 1977, Lewis Binford, in his introduction to *For theory building in archaeology* argued for the need of a new way of theorizing. He stated the need for both general, as well as middle-range theories. The latter being a (relatively) new term to archaeology (Pierce 1989, 1; Raab and Goodyear 1984, 259; Tschauner 1996, 4). In his view, general theories concern the causes of change within the organisations of living things. Middle-range theory, on the other hand, address the inferred link between the organisational dynamics of the past, which are unobservable to archaeologist nowadays, and the static archaeological record which is observable and formed by these dynamics. (Binford 1981, 29; Pierce 1989, 1-2). In other words, general theories concern the question *why* the archaeological record became the way it is today, while middle-range theories concern themselves with *how* the archaeological record became the way it is today. Binford (1981) further argues that middle-range theory should be developed 'intellectually independent' of general theory. This is because Binford believes that the latter should be evaluated using instruments or tools developed through middle-range research (Binford 1981, 29).

However, the idea of middle-range theory does not originate in archaeology, but in sociological sciences. It has been argued that there is little evidence of an archaeological understanding of the Middle-range theory as originally perceived in the social sciences (Raab and Goodyear 1984, 255). A connection between the term and the social sciences rarely gets addressed in publications discussing the term in an archaeological context (Raab and Goodyear 1984, 258). The author believes that, in order to correctly understand the usage of middle-range theory in archaeology, one must learn about its origins. Therefore, this chapter will discuss both the roots the concept has in the social sciences, as well as the adoption of the term in archaeology. It will also go into the pitfalls the theory might have, as well as how it will further be used in the interpretation of the results in this particular research.

4.1.1 The middle-range theory in social sciences

After the Second World War, sociological theory started to see major changes. The focus started to shift from the individual to societal systems, which needed an a priori and over-arching theory, encompassing all social phenomena. This was accepted, even if it would result in constructing enormously abstract and generalised concepts, which could be difficult to relate to actual research (Raab and Goodyear 1984, 256).

However, not all sociologists were willing to follow this. One of these sociologists, Merton, critiqued the grand-scale "models", vastly abstract "approaches" and other widely-conceived theoretical schemes, as these showed little to no promise of actually being tested with actual research. In doing this, he was not arguing for the overall rejection of grand theories, instead he argued for an understanding that these grand, abstract ideas might not result in tested, or testable theories (Merton 1968, 169-150; Raab and Goodyear 1984, 256). Merton also took issue with empirical research that lacks a theoretically well-guided foundation and addressed this in his objective of middle-range theory (Raab and Goodyear 1984, 256).

Middle-range theory, in Merton's eyes, was to be the critical bridge between 'abstract' theory and (empirical) data. To make this work, Middle-range theory should be able to vary in levels of abstractions. It should be flexible in attaining sources of working hypotheses and should aim to acquire a body of theory. As research problems vary between areas of research and even within, middle-range theory can serve as a middle ground between specific research and their problems, and the general theories one applies to these (Raab and Goodyear 1984, 257).

Of course, it can go without saying that the concept of Middle-range theory did not only receive praise. Even after decades of debate, uncertainty exists about what it actually is and what the value of such a concept may be (Raab and Goodyear 1984, 257-258).

4.1.2 The beginning of middle-range theory in archaeology

The concept of middle-range theories used in archaeology differ from the ones proposed by Merton from 1968 onward. The difference is understandable, as archaeologists are concerned with reading and understanding the archaeological record and how it was shaped. We aim to infer the behaviour of peoples from the past from the material traces that were left and not from the people themselves (Raab and Goodyear 1984, 255; Tschauner 1996, 4).

As previously mentioned, Binford addressed his view on the need of a new way of theorizing in 1977. He named it 'middle-range theories' after the ideas of Merton. Even though it was an established concept in sociology, it was a new term for published archaeological literature (Pierce 1989, 1; Raab and Goodyear 1984, 259-260; Tschauner 1996, 4). Contrary to the term, the way of thinking was not entirely new to archaeology, as it is highly reminiscent of the earlier "archaeological theory" which came up in the 1960's (Raab and Goodyear 1984, 259-250; Tschauner 1996, 4). During this period, concerns regarding the adequacy of the scientific interpretation of the archaeological record arose and became a major focus of the New Archaeology. This movement was innovative and significant due to its questioning of archaeology, and the entire theoretical structure, as a science (Binford 1981, 22-23; Raab and Goodyear 1984, 259).

Binford believed that, until the scientific adequacy of archaeology was improved, there would be no relevant contributions from archaeology to anthropology's broader goals. The main methodological issue he describe was making plausible interpretations based on the archaeological record and, using these to explain past processes. This was described by Binford and his students as "bridging arguments", "arguments of relevance", and "*archaeological theory*" (Binford 1981, 23; Raab and Goodyear 1984, 259). The assumptions of this archaeological theory, or New Archaeology, can be summarised as follows: The archaeological record is a contemporary circumstance, created by the past. This past cannot be experienced or observed directly, but merely indirectly through the usage of the right instruments (Binford 1981, 25; Raab and Goodyear 1984, 259). Additionally, meanings are carried by arguments and concepts, not by the contemporary arrangement of materials that is the archaeological record (Binford 1981, 23).

This implies that archaeological remains encompass no inherent or objective meaning, but are given meaning by the contemporary observer. Therefore, one must separate the past dynamic or systematic context of events, from the currently observable, and more or less static, archaeological context. When a distinction between the past dynamics and contemporary statics has been made, concepts needed for accurately translating the former into the latter can be identified. To realize these translations, the natural and behavioural processes responsible for the creation of the contemporary material record should be thoroughly identified, in order to build a 'structure of inference'. Moreover, in order to provide reliable knowledge, the concepts of translation must be covered by law-like hypothesis and be based on uniformitarian assumptions (Binford 1981, 22; Raab and Goodyear 1984, 259).

Later, Binford called for a new way of theorizing, naming it middle-range theories. Even though a formal description of the term was never provided, some passages in his works give a good idea of what was intended:

> There are urgent needs for theory building on at least two levels. One level is what I refer to as middle-range theory. If one accepts observations made on the archaeological record as contemporary facts along with the idea that such facts are static, then clearly basic problems for the archaeologist include (a) how we get from contemporary facts to statements about the past, and (b) how we convert the observationally static facts of the archaeological record to statements of dynamics (Binford 1977, in Raab and Goodyear 1984, 260).

This separation between general and middle-range theories Binford argues for, is reminiscent of Merton's view on Middle-range theory as being a bridge between interpreting data, and theory. Through using the middle-range theory one can go from raw data, to a higher level of abstract, or general, theory.

Not only is the way Binford described middle-range theory reminiscent of Merton's ideas in sociology, it is also highly reminiscent of the previously discussed Archaeological Theory. Some even argue that these terms encompass the same ideas, and the label was merely changed by Binford (Raab and Goodyear 1984, 259). When examining the structure of Middle-range theory, this becomes evident as well.

Pierce, in an unpublished paper (1989), gives an overview of the components used in Middle-range theory. He describes four: 1) the documentation of causal relations between the now observable statics, and the dynamics of the past; 2) identifying signature patterns in the static archaeological remains; 3) inferring past dynamics by observing signature patterns in the archaeological record; and 4) evaluating these inferences (Pierce 1989, 2). As one can see, as with *archaeological theory*, a distinction between the past dynamics and the present static record can be observed. Additionally, it is argued that signature patterns must be identified in order to translate the archaeological record to past dynamics which created these patterns. To make the similarities more clear, one needs to better understand these four components.

4.1.2.1 *Separation between dynamics and statics*

As previously noted, the archaeological record is merely a contemporary arrangement, and it is the dynamics of past cultural systems which shaped this record, which archaeologists aim to understand. It has therefore been argued that to understand these past systems we must identify their static material by-products that end up forming the static archaeological record (Pierce 1989, 2; Tschauner 1996, 4). One could argue that the archaeological record is an untranslated language that needs to be decoded to translate it from static to the dynamics of past cultural systems. Middle-range theory has been argued to be the 'Rosetta Stone' in this decoding process (Binford 1983, 24-25; Tschauner 1996, 4). However, to understand the material record and link them to the past, one must look at situations where both the dynamics and statics are observable to be able to make inferences (Binford 1981, 22, 27, 29; Tschauner 1996, 4). This research done in 'living systems' are what Binford calls actualistic studies (Binford 1981, 22, 27; Pierce 1989, 2). These actualistic studies can be done in the present using ethnographic or historical sources, as well as doing experimental archaeology (Pierce 1989, 2), as is the case in this research.

A crucial aspect of the linkages between past dynamics and contemporary statics, is that they must be causal instead of coincidental (Pierce 1989, 2). It is important to be able to identify unambiguous causal relationships between things. Only then a strong warrant for the inference of these causes from the observed outcome can be created (Binford 1981, 26).

4.1.2.2 *Signature patterns*

When aiming to identify the cause creating certain patterns in the archaeological record, thus linking the dynamics to the statics, one must consider certain things. Firstly, the different agents and processes influencing or causing a certain pattern, must be isolated. Secondly, to develop criteria used in recognising these patterns in the archaeological record, these agents and processes must be studied in the contemporary world by means of actualistic research. This results in criteria used to recognise the different traces, or 'signature patterns', in the material record (Binford 1981, 26). In order for these signature patterns to be useful and diagnostic of particular dynamics, they must be unambiguous (Pierce 1989, 3).

4.1.2.3 Recovering past dynamics

Once signature patterns have been identified, inferences can be made. When making these inferences, one gives dynamic meaning to the static archaeological traces (Pierce 1989, 3). This can therefore be seen as the aforementioned translation process in which middle-range theory functions as the Rosetta Stone, converting the observations made in the present to arguments and concepts that carry meaning (Binford 1981, 26-28; Pierce 1989, 3). What is important here, is the identification of established signature patterns in the archaeological record, as well as the assumptions that the static-dynamic link was characteristic in the past as well as in the present and existed in both. To infer past dynamics, uniformitarian assumptions are necessary (Pierce 1989, 3).

4.1.2.4 The evaluation of inferences

Since we cannot observe the past dynamics anymore, all inferences made based on the archaeological record are reconstructions of these dynamics (Binford 1981, 26; Pierce 1989, 3). This means that the accuracy of the inferences rests entirely on the accuracy of the assumptions, which serve as the basis of our inferences, as well as the accuracy of the methods used to come to these assumptions (Binford 1981, 29; Pierce 1989, 3). However, this means that we can neither use the archaeological record, nor the inferences of the past to test these assumptions (Binford 1981, 29). Instead, archaeologists should engage in actualistic research designed to test the links between the dynamic organisations of the past, which archaeologists want to understand, and the static material record, which archaeologists can study because it existed in the past and present (Binford 1981, 29). Or in short: one must engage in middle-range Research.

However, as middle-range theory is used to both reconstruct the past, as well as test the assumptions about it, it is important for it to be intellectually dependent of the theories used to explain the past – the general theories (Binford 1981, 29; Pierce 1989, 4). Binford stresses that middle-range theory must be primarily tested using actualistic research and living systems. General theory on the other hand, must be tested using the archaeological record, which has been given meaning through middle-range theory. In other words: general theory must be evaluated by using tools for measuring variables which are specified in the theory. These tools should be developed independently by conducting middle-range research. When no tools or methods for measuring the critical variables exist, no archaeological test of general theory can be done. Binford thus believes one cannot 'know' the past without middle-range research and we cannot test our ideas of the past, and why it was the way we assume it was, without the right tools developed through middle-range Research (Binford 1981, 9-30).

4.1.3 Critique of the middle-range theory

Of course, middle-range theory is not without flaws, and these critiques should be taken into mind when using it. Several critiques can be given, mostly focussed on how inferences are made and evaluated. The main issue that comes to mind with the concept of middle-range theory is the notion of, and reliance on, law-like uniformitarian assumptions. It is assumed that, through actualistic research, dynamic-static links are established which exist in both the present and past.

These links, or signature patterns, are used as universal laws. However, as rightfully argued by several authors (Johnson 1999; Pierce 1989) the analogies or links made with middle-range theory can never be tested with a hundred percent accuracy. Even when, for example, a feature is identified as a storage pit since it has fifteen characteristics in common with a storage pit observed during ethnographic research, one cannot be absolutely sure that the interpretation is wrong (Johnson 1999, 60; Pierce 1989, 5).

Johnson (1999) states that uniformitarian assumptions based on cultural similarity can be very strong, when assuming that human cultures go through the same stages. However, when insisting that all cultures are historically unique and develop in their own way, one cannot apply ethnographic analogies on a culture that is located on the other side of the world. He then further states that this undermines the notion of Middle-range theory being independent of General Theory, as the aforementioned dilemma is clearly linked to general theories on social evolution (Johnson 1999, 60). An argument also given by Pierce (1989) as being one of the current flaws in Middle-range theory. Of course it can be argued that, even though these links and analogies come from other cultures, they can still be tested. Even though we can never be a hundred percent sure that the feature was indeed a storage pit, but one can assess the plausibility against alternative inferences (Johnson 1999, 60).

Another argument for being careful with uniformitarian assumptions, is the possibility of certain dynamics which have not been observed yet, creating the same static material record as other dynamics (Pierce 1989, 6). A simple example of this can be accidentally dropping a delicate cup on the floor, breaking it, as well as purposely dropping it. This is of course an oversimplified example, but an example of two different dynamics with the same outcome nonetheless. Another argument relating to different dynamics with different meanings is given by Johnson regarding cultural ideas influencing behaviour. Not only do cultural believes affect 'obviously cultural' things such as burial practices or marriage rituals, they also influence 'mundane' activities such as the organisation of household spaces or the way someone interacts with certain types of trash. These ideas influence the way materials are deposited, and therefore must be taken into account when researching the formation of the archaeological record (Johnson 1999, 61-62).

However, even though there may be critiques on the middle-range theory, this does not render the approach irrelevant. As Pierce also states, certain ideas of the middle-range theory cannot be denied, like the notion that the contemporary archaeological record carries no meaning until the observer gives it one. Pierce also agrees with the necessity of uniformitarian assumptions to translate the archaeological record. However, he does state that, to justify these assumptions, they must be established on universal theoretical laws. To summarise his critique, Pierce states that for archaeology to grow as a science, robust and unambiguous general theory must be developed, to aid in structuring our observations and expectations of the empirical archaeological record (Pierce 1989, 7).

In short, the author wants to state that one must always be careful in using analogies. As has been argued in this chapter, assumptions will never be tested for hundred percent accuracy. One will never be sure of our interpretations. However, we can strengthen them by studying living cultural systems, historical sources, the material record, and by doing experimental archaeology. By gathering more knowledge, we can strengthen our understanding of the past.

4.2 Ethnography and ethnoarchaeology

4.2.1 Ethnography and anthropology, a brief introduction

To understand the importance of ethnography in this thesis, it is important to understand what ethnography and anthropology as disciplines entail and how they came into existence. Of course, any archaeologist has heard or studied some ethnographical works, but a brief overview might still be beneficial. Anthropology is a wide set of sciences, which in some parts of the world includes archaeology while other parts of the world do not. It encompasses the study of people – usually Non-Western and less industrialised peoples. The discipline is rather generalising and includes ethnography and ethnology (Hodder 2012, 28). It is for that reason that Monaghan and Just (2000) describe ethnography to be to anthropologists what working in a laboratory is to a biologist, or what excavating is to an archaeologist (Monaghan and Just 2000, 13). It is 'the analytical study of contemporary ethnic groups; an examination of their material, social and linguistic characteristics' (Hodder 2012, 28). To describe ethnography further, the term "participant observation" is often used, even though this is considered to only partially be true (Monaghan and Just 2000, 2, 13).

It can be argued that the earliest ethnographies are descriptions of the native inhabitants of England, France and the lower Rhine area by Tacitus and Caesar (Hodder 2012, 31). This was of course followed by accounts written during the exploration into the, for Europeans, unknown world. By the beginning of the 20th century, anthropologists were no longer content with relying on written accounts by colonial officials, travellers, missionaries, or other non-specialists as a source of primary data, they started to go on ethnographical fieldwork. This went together with the seemingly simple notion that to peoples daily lives, or 'what people are up to' as phrased by Monaghan and Just, is best observed by interacting with the people both intimately and over an extended period of time. Of course, this is not the only way to gain information, questionnaires or other information gathering can also be used. However it is felt that this does not reflect the people studied completely, especially when the people one is working with do not fit our subjective Western normativity (Monaghan and Just 2000, 2, 13).

When anthropology and ethnography were still in its infancy, the profession mostly concentrated on what was then called "primitive" societies. It grew out of the intersection of European colonialism, natural science and the believe of European "discovery". The societies that were observed were small, non-Western communities branded as having limited and simple social institutions. As anthropologists were aiming to reconstruct the stages of social and cultural evolutions, these communities were interesting since it was assumed that they provided anthropologists with the "elementary" workings of society. This clearly contrasted with the rather complex "modern" or Western society which were higher up the evolutionary chain. (Monaghan and Just 2000, 1, 14). As one can see, at that stage anthropology operated under a very colonial mindset, assuming Western superiority.

Another reason for conducting ethnographical fieldwork, was the sense of necessity in recording the workings in these societies, as many of them had no writing and their way of life was rapidly chancing due to colonialism. Of course these societies were never static to begin with, and most probably did go through societal changes way before the (European) colonisers came in (Monaghan and Just 2000, 2, 14). However, in the latter part of the twentieth century anthropology has shifted from focussing on small scale, non-Western societies, to researching all parts of society, including (Western) labour unions, or social clubs, but also subjects like capitalism and global consumerism, or gender. Anthropology and ethnography aim to conduct comparative studies, taking into account all societies, and also treating them as equally significant (Barnard and Spencer 1996, IX; Monaghan and Just 2000, 2).

4.2.2 Possible pitfalls in ethnography

As with all disciplines, ethnography is not without its pitfalls. One should keep this in mind when consulting or conducting ethnographical research. It can be argued that the very strengths of ethnographic research, such as participant observation, can also be the biggest weakness if not used correctly. A possible problem with this type of research is the presentation of the communities in some sort of spatial and temporal isolation, as if they are frozen in time (Hodder 2012, 8; Jamieson 2005, 353; Monaghan and Just 2000, 25). Sometimes no notion is given on neighbouring societies, the states or countries they are located in, or historical context. This practice, known as the ethnographic present, was especially visible in accounts from the 1930's and 1940's (Monaghan and Just 2000, 25). Another critique one might give on the ethnographic present, is the tendency of researchers to write in such a way that it seems they were not actively involved in obtaining the information presented. Some ethnographers tend to write in an "all-knowing" third-person voice, omitting their own role and presence in occurrences described (Monaghan and Just 2000, 26).

Other issues one might raise are the issue of representativity and objectivity. Ethnographers spend long periods of time with the communities they are working with, which allows for an in depth view of the complexity and subtleties of the social and cultural lives of these peoples. However, their contact may be intensive, they still work with relatively small groups of people. This raises the question how representative these researches may be for larger social and cultural structures (Monaghan and Just 2000, 26). At a first glance, one would say that these ethnographies are only representative for their corresponding communities. However, Monaghan and Just (2000) argue that one should keep in mind that ethnography is incomplete when only focussing on separate accounts. The strength lies in the cross-cultural comparisons, in which unique accounts can find 'a comparative spatial and temporal context' (Monaghan and Just 2000, 26). This is incredibly important to keep in mind while using ethnographic works, otherwise misconceptions will occur.

Next to this, the ethnographer conducting research is a unique individual as well. It therefore can and will occur that two ethnographers working with the same groups of people will come to different conclusions about their cultural and social lives (Monaghan and Just 2000, 27). Even though people try to be subjective, their point of view is influenced by who they are and what they value. This seems like a hard issue to overcome, and it is. Some “solutions” have been suggested, like re-studying communities that have been studied by other ethnographers in order to counter subjectivity or observer bias. However, this practice is less than common as ethnographers feel the urge to study the smaller societies with a traditional way of life that are disappearing rapidly, to conduct ‘salvage ethnography’ (Monaghan and Just 2000, 28). Next to this, there is only a small chance that ethnographers working with communities that were studied before, take the same approach and study the same theoretical and ethnographic topics as their predecessor. Next to this, possible rapid changes in society, a few year between two studies can make a big difference and can make restudying a society to check for ethnographic objectivity difficult to impossible (Monaghan and Just 2000, 28-29).

Of course, not all ethnographers agree with the issue of bias. They argue that objectivity, or rather our subjectivity, is a false issue. Our point of view is formed by our social and historical situation, so this bias can also be seen as a resource one can utilize when interpreting research. Nevertheless, one could ask themself if it is not rather audacious to present a definitive description of the lives of another people, even though it is based on long-term participant observation (Monaghan and Just 2000, 30)? Should other fields of research not be involved as well? Is it not problematic that Western ethnographers research non-Western communities? Monaghan and Just (2000) argue that this weakness, can also be a strength. While the amount of non-Western ethnographers is growing, some of them seem to have taken an interest in studying Western societies. The perspective of an outsider can be valuable to observing and describing things that the local community would label as common sense, or normal ways of thinking, while the perspective of an insider can pick up very subtle local variations. The insider would probably not mention the same things as an outsider would and vice versa (Monaghan and Just 2000, 30).

To conclude, ethnography can be crucial in understanding ways of life that are either rapidly changing or extinct. However, it draws it strength from making comparisons. This should be kept in mind for this whole thesis, as drawing direct analogies will never be possible when studying the lives of peoples in the past. The historical sources, as argued, are prone to observer bias. Especially as some of them are the tales of travellers, and not of trained ethnographers. Nevertheless, they are valuable descriptions, even though they are written with an outsiders perspective.

4.2.3 Ethnoarchaeology, best of both worlds?

The term ‘ethnoarchaeology’ is not new, even though it only recently became popular. The term was first used in 1900 by Fewkes, but it can be argued that the practice is far older (David and Kramer 2001, 6; Hodder 2012, 28). However, before diving into its history, a definition should be given. Two definitions can be given based on the ideas of different scholars. Gould (1978) and Stiles (1977) define ethnoarchaeology as ‘the comparison of ethnographic and archaeological data’ (David and Kramer 2001, 7; Hodder 2012, 28). As one can see, this is a rather broad definition and only a little helpful in explaining what it really is. Au contraire to Gould and Stiles, Stanislawski (1974) provides us with a clearer definition stating that ‘ethnoarchaeology is the collection of original ethnographic data in order to aid archaeological interpretation’ (Hodder 2012, 28). It is therefore not merely the usage of ethnographic analogies, but also collecting the needed data ourselves. However, these are just two examples of the many different descriptions proposed (See David and Kramer 2001, 9-14 for more).

All our interpretations are actually analogies. When determining the function of an object, all we can do is guess. This guess, however, can be reasonable based on the similarities between the object and contemporary objects with the same function, in either our own or other contemporary societies. To get a better idea of the usage of the object, one can research residues on the object, do use wear analyses, or experiments to discern its functionality. However, these studies are all subsidiary and will help support or weaken the initial analogy. They cannot confirm it. (Hodder 2012, 11). In analogies, we recognise two types: (1) formal analogies, which is based on the idea that when two objects or situations have some similar characteristics, they probably share more common properties; and (2) relational analogies, which look for a cultural or natural link between the different facets of the analogy and not merely similarities. The first type of analogy is rather weak, as it can be based on coincidence rather than an actual link. The latter focusses on independent aspects of analogies, which are not linked by accident (Hodder

2012, 16). As previously noted, supplemental studies can be done to strengthen analogies, and one of these is ethnoarchaeology.

As aforementioned, it can be argued that some of the earlies ethnographies date back to the time of Caesar and Tacitus, describing the native people of the areas the Romans colonised. These accounts support archaeologists in their research. After this, accounts written during European exploration of to them unknown parts of the world resulted in accounts on the lives of Indigenous peoples. Back then, possible parallels between ethnographies and the European prehistory were already used. An example is de Bry, who in 1590 printed watercolours made of the Indians of Pomeiock by John White, stating that these pictures could show how life in Great Britain could have been in past times (Hodder 2012, 31). Other parallels include the interpretation of early stone tools. Previously believed to be thunderbolts or elven arrows, ethnographic parallels were used to show otherwise in 1656, 1686 and 1713. In 1800, Palaeolithic hand axes were described as 'weapons of war' through these analogies (Hodder 2012, 32).

Throughout the sixteenth to eighteenth century, ethnographic parallels were adopted to make simple and formal analogies, which were used to clarify and support interpretations of the past. However, no concern for the dangers of ethnographic parallels was voiced. This continued in the nineteenth century as well, with exceptions of archaeologists like Nilsson and Pitt Rivers. While both of them saw the importance and relevance of using ethnography to interpret archaeological remains, they also were wary of using only simple parallels. Nilsson noted that 'similarities such as the presence of similar stone arrows in Scania and Tierra del Fuego do not always prove one and the same origin'. While Pitt Rivers noted that both functional and formal identity must be demonstrated when making an analogy (Hodder 2012, 33). Unfortunately, their cautions often were ignored and formal parallels were assumed with almost no attention to their contexts and the dangers were scarcely discussed (Hodder 2012, 33).

Besides Pitt Rivers and Nilsson, archaeologists of the second half of the nineteenth century began to adopt the use of ethnography in comparative archaeology more and more. This increase can according to Hodder (2012) be ascribed to two additional developments: 1) interpretations of the past often included references to the folklore survivals of 'primitive' ancestors; 2) the dividing of archaeological material into epochs started to be replaced with divisions in cultures instead. The latter was thanks to the European school of what is called 'anthropogeographers', who in West Africa and

Melanesia started describing cultural areas (Hodder 2012, 33). The increasing links between anthropology and archaeology continued in the first half of the twentieth century, although and increase in quantity did not mean an increase in quality. Concern with contexts of archaeological remains were still minimal, and analogies remained mostly formal. An example is the work of Thomson, who in 1939 studies the Wik Munkan Aborigines of the Cape York Peninsula of Australia. He came to the conclusion that these people led such different lives in different seasons of the year, that archaeologists finding only the assemblages would assume they were made by complete different people. Next to this, he added that much of the material would not even survive to be found by archaeologists (David and Kramer 2001, 6; Hodder 2012, 34). Hodder (2012) notes that this is the first, and a good, example of a pessimistic and negative type of analogy, which later became common as 'cautionary tales'. These tales share the characteristic of not being concerned with context influencing the archaeological materials (Hodder 2012, 34).

In more recent studies the concern for context and relevance result in more careful and informed analogies. However, the emphasis on formal analogies remains, but is decreasing as warnings were given (see for example Ucko 1969) and assessments were published (Hodder 2012, 35). Ucko (1969) argues that ethnography is indeed useful, but only to diversify the possible interpretations one can draw from the archaeological record. Only on very rare occasions can ethnographic parallels show a one-to-one correlation between the lives and actions of society A, and the material remains of culture B. Most of the times, ethnologies are better suited to show the range of possibilities that can lead to the material record characterising culture B (Ucko 1969, 262-263; 376). It was also during this time that ethnoarchaeology was defined as a distinct area of research within anthropology (David and Kramer 2001, 6; Hodder 2012, 37-38). In the 50's and 60's, when New Archaeology took up 'anthropological archaeology' as their main focus searching for general laws and uniformitarian assumptions (David and Kramer 2001, 18-19; Hamilakis and Anagnostopoulos 2009, 68; Hodder 2012, 37-38). Ethnoarchaeology, amongst others, could be useful for this as it is seen as actualistic research used to come up with law-like hypotheses to interpret the past (Binford 1981, 22; David and Kramer 2001, 13, 21; Raab and Goodyear 1984, 259). It was also in this period that the Binfords, who as stated before were prominent figures in the New Archaeology movement, published a collection of essays edited by them, including important ethnoarchaeological studies. This led to a boom in publications and researches (David and Kramer 2001, 18-19; Hamilakis and Anagnostopoulos 2009, 68; Hodder 2012, 37-38).

This, of course, led to several critiques and ethnoarchaeology has diversified since then. Several researchers have taken the criticism to heart and attempts to develop new trends in ethnoarchaeology (Hamilakis and Anagnostopoulos 2009, 68). It can be argued that the newer waves of ethnoarchaeology (at least between 1980 and 2000) are heavily influenced by the redefinition of contemporary archaeology, which was heavily politically loaded. This shift came due to both intellectual developments within the archaeological tradition, as well as stimuli from outside. The biggest influence came from diverse social groups who challenged the authority of Western archaeology and criticised the Eurocentric bias of the discipline. These groups included non-Western archaeologists and scholars, as well as indigenous peoples opposing to their objectification as "scientific study material" (David and Kramer 2001, 28; Hamilakis and Anagnostopoulos 2009, 68). David and Kramer argue that in the Recent period, which they date between 1982 and 1989 for the Recent 1 period and 1990 and 1998 for the Recent 2 period, a significant improvement can be seen in both the practice and publication of ethnoarchaeological research (David and Kramer 2001, 31). The incorporation of ethnographic work within specific archaeological studies now more commonly starts from the beginning of the research and is not merely incorporated after the fact (Hamilakis and Anagnostopoulos 2009, 70). However, the discipline has not reached maturity yet and more developments are still to come (David and Kramer 2001, 31).

4.2.4 Possible pitfalls in ethnoarcheology

When looking at the flaws of ethnoarchaeology, one can conclude most are rather similar to the pitfalls of ethnography. This is of course no surprise, as ethnoarchaeology also draws upon ethnographic works. Nevertheless, they should be briefly mentioned. Like ethnography, ethnoarchaeology sometimes presents the studied societies as 'frozen in time'. It is argued by David and Kramer (2001), and Hamilakis and Anagnostopoulos (2009) that at some point, the contemporary societies were primarily seen as sources of information or scientific study material instead of living societies. They were even seen as 'living fossils', completely erasing their developments between the material remains one tries to understand, and the society as it is now (David and Kramer 2001, 28; Gosselain 2016, 219; Hamilakis and Anagnostopoulos 2009, 68). This is of course a huge and unacceptable flaw. It also ties in to critique given by Gosselain (2016), stating that certain societies were never visited by ethnoarchaeologists, possibly because their way of life did not fit the image of prehistoric people the researchers were looking for (Gosselain 2016, 219). If this is the case, are the analogies drawn from certain ethnoarchaeological research even valid, as they do not take into account all possibilities?

This preconceived image of what prehistoric people looked like, can result in a huge observer bias. When a researcher goes into the field with a certain idea in their head of what they want to find, this can result in overlooking other possibilities that led to the formation of the archaeological record. This is why it is important to strengthen our arguments, and to not only base our descriptions on formal analogies. It is in these formal analogies that the biggest danger of ethnoarchaeology lies.

One can almost never find a one-on-one correlation between the actions of a studied contemporary society on the one hand, and the material record of another culture on the other (Twiss 2019, 19; Ucko 1969, 263). However, especially in the earlier stages of ethnoarchaeology, similarities between contemporary peoples and the archaeological record were seen as confirmation of actions and circumstances creating this record. Even when the society lived in completely different circumstances than the peoples of the past did (Gosselain 2016, 219). It echo's a universal generalisation of cultures, and the idea that all cultures evolve taking the same steps (Hodder 2012, 37). Of course, this does not happen anymore, at least not that often, but it remains a weak point in ethnoarchaeology. This means that, when using ethnographic or ethnoarchaeological information, one should be looking at context as well as similarities and differences. Analogies based solely on formal arguments should be regarded as unreliable, without regard of how many supplementary research has been added to strengthen it (Hodder 2012, 19). Next to this, similarities in outcomes does not mean that they activities were the same, as two very different activities might produce the same outcome (Twiss 2019, 19).

To summarise, ethnoarchaeology can be immensely useful in strengthening analogies about the past. However, the contemporary societies one works with should not be seen as a direct example of the peoples of the past. The contemporary societies are not static, living fossils, or scientific objects. They are people with their own context and way of life. Even though similarities can occur between the contemporary people and the material record, this does not mean they are the same. Especially as different activities can result in similar patterns. One should always keep in mind that ethnographic research is not to confirm a certain idea, but to broaden the scope of possible interpretations. As long as one keeps this in mind, ethnoarchaeology can be extremely helpful in gaining a better understanding of the past.

4.3 Experimental archaeology

As stated previously, experimental archaeology is one of many possible supplements to strengthen or weaken analogies. It is, like the previously discussed methodologies and theories, not a new concept (Millson 2010, 1; O'Sullivan and Souyoudzoglou-Haywood 2019, 1). On the contrary, it was already used in the late 1800's, when Pitt-Rivers reconstructed antler picks modelled on the ones found at Cissbury, Sussex. He argued these were used to dig ditches at a hillfort, and showed by using the replicas that this certainly was possible (Millson 2010, 1). However, experimental archaeology stayed under the radar until the 1960's, when Lewis Binford and others in the New Archaeology trend started advocating for experimental archaeology (Millson 2010, 2; O'Sullivan and Souyoudzoglou-Haywood 2019, 1). It was then that is became a practice in its own right. As stated before, Binford and others were looking for ways to make inferences about the past, using the present. Through actualistic research, such as ethnoarchaeology and experimental archaeology, ideas about the past could be tested and strengthened.

However, in the beginning of the 1980's, New Archaeology got criticised and rejected by new movements. This also meant the rejection of its sub-disciplines, including experimental archaeology. The Post-processualists, against New Archaeology or Processualism, argued that scientific laws cannot be applied to cultures as they all vary so greatly from each other. This is of course true, but the Post-processualists took it a step further and rejected all science within archaeology. This was their greatest flaw. In the 1990's, it became evident that a completely humanistic approach was also not advisable. Archaeology as a discipline had changed (for the better) under the Post-processualists, but it was now time to incorporate science once again. New techniques and applications were on the rise, and these were useful in supporting theory through gaining new forms of data. Science got back to a notable position within the discipline (Millson 2010, 2-3).

It can be expected that experimental archaeology gained more ground after science became important to archaeology, however this is not entirely the case. Millson (2010) argues that this is because the wider archaeological community does not fully understand experimental archaeology and its potential. She proceeds to give a definition:

> 'Experimental Archaeology is a process whereby controlled experimentation is used to answer specific questions (Millson 2010, 3)'

This process can take two forms: 1) experiments with the goal to test hypotheses made about either a site or a type of artefact; and 2) experiments to test methods used to gather data about the past, done to ensure that the collected data is a representation of the past (Hansen 2014, 167-168; Millson 2010, 3; Paardekooper and Reeves Flores 2014, 7). O'Sullivan and Souyoudzoglou-Haywood (2019) add that through this, we can create a better understanding of both the role and character of materiality and material culture in the lives of peoples of the past (O'Sullivan and Souyoudzoglou-Haywood 2019, 1). Testing is at the core of experimental archaeology, as it aims for an objective approach which should result in data that can be empirically understood. A scientific method, including precise recordings of the experiments, is important to ensure its replicability as well as falsifiability of the conducted research. When ensuring this, experimental archaeology can become an invaluable bridge between data and theory, where hypotheses and inferences about the past can be tested and confirmed or rejected. This can lead to the re-evaluation of more general theories, considering the new information. It can also serve as a new foundation from which other research can be conducted (Millson 2010, 3-4). Experimental archaeology is therefore incredibly promising, if done right.

4.3.1 Facts or experience: possible pitfalls in experimental archaeology

As has been argued before by Post-processualists, archaeology cannot be conducted by (only) using science as this does not account for variability in cultures and we risk omitting certain aspects of peoples lives, such as emotions and experiences. This argument is still given to highlight the flaws in a fully scientific approach in experimental archaeology. It is argued that the experience of creating, and the feel of the objects, are also an important part of experimental archaeology as it sheds light on non-material aspects of the lives of peoples of the past (O'Sullivan and Souyoudzoglou-Haywood 2019, 1). Millson (2010) counter arguments this however, as our experiences are still modern and will therefore always be biased (Millson 2010, 3).

Another pitfall, as with ethnography and ethnoarchaeology, is seeing the results of experiments as 'absolute' proof of the past. This can happen when one does not take into account that two different activities can result in the same or similar patterns in the archaeological record (Twiss 2019, 19). Again, analogies can be strengthened or weakened by supplementary research, but our ideas about the past will never be foolproof, unbiased, and confirmed. We can never recreate or reconstruct artefacts or situations as they were in the past. This should be kept in mind when conducting research: we can aim to understand the past, not confirm it.

4.4 Middle-range theory, ethnography and -archaeology, and experimental paleoethnobotany in this thesis

In this chapter, several theories and methodologies have been highlighted and their merits and pitfalls have been discussed. As none of the discussed theories or sub-disciplines is without its flaws, they will be combined in this thesis to strengthen the assumptions made. First of all, Middle-Range theory will be the point of departure for this thesis: ethnographical and historical works are used to study recipes. Recipes of which the damaged starch grains might still be on the archaeological remains that were excavated and analysed. However, to see if this is the case, experiments are conducted. In this case, the experiments serve as a bridge between the static material record, and the dynamics that created it inferred by descriptions of past and contemporary practices.

This takes the ideas of interpreting the static material record by comparing it to other parts of archaeological research, such as ethnoarchaeology and experimental archaeology, to strengthen or weaken the interpretations. This thesis aims to create a better understanding of damage patterns due to cooking, which potentially can be applied more broadly than only on the specific starch grains researched. In this sense, the experiments are the actualistic research testing the links between the dynamic organisations of the past, and the static material record. However, in doing this research, it needs to be kept in mind that: 1) analogies or inferences of the past cannot be confirmed, we can merely strengthen or weaken our ideas; and 2) the results from these experiments are one of the many possibilities, it can be that there are more ways to create a certain damage pattern that were not tested yet. As this thesis only focusses its comparison to the archaeological record of two sites in the Dominican Republic, some generalisation can be applied. However, it should also be kept in mind that the universal laws or generalisations proposed in the middle-range theory can be problematic, as it is assuming all cultures might do things the same way since their archaeological record show similar patterns. Even within one household, recipes can differ, but the results will be more or less the same. Universal laws will therefore not be assumed.

To understand the ways peoples of the past might have prepared food, ethnographical and ethnohistorical sources have been consulted. Some of these sources include, but are not limited to, a copy of Christopher Columbus' journal by Las Casas , the natural history of the West Indies by De Oviedo, a study into the lives of the Waiwai people by Howard (2001), and ethnohistorical and archaeological research in Trinidad, Tobago and the lower Gisnoca Interaction Sphere by Boomert (2000). Some 'recipes' were also supplemented with contemporary recipes, as the historical sources often do not describe the preparation of the food in detail, if at all. This perfectly illustrates the problem of bias in these accounts. In historical, but also contemporary accounts of societies, the writer has a say in what gets reported and what not. This means that what the ethnographer deems important will be discussed in more detail than what they do not notice or see as less important. This might not have been done on purpose, but still affects the way we can use these sources in our own research. Next to this, ethnographical, ethnohistorical and ethnoarchaeological sources are useful in broadening our perspectives on what might have been. They can, however, not confirm anything. Even if a cultural link between the material record and the contemporary societies can be established, this does not mean nothing has changed and how the people live now is how they lived hundreds of years ago. People and cultures are dynamic, they change. However, using these sources, with care, helps broaden our horizons and gives us a multitude of possibilities which we can strengthen or weaken by using other supplementary research.

In order to compare the archaeological record with the ethnographical sources, a bridge is needed. In this case, the experiments conducted and their results are used to see if our ideas of which foods have been processed on the excavated ceramics make sense. Again, we cannot confirm our ideas, but we can strengthen them. It is also taken into account that the results may be similar, but not exactly the same. There are so many factors that can possibly influence the results, such as moisture and heat in the air, the artefacts being buried in soils for centuries, the production of the ceramics, etcetera. The experiments in this thesis were conducted indoors on a cooking pit to keep the variables as stable as possible, so that the experiments could be replicated and are falsifiable. This is most probably very different from the way the archaeological starch grains with which the results will be compared were prepared. This is really important to keep in mind when comparing these results, but also other results from experimental archaeology.

To conclude, whether analogies are (now) very obvious and widely accepted, such as the example of stone axes previously mentioned, or very obscure, they are still based on our interpretations. It is therefore important to use as many different sources as one can to strengthen or weaken these.. That is why this thesis is basing its methodology on the middle-range theory, and ethnography and ethnoarchaeology, and experimental archaeology. These studies together are compared to the material record to understand what processes could have shaped it. In doing so, this thesis will hopefully shed light on possible preparation techniques in the past, strengthening our understanding of foodways.

5 MATERIALS AND METHODS

This chapter will describe the materials and methods used in the experiments and the previously published archaeological starch grain research done on the Dominican Republic. A short overview is given on the used ingredients and tools, as well as the steps taken to process the foodstuffs. To illustrate the experiments appendix A can be consulted for a selection of videos of the conducted experiments.

5.1 EXPERIMENTS

5.1.1 The selection of the used ingredients and tools

Several tools were acquired in order to conduct the experiments, which will be listed here. Cheesecloths acquired from a local home store. These were used to separate the macroremains from the starch residue during the experiments, and were used to boil the *pan de maíz* in. They were washed and boiled before use, and discarded after use. Next to this two 'griddles' were bought (see figure 5-1), one for the purpose of maize experiments and one for the manioc experiments. They were bought from www.terracottaworld.co.uk, and made from red mine clay and river bed clay from an unknown location in India. They are processed to remove sand impurities before they are moulded into plates. The plates are fired in an earthen kiln, fuelled with wood and waste paper, reaching temperatures between 700 and 800 degrees Celsius. The temperature is gradually increased, kept steady for a while and then gradually decreased (Terracottaworld, personal communication via email on 23/01/2020). The griddles were washed before use and rinsed with boiled water.

Demineralised water was acquired at the local supermarket to soften the samples with. A new peeling knife was bought for the experiments, and washed in between experiments and heated when wet until red-hot to eliminate or gelatinise possible residue starch grains. Several new measuring cups were acquired as well, to soften the samples in. They were washed after each sample and rinsed with boiling hot water to eliminate residue starch grains. A food thermometer was borrowed. Before using it, it was washed multiple times and heated until red hot. This was also done in between experiments.

Metal cooking pans from the kitchen were used. However, before use they were washed multiple times and rinsed with boiling water. This was also done between experiments..

A stone mortar and pestle were acquired new for the experiments from local home store. They were washed multiple times before use, and in between experiments. They were also rinsed with boiling water before use. For grating the manioc, a grater was bought from a local home store. This one was also washed multiple times before use, as well as rinsed with boiling water. This was also done between experiments. Lastly, 'Bresser' microscope slides and cover slides were acquired from an online photography store to put the samples on for analysis.

Different ingredients were gathered to cook with, including manioc of the sweet, non-poisonous variety, acquired from the local supermarket, uncooked ripe sweet corn in husk from the local supermarket, and dried maize (type unknown) from the local pet store.

Figure 5-1
One of the two 'griddles' acquired for this thesis. This particular one was used to roast maize on the cob and as loose kernels, as well as several samples of pan de maíz. The cracking occurred during the last experiment.
Photo by: Anika Hellemons

5.1.2 The sampling and processing of the prepared foodstuffs

As beforementioned, extracting starch grains from prepared foodstuffs has to be done with a different approach than when extracting them from archaeological remains. As this thesis focuses on the changes through food preparation, after each preparation step a sample was taken of at least 3 cm^3 , if possible. These samples were put in beakers, which are cleaned and sterilized beforehand. Demineralised water was added to soften the samples and the two were mixed together (Pagán-Jiménez *et al.* 2017, 36). In the case of the undamaged maize kernels, or roasted kernels, the outside of the kernels was carefully sliced open an the endosperm was extracted.

After the water and sample have been properly mixed, the concoction was filtered through new pieces of cloth, which were washed and boiled beforehand in order to eliminate contaminating starch grains. The filtering is done to separate the macroscopic waste from the starches. The remaining starchy water is homogenized before extraction is done with a pipette. This should be done approximately five millimetres above the bottom of the beaker and within five seconds after stirring. The extracted sample was then placed on a new, clean slide, dispersed with the pipette and covered with a new glass cover slide. They are then ready to be analysed and described (Pagán-Jiménez *et al.* 2017, 36).

5.1.3 Conducting the experiments

In order to determine which foodstuffs were going to be prepared and how, several historic sources as well as more recent ethnographic works have been consulted. In total four foodstuffs were selected as these seemed promising in terms of creating different types of damage patterns on the starch grains within the used plants. The plants used in these experiments are also some of the plants that have been recovered most in previous research, or were expected to be most ubiquitous in the Caribbean (Berman and Pearsall 2008, 183-184; Ciofalo *et al.* 2019, 1636-1367; Deagan 1988, 194; Keegan and Hofman 2017, 49, 105, 135, 183, 250; Mickleburgh and Pagán-Jiménez 2012, 2468-2470; Newsom and Wing 2004, 183; Oliver 2009, 15; Pagán Jiménez 2011, 326, 341; Pagán Jiménez 2013, 394, 396, 401; Wilson 2007, 86-87). Table 5.1 shows starches recovered in previous research on the Dominican Republic and their ubiquity. The following section of this chapter will explain what foodstuffs were prepared in what way.

Site	Species	Total	Ubiquity
El Cabo			
	Fabaceae	1	100%
	Ipomea batatas	1	200%
	cf. *Ipomea batatas*	1	x
	cf. Marantaceae	1	100%
	Zamila pumila	1	100%
Juan Dolio			
	cf. Fabaceae	1	50%
	Ipomea batatas	2	100%
	Phaseolus vulgaris	1	50%
	Phaseolus sp.	1	50%
	Zea mays	3	150%
	cf. *Zamia pumila*	2	100%
Punta Macao			
	Zea mays	2	50%
	Fabaceae	1	25%
	Ipomea batatas	2	50%
	Zamila pumila	2	75%
	cf. *Zamia pumila*	1	x
El Flaco			
	Zamia spp.	3	8%
	Manihot esculenta	5	13%
	cf. Zingiberaceae	1	3%
	Zea mays	5	28%
	cf. *Zea mays*	6	x
	Ipomea batatas	1	15%
	cf. *Ipomea batatas*	5	x
	Capsicum sp.	1	3%
	Fabaceae	3	10%
	cf. Fabaceae	1	x
La Luperona			
	Zamia spp.	2	20%
	cf. *Zamia* spp.	5	x
	cf. *Xanthosoma sagittifolium*	2	6%
	Capsicum spp.	1	3%
	cf. *Manihot esculenta*	1	3%
	Ipomea batatas	1	3%
	Zingiberales	2	6%
	Fabaceae	2	6%

Table 5.1
This table provides an overview of the recovered starch grains from different sites and different samples. The samples from El Cabo, Juan Dulio and Punta Macao were analysed by Mickleburgh and Pagán-Jiménez (2012), and were taken from dental calculus. The samples from El Flaco were taken from ceramics, and ceramic griddles (Ciofalo 2019; Hellemons 2018) and shell tools (Ciofalo 2020). The samples from La Luperona are taken from ceramic griddles and shell tools (Ciofalo 2019; Ciofalo 2020).
Ubiquity refers to the amount of securely and tentatively identified taxa, divided through the amount of artefacts analysed. For the sites with dental calculus samples, this results in a high ubiquity as a low amount of samples were analysed. El Flaco and La Luperona provide a better overview of the presence of certain species.

5.1.3.1 *Pan de Casabe:*

Pan de Casabe, or simply cassava, is a bread made of manioc. The use of manioc to make *Pan de Casabe* been described by several chroniclers, ethnographers and historians (Columbus [1492-3], 78, 108, 113, 123, 136, 163; De Acosta [1604], 232; Dunmire 2005, 85-86; Howard 2001, 212; Kipple 2009, 131-132; Mckillop Wells 2015, 42, 178-180; Oviedo [1592], 16-17; Politis and Alberti 2007, 215; Williams 1970, 28; Solokov 1991, 21-22). These sources describe the process as done with bitter manioc, the poisonous variant, as they describe how the juice is squeezed out of the grated mass in order to cleanse the dough from the poison. Even though these experiments will not make use of bitter manioc, this process was still replicated as pressure can also leave traces on the starches. The following steps were done in order to prepare the cassava:

1. Peel the manioc
2. Grate the manioc
3. Rinse the mass with water, squeeze it dry, rinse again and then squeeze a final time
4. Place the mass on a hot griddle, bake until firm

The manioc was peeled with a potato peeler only used for peeling manioc, which was cleaned every time by washing it and subsequently heating it until red hot. If any starches would remain on the peeler, they would be gelatinized due to the heat in combination with water (Hellemons 2018, 33; dr. Pagán-Jiménez 2018, personal communication, Pearsall 2015, 342). This would make any contamination clear. After the peeling, the manioc was grated with a grater. This grater, like the peeler, is cleaned every time.

After the manioc was grated, the mass was rinsed with water, put in a clean cloth, squeezed dry, and rinsed and squeezed again two more times. After this, the cloth was discarded to prevent contamination. The squeezed mass was sampled and then baked on a hot griddle. After baking, the *Pan de Casabe* was sampled and the hot griddle rinsed.

The temperature of both the food and the ceramics was measured right before extracting the samples with the aforementioned thermometer. The duration of the grating and the cooking was done with different timesteps. This means that first, the manioc was peeled with a knife and then grated for either 10, 20 or 30 minutes (figure 5-1). Following this, the grated manioc was divided into three groups; one that was baked for 2 minutes, the other was baked for 5 minutes and the last one baked for 10 minutes. This resulted in 9 samples all of which were grated and baked at different periods of time.

Figure 5-2
Photo showing grated manioc mass together with the manioc tuber. The manioc was grated for either 10, 20 or 30 minutes before being baked on a griddle.
Photo by: Anika Hellemons

5.1.3.2 Pan de maíz:

Pan de maíz, as the name suggests, is a form of bread that is made of maize or corn. As with Pan de Casabe, the process of making this has been described in both chronicles and ethnographic works (Boomert 2000, 98; de Acosta [1604], 230; de Gomara [1552], 185;

Oviedo [1526], 15; Politis and Alberti 2007, 210). Variation occurs in these sources when considering how the dough is heated. It can be boiled (Boomert 2000, 98; Oviedo [1526] 15; 113), mixed with sugar and then baked (De Acosta [1604], 230), mixed with salt and then baked (Mckillop Wells 2015, 39), fried (Boomert 2000, 98) and wrapped in leaves and put in the coals (de Gomara [1552], 185; Oviedo [1526], 15). As sugar does not originally grow in the Caribbean and was introduced by the colonists, this will not have been used in Pre-Colonial times (Dunmire 2005, 89, 95; O'Connel 2004, 8, 24, 31; Plasa 2015, 2; Williams 1970, 25). Additionally, since this thesis focuses on ancient starch grains recovered from excavated ceramics, the dough wrapped in leaves and put in coals will not be prepared.

1. Dry out the kernels
2. Soak the kernels
3. Grind the maize with a mortar and pestle, add water from time to time during the grinding
4. Make sure the dough is mixed well
5. Heat the dough:
    1. Make rolls and boil these
    2. Fry parts of the dough
    3. Mix with salt and then bake

The kernels were already dried out when acquired to speed up the process. The kernels were soaked in water for one hour, after which the kernels were rubbed together to separate the endosperm from the pericarp, which is the outer layer (Nannas and Dawe 2015; 659). They were then patted dry.

Before grinding the soaked kernels, a sample was taken to be analysed. Then, the maize was ground with a mortar and pestle, adding a bit of water from time to time to make a kneadable dough. The dough was then sampled. The mortar and pestle were cleaned thoroughly every time. The dough was split in three parts and were either 1) made into rolls and boiled, or 2) fried in smaller bits on a hot griddle. The finished products was sampled and the used ceramics rinsed.

Again, as with the previous experiments, temperature is not a variable, but was measured nonetheless with a food thermometer right before extracting the samples. Instead there are time variables for 1) grinding the maize for 10, 20 or 30 minutes; and 2) heating the dough. The heating of the dough was done in three different ways, of which the boiling was done for 5, 10 or 20 minutes, and the frying and baking for either 2, 5, or 10 minutes.

5.1.3.3 Roasted or boiled maize:

Roasted or boiled maize could be considered an easy way to prepare this type of starchy food. It has been reported by several chroniclers as one of the ways the Indigenous Peoples on 'the islands' prepared their maize (De Acosta [1604], 230; De Gomara [1551], 185; Oviedo [1526], 15). It has also been reported by Boomert (2000) that in the Caribbean maize was usually boiled or roasted. The preparation could either be done by preparing the whole cob, or by slicing of the kernels and preparing these.

As boiling and roasting has been described by several sources to be the way it was traditionally prepared on the islands, it is valuable to also experimentally prepare this type of food.

1. Prepare the maize
    a. Clean the cob
    b. Clean the cob and slice kernels off
2. Heat the maize
    a. Boil
    b. Roast

There are several ways of preparing maize which include on the cob or slicing off the kernels and either boiling or roasting the cob or the kernels. Firstly the cob was cleaned by taking off the husks and rinsing of nay dirt. Following this, the cob was either boiled in a pan or roasted on a hot griddle. The other way of preparation includes slicing off the kernels with a knife only used to slice off maize kernels. The knife was washed and heated until red hot between samples to eliminate contamination. The kernels were then either boiled or roasted. In both scenarios, the finished product was sampled, and the griddle was rinsed. The pans were washed thoroughly and rinsed with boiling water before conducting new experiments in them.

Again, temperature is not a variable in this experiment but was measured with a thermometer right before extracting the samples. The other two variables were 1) boiling for either 10, 20 or 30 minutes, or 2) roast for either 10, 20 or 30 minutes.

5.1.4 Analysing the starch grains

The samples taken from the experiments were analysed at Leiden University with a Leica DM 2700 polarising microscope. As the global pandemic influenced the time available to the author for the analysis of the slides, the decision was made to describe ten starch grains per sample. These starch grains were selected arbitrarily, without any system. This resulted in a total of 504 analysed starch grains. Of each grain, the shape, size, Maltese cross or birefringent properties, as well as damage patterns and other striking characteristics were noted. A full overview can be seen in appendix B, presenting the sample logbook. Additionally, photos were taken per grain as well.

5.2 Archaeological comparative collection

Previous research in both the ancient foodways of the Caribbean and Amazonia, as well as to morphological changes in starches due to the usage of certain food processing techniques have been conducted. Both these topics are of importance to this research as they present datasets usable for comparison with the conducted experiments. Especially previous ancient starch grain analysis conducted in the Dominican Republic are of importance, as these will function as a comparison to the known archaeological record.

In total the author considered 3 different ancient starch grain studies conducted on clay gridles, cooking pots and shell tools. A study on starch grains trapped in human dental calculus by Mickleburgh and Pagán-Jiménez (2012) was omitted as these starches will show additional chewing damage, which might obscure the damage patterns done by processing the foodstuffs prior to consuming them. The studies of clay griddles and cooking pots (Ciofalo *et al.* 2019; Hellemons 2018) are chosen as they are the archaeological equivalent of the tools used in the experiments, which also used griddles and cooking pots. Additionally, the study on shells (Ciofalo *et al.* 2020) was included as these were most likely tools used for processing certain crops such as manioc (*Manihot esculenta*), maize (*Zea mays*), and sweet potatoes (*Ipomea batatas*) (Ciofalo *et al.* 2020, 363). Therefore, the starch grains recovered from these shells might show damage patterns related to peeling or cutting manioc and maize, the crops used in the experiments.

Both of the selected sites are located along the *Ruta de Colón*, the route Columbus took when he travelled in 1494 from the coast to the interior of *Ayiti,* the island which is now called Hispaniola. They were excavated between 2013 and 2016 by a team from Leiden University as part of the ERC-synergy project "NEXUS1492: New World Encounters in a

Globalizing World" (Guzzo Falci *et al.* 2020, 183; Hellemons 2018, 8; Hofman and Hoogland 2015, 5; Hofman *et al.* 2018, 203; Jean 2019, 19; Keegan and Hofman 2017, 128; Ting *et al.* 2016, 377). Both sites will now be discussed in further detail.

5.2.1 El Flaco

El Flaco is located in the foothills of the Cordillera Septentrional, on the southern site and lies 300 metres above sea level. Its location is close to *El Mirador de Colón*, from which it is said that Columbus overlooked the Cibao Valley for the first time when making his way along the *Ruta de Colón* to the interior of the island. El Flaco lies approximately 20 kilometres from the coast, and 8,5 kilometres from La Luperona, and has been interpreted as a midsize hamlet with permanent households. Two periods of occupation have been determined. The first one dates from A.D. 800 to 900, characterised by the mixed Ostionoid and Meillacoid assemblage. The main occupation has been dated between the thirteenth and fifteenth century, with the final date being around A.D. 1490. This occupation is characterised by Chicoid style pottery, with lower quantities of Meillacoid style pottery. (Ciofalo *et al.* 2019, 1638; Guzzo Falci *et al.* 2020, 183; Hellemons 2018, 8; Hofman and Hoogland 2015, 8; Hofman *et al.* 2018, 210; Keegan and Hofman 2017, 128; Ting *et al.* 2016, 377).

Between 2013 and 2016, excavations, drone flights, and topographic mapping with a robotic total station unveiled an archaeological landscape consisting of flattened areas with house structures, surrounded by earthen mounds and walls. The flattened areas were created by levelling the limestone bedrock (*calice*), which allowed for the building of both housed and ancillary structures, such as cooking huts. Additionally, hearths were uncovered surrounding the houses or deposited within the mounds. These mostly consisted of fire-cracked stones, surrounded by ceramic or stone griddles, which are of interest for this thesis (De Mooij 2018, 102-109; Hellemons 2018, 8; Hofman and Hoogland 2015, 8-9; Hofman *et al.* 2018, 210; Guzzo Falci *et al.* 2020, 183; Keegan and Hofman 2017, 128-129; Sonnemann *et al.* 2016, 6).

Different domestic and rituals took place on these walls and mounds, which consist of layers of black and brown soil. These alternate with lenses of ash and hearths, which represent the garbage that was swept away from the flat areas and then burned. Next to ash, these lenses include enormous quantities of land snails (*Pleurodonte* sp.), the remains of crabs, rodents, snakes, turtles and birds, small amounts of clams originating from the mangroves, ceramics, (stone) tools, and a variety of paraphernalia. Mixed together with earth, the white marl from creating levelled platforms, and the ash from active cooking zones, the garbage ash lenses result into fertile soils suitable for kitchen gardens (Hellemons 2018, 8-9; Hofman and Hoogland 2015, 9; Hofman *et al.* 2018, 210-211; Guzzo Falci *et al.* 2020, 183; Keegan and Hofman 2017, 128-129; Sonnemann *et al.* 2016, 6). Phytolith analysis on samples from one of these household mounds argue for a subsistence primarily focussed on agroforestry and orchard-type plant production (Pagán-Jiménez *et al.* 2020., 11-13).

5.2.1.1 Starch grain analysis at El Flaco

To the knowledge of the author, three researches into the starch grains have been conducted that are accessible. Two of those are published (Ciofalo *et al.* 2019, Ciofalo *et al.* 2020), the other is an unpublished Bachelor thesis from the University of Leiden (Hellemons 2018). Two of these studies focus on ceramics, of which one solely on clay griddles (Ciofalo *et al.* 2019), and the other on a mix of ceramics (Hellemons 2018). The other research was conducted on shell artefacts (Ciofalo 2020). A mix of several types of plants was recovered, including zamia (*Zamia* spp.), manioc (*Manihot esculenta*), ginger (cf. Zingiberaceae), maize (*Zea mays*), sweet potatos (*Ipomea batatas*), starches from the bean family (Fabacaea), and chili pepper (*Capsicum* sp.) (Ciofalo 2019, 1646; Ciofalo *et al.* 2020, 369; Hellemons 2018, 39). The results of these researches, specifically concerning the damage patterns, will be discussed in further detail in the results chapter of this thesis.

5.2.2 La Luperona

As stated previously, La Luperona is located at around 8,5 kilometres from El Flaco. It lies on the other (northern) side of the Cordillera Septentrional and has a view of the coastal zone, from which it lies 12 kilometres. Like El Flaco, the site has been interpreted as a hamlet of permanent household, operating within a network of other settlements (Ciofalo *et al.* 2019, 1638; Ciofalo *et al.* 2020, 364; Guzzo Falci *et al.* 2020, 183; Hofman and Hoogland 2015, 5; Ting *et al.* 377). The site was discovered in 2011, and in 2013 excavations were carried out uncovering posthole features suggesting habitational structures. These were surrounded by kitchen areas and hearths, the latter consisting of fire-cracked stones and griddle fragments like encountered at El Flaco. Unlike at El Flaco, the burned garbage deposits did not result in mounds, but only in very small undulations in the local terrain of the site (Hofman and Hoogland 2015, 6; Guzzo Falci *et al.* 2020, 183).

During excavations, land snails, fishbones, sea shells and the remains of terrestrial fauna have been unearthed, characterising the subsistence remains of the site. Additionally, tools, beads and other regalia made from bone, shell and lithics have been uncovered. The ceramic assemblage is characterised by Meillacoid and Chicoid pottery, as is the later occupational phase in El Flaco, with a few Ostionoid sherds. The settlement has been dated between the thirteenth and fifteenth century A.D. (Ciofalo *et al.* 2019, 1638; Ciofalo *et al.* 2020, 364; Hofman and Hoogland 2015, 5-6; Guzzo Falci *et al.* 2020, 183; Ting *et al.* 2016, 377).

5.2.2.1 Starch grain analysis at La Luperona

As far as the author is aware, only two researches into the artefacts of La Luperona have been conducted. One was focussed on the clay griddles (Ciofalo *et al.* 2019), while the other researched shell artefacts at the site (Ciofalo *et al.* 2020). The recovered starch grains include zamia (*Zamia* spp.), chili pepper (*Capsicum* spp.), sweet potato (*Ipomea* batatas), ginger (Zingiberaceae), plants from the bean family (Fabaceae), a possible white yautia starch (cf. Xanthosoma sagittifolium) and possibly manioc (cf. *Manihot esculenta*). No maize (*Zea mays*) was recovered (Ciofalo 2019, 1646; Ciofalo *et al.* 2020, 370). The damage patterns registered on the starch grains will be discussed in more detail in the results chapter of this thesis.

6 RESULTS

In total, 503 starch grains were documented, the results of which will be published here. Per step, per experiment, samples were taken and analysed under a Leica DM 2700 P microscope. Per sample, 10 starches were picked out and documented in detail, by noting their size, shape, visible damages and Maltese crosses. Several photos were also taken per starch, some of which will be shown here to illustrate the results. This chapter will present the results of the analysis and briefly discuss the visible damage per sample. For a full overview of the recorded grains per experiment per sample, one can refer to appendix B. A more in depth discussion on the results and their meaning will be given in the next chapter. Next to the results from the experiments, three previously conducted researches into starch grains from the Dominican Republic were consulted. These studies serve as a comparative collection and their results will also be presented in this chapter..

6.1 UNDAMAGED *ZEA MAYS*

To better understand what damage has occurred after processing the maize, both previously published research and samples taken of the unprocessed grains before the experiments in this thesis are consulted. The samples taken for this thesis will be discussed here, the results are presented in table 6.1.

Experiment ID	Maize
Size range	9.4 - 16.8
Mean	13.0
Undamaged	x
Central depressions	x
Bright ring	x
Surface cracking	1
Empty or flat	x
Enlarged	x
Wrinkled surface	x
Gelatinisation	x
Melting	x
Crust	x
Fissures	4 Stellate fissures

Table 6.1
This table presents the results from samples taken from undamaged Zea mays*. The size range and mean, as well as various damage patterns are noted. Whenever an X is noted, no presence of this category was documented in the samples.*

6.1.1 Shape:

Of the ten documented starches, none were perfectly spherical. Four were almost but had hints of flatter sides, although one of these might have been completely spherical but obscured by another starch laying over it. Four starches were documented as being partially oval, of which two were showing rather irregular shapes. One of these was a clear double oval, while another one was more triangular in shape. Only one very clear truncated starch was documented. The last one had a rounded pentagonal shape.

6.1.2 Size:

Per starch, two measurements were taken. The size of the documented starches ranged from 9.4 µm to 16.8 µm. The mean of the starches is 13.0 µm.

6.1.3 Maltese cross:

In all but one starch, the Maltese crosses are visible enough for documentation. In all nine of the starches, the Maltese cross is, in fact, a cross. In five cases, one arm is slightly bended. In one of these five, it seems like an extra arm had occurred. In three cases the arms were straight, and in one case the arms were damaged so that it looked like it had more than four arms (figure 6-1).

6.1.4 Damage patterns:

Even though the starches were not intentionally subjected to grinding or heating, some did show possible damage. One of the starches did not display a Maltese cross, while two others had either damaged arms or a split one. One of the starches seemed to have a damaged border, marked as surface cracking. Additionally, the stellate fissures seem to be enhanced (see figure 6-1 for an example of this, and other damage).

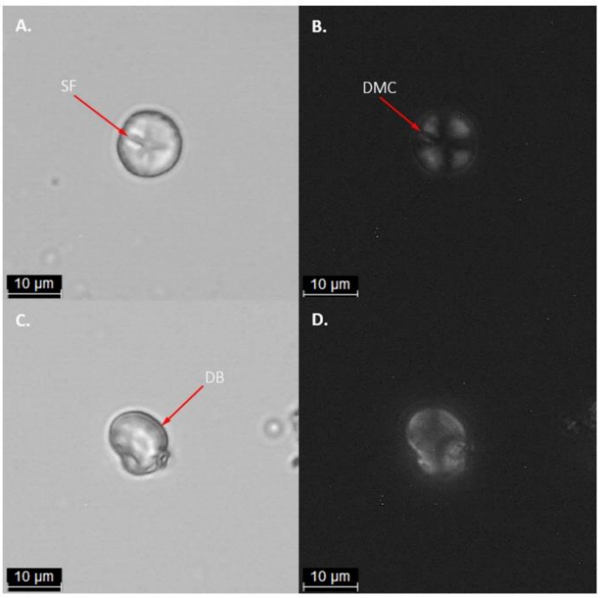

Figure 6-1
Starch grains documented in the unprocessed Zea mays *samples. A: Starch grain M4, Irregular oval shaped starch grain, with a stellate fissure. B: Same as A, but under polarised light, showing a cross shaped Maltese cross with straight arms. One arm seems damaged. C: Starch grain M10, double oval shaped starch grain with a double border. D: Same as C, but under polarised light, showing a cross shaped Maltese cross with straight arms.*
DB: Double border; DMC: Damaged Maltese cross; SF: Stellate fissure.
Photos taken by Anika Hellemons with a Leica DM 2700 P (630x) microscope.

6.2 DAMAGE PATTERNS FROM ROASTING MAIZE

The maize was roasted both on the cob and as loose kernels. MKR1 discusses the samples that were cut off the cob before toasting them to see what damage this does to the grains. This was also done to the boiled maize, but not discussed as it is done here.

6.2.1.1 Roasting maize on the cob

An increase can be seen in the mean and size ranges of the starch grains (see table 6.2). When looking at the recorded damage one can see that all samples show enlarged grains, but in low quantities. Two of the samples also seemed to have a grain without any damage. Both of these granules still have their birefringent properties, but the grain in MCR1 has no clear cross anymore. The grain from MCR2 shows a vague cross with possible straight arms. In all samples, Maltese Crosses are recorded: MCR1 shows five grains with crosses of which four are straight and one is wavy; MCR2 has four recorded crosses, they are all straight; MCR3 only has two recorded crosses of which one is cross-shaped and straight, the other one is X-shaped and straight. A downward trend in visible Maltese Crosses can be seen.

All samples show five grains with central depressions. A downward trend can be seen in surface cracking. Some sort of trend can be seen when looking at gelatinisation, even though the numbers are low. MCR1 and MCR2 have less gelatinised grains than MCR3, which could mean that the cracked grains gelatinise faster explaining the difference. Three grains show signs of melting (see figure 6-2 for an example of melting and other damage), and two are encrusted, both seem to have no real trend.

Experiment ID	MCR1	MCR2	MCR3
Size range	7.9 - 35.2	8.0 - 27.2	4.6 - 61.9
Mean	16.7	12.4	19.0
Undamaged	1	1	x
Central depressions	5	5	5
Bright ring	x	x	x
Surface cracking	7	4	4
Empty or flat	x	x	x
Enlarged	2	1	3
Wrinkled surface	x	3	5
Gelatinisation	2	1	3
Melting	2	x	1
Crust	x	x	2
Fissures	1 stellate, 1 y-fissure	1 linear fissure	1 linear fissure

Table 6.2
This table presents the results from samples taken from roasting the whole Zea mays *cob with various roasting times. MCR1 was roasted for 2 minutes, MCR2 for 5 minutes, and MCR3 for ten. The size range and mean, as well as various damage patterns are noted. Whenever an X is noted, no presence of this category was documented in the samples.*

A relatively low amount of grains lost their shapes due gelatinisation or other damage. In MCR1, three starch grains lost their shape, MCR2 has only one without a clear shape, and MCR3 has four without a shape. It could be that, since the kernels of the maize were still packed together tightly on the cob while roasting, this affected the how the starch grains reacted to the heat. There is less room for gelatinisation and enlargement, which resulted in the lower size ranges and low quantity of gelatinised grains. This can also explain the preservation of most of the shapes, as there is less space to change shapes.

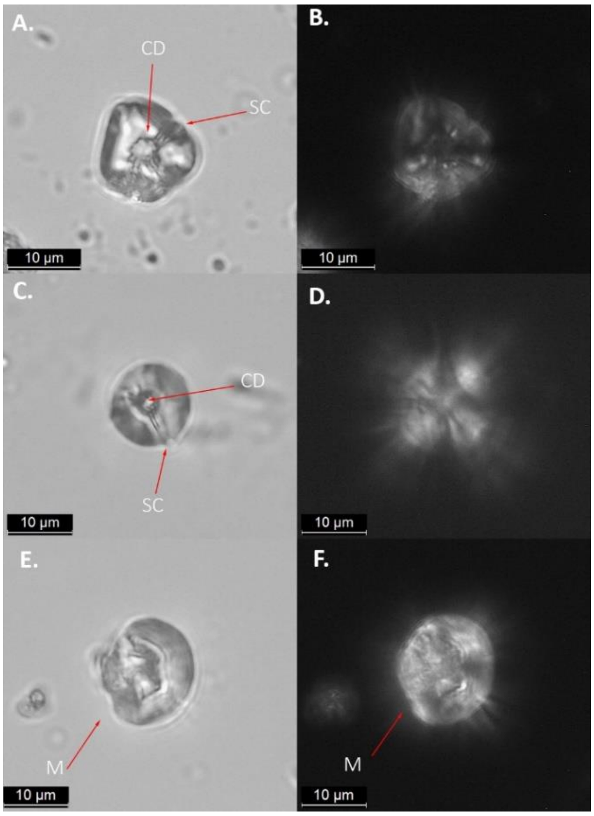

Figure 6-2
Starch grains documented in the Zea mays *samples roasted on the cob. A: Starch grain MCR1-2 showing surface cracks and a central depression. B: Same as A., but under polarised light. Showing a cross with straight arms. C: Starch grain MCR2-10 showing a central depression and surface cracks possibly originating from a linear fissure. D: Same as C., but under polarised light. Showing a cross with straight arms. E. Starch grain MCR3-9, showing signs of melting. F. Same as E., but under polarised light. The Maltese cross has been damaged by the melting of the grain.*
DB: Double border; DMC: Damaged Maltese cross; SF: Stellate fissure.
Photos taken by Anika Hellemons with a Leica DM 2700 P (630x) microscope.

6.2.1.2 *Roasting loose maize kernels*

When looking at the results of the roasted loose maize kernels, the change in size is striking. All of the samples show ranges outside of the previously documented ranges for undamaged grains (table 6.3 for the size range, means and other damage). Means are varying, but all higher than the described 13.0 µm in this research, or the 8.0 to 19.0 µm described in other previously addressed sources. This does not include MKR1, since this sample was only sliced not roasted. The enlargement of the grains can also be seen when looking specifically at the damage patterns. When not considering the high amount in MKR2, an ascending trend can be observed, with more enlarged grains the longer the kernels were roasted. It is interesting that MKR1 does show enlarged grains, which might be due to the pressure of the knife slicing true, opening up the grain.

Experiment ID	MKR1	MKR2	MKR3	MKR4	MKRB
Size range	5.4 - 45.7	6.5 - 61.8	10.4 - 41.2	10.5 - 55.2	13.8 - 43.6
Mean	19.1	31.0	22.6	29.7	27.3
Undamaged	4	x	x	x	x
Central depressions	1	1	x	3	1
Bright ring	x	x	x	x	x
Surface cracking	4	9	9	7	8
Empty or flat	1	x	x	x	x
Enlarged	3	8	4	5	7
Wrinkled surface	3	1	9	7	3
Gelatinisation	x	9	8	5	6
Melting	x	x	3	4	1
Crust	x	x	2	3	2
Fissures	x	x	x	x	x

Table 6.3
This table presents the results from samples taken from roasting loose Zea mays *kernels with various roasting times. Additionally, MKR1 shows the damage done by slicing of the kernels. MKR2 was roasted for 2 minutes, MKR3 for 5 minutes, and MKR4 for ten. The size range and mean, as well as various damage patterns are noted. Whenever an X is noted, no presence of this category was documented in the samples.*

Another damage pattern that is striking is the gelatinisation of the starch grains, as this is a descending trend. It could be that during the heating the starch grains are so gelatinised that they are damaged beyond recognition or fall apart. The longer the starch grains are heated, the less starch grains keep existing, especially when they are already gelatinised. The prolonged heat could also be why the first two samples do not contain any 'melting' starch grains, indicating that melting might only occur after a certain amount of time and heat.

Of course, slicing the kernels of leaves some traces as well. MKR1 shows damage patterns that are also visible in the heated samples such as enlargement, but also shows four undamaged grains while the other samples have none. Next to this, one starch grain is enlarged, has cracks around the edges of the grain and looks flat and empty. This first was mistakenly identified as gelatinised, which is considered not possible as gelatinisation is associated with heating. However, empty looking grains with a flat appearance have been described by Babot (2003) as well. Next to this, four grains display surface cracks (see figure 6-3). It seems that heating starch grains in low humidity makes their surface crack, which also happens in low quantities while slicing kernels of a cob. The amount of surface cracks in the heated samples seems to be quite stable, in contrast to the roasted cob. Here an ascending trend with a lower amount of cracks can be seen. Interesting is also the amount of wrinkled surfaces present in the samples. It is highly variable, and an interesting characteristic (see figure 6-4 for this type of damage and others).

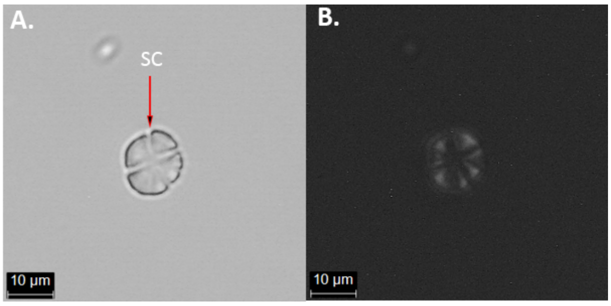

Figure 6-3
Starch grain encountered in the sliced Zea mays *samples. A: Starch grain MKR1-3 showing surface cracks. B: Same as A., but under polarised light. One can see the damage the Maltese cross has taken due to pressure. SC: Surface cracks.*
Photos taken by Anika Hellemons with a Leica DM 2700 P (630x) microscope.

In four of the five samples, starch grains with central depressions were registered. They are found in low quantities though. Next to this, only three samples showed a crust forming around the starch grains, coincidentally the same samples that showed melting starch grains. It could be that the formation of crust is linked with the melting of starch grains, but not al starch grains with crust seemed to be melting and not all melting grains seem to have formed a crust.

Also interesting are the Maltese crosses. MKR1, not having been heated, shows six clear crosses of which five still show all their arms. Two grains have vague birefringence and two have none. This changes a lot when looking at the samples that have been heated, MKR2 yields six grains without birefringent properties and four with only vague birefringence left. In MKR3 only one grain has lost its birefringence completely. MKR4 has six grains that are clear, of which three also still show a cross. MKRB only shows one clear

X-shaped cross, the other seven have little to no birefringent properties left. This shows that even though maize starch grains might be heated for a long time (30 minutes), they still seem to have some grains left with birefringent properties

It seems that the starch grains in the loose kernels take more damage than the grains on the cob. They expand more, gelatinise in higher quantities, and show more surface cracks. The amount of recognisable shapes and Maltese Crosses seems to be about the same. As the grains in the kernels on the cob are still 'protected' by their neighbours, they might be more protected from the heat than the loose kernels. As they are packed together, this could also mean that they have less space to expand.

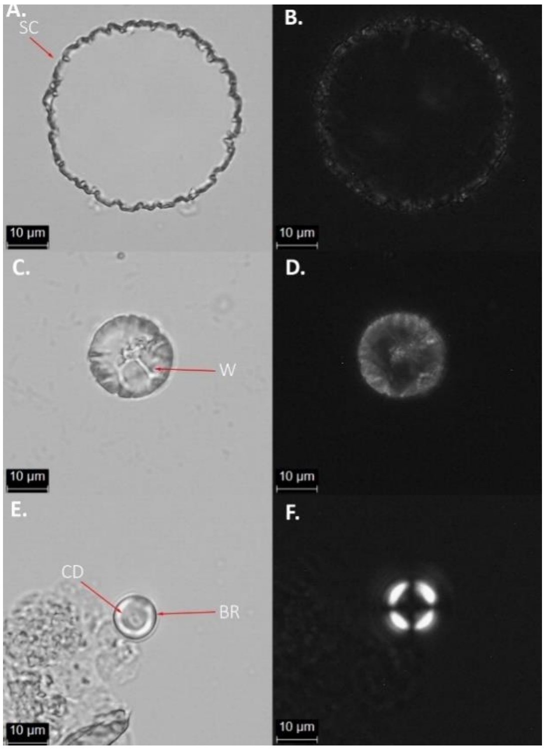

Figure 6-4
Starch grains encountered in the roasted loose kernels of Zea mays*. A: Starch grain MKR2-10 showing swelling and surface cracks. B: Same as A., but under polarised light. Displaying only very little birefringence. C: Starch grain MKR3-3 showing wrinkling of the surface. D: Same as C., but under polarised light. The wrinkling of the surface is also visible in the Maltese cross. E. Starch grain MKR4-10 showing both a bright ring around the hilum area and a central depression. F: Same as E, but under polarised light. The central depression is visible in the Maltese cross, however a cross with straight arms can still be identified.*
BR: Bright ring around the hilum area; CD: Central depression; SC: Surface cracks; W: Wrinkling of the surface;
Photos taken by Anika Hellemons with a Leica DM 2700 P (630x) microscope.

6.3 DAMAGE PATTERNS FROM BOILING MAIZE

As with the roasting, the maize was boiled both on the cob and as loose kernels for 10, 20 and 30 minutes. As mentioned previously, in this experiment the kernels were also sliced off the cob, but this damage was not taken into discussion as it is already presented in the previous part of this chapter.

6.3.1 Boiling maize on the cob

The size range, mean and amount of damage is registered in table 6.4.

When looking at the samples taken of the boiled maize on the cob, one immediately notices the increase in size. As one can see, the ranges and means of all samples lay higher than that of the undamaged grains (9.4-16.8 µm, with a mean of 13.0 µm). Their ranges also exceed the ranges of multiple types of maize, documented by different researchers (Mickleburgh and Pagán-Jiménez 2012, 2493; Pagán-Jiménez 2007, 240-254; Pagán-Jimenez 2011, 339; Pagán-Jiménez 2015a, 102-179; Pagán-Jiménez *et al.* 2016, 150; Pearsall *et al.* 2004, 431). Enlargement of starch grains is thus definitely present.

Experiment ID	MCB1	MCB2	MCB3
Size range	6.4 - 37.9	14.5 - 56.4	19.4 - 57.2
Mean	20.1	31.0	29.8
Undamaged	x	1	x
Central depressions	1	x	x
Bright ring	x	x	x
Surface cracking	6	6	6
Empty or flat	x	x	x
Enlarged	5	7	5
Wrinkled surface	8	7	6
Gelatinisation	2	6	7
Melting	1	2	1
Crust	x	x	x
Fissures	x	x	x

Table 6.4
This table presents the results from samples taken from roasting loose Zea mays *kernels with various roasting times. MCB1 was boiled for 2 minutes, MCB2 for 5 minutes, and MCB3 for ten. The size range and mean, as well as various damage patterns are noted. Whenever an X is noted, no presence of this category was documented in the samples.*

In all three the samples, six starch grains were encountered with surface cracking. Other damage includes enlargement, wrinkled surfaces, melting and gelatinisation. One can see an ascending trend in the gelatinisation of starch grains when exposed longer to heat. Interestingly enough, MCB1 has one grain displaying a bright ring around the hilum area (figure 6-5). This might have happened when taking the samples.

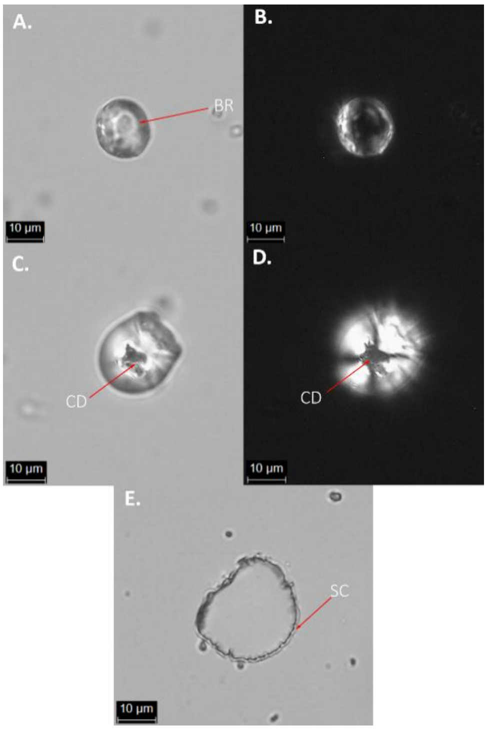

Figure 6-5
Starch grains encountered in the boiled whole cob of Zea mays*. A: Starch grain MCB1-4 showing a bright ring around the hilum area. B: Same as A., but under polarised light, showing a cross shaped Maltese cross. One of the arms seems damaged. C: Starch grain MCB2-5, showing a central depression. The grain seemingly has some damage to the top right, making it truncated of shape. D: Same as C., but under polarised light, the central depression and damage to top right are visible in the Maltese cross. Nonetheless a cross shape with straight arms can be discerned. E: Starch grain MCR3-10, showing surface cracks and damage to the sides. The grain is also swollen. No birefringence was encountered, so no view under polarised light is presented. BR: Bright ring around the hilum area; CD: Central depression; SC: Surface cracks; W: Wrinkling of the surface;*
Photos taken by Anika Hellemons with a Leica DM 2700 P (630x) microscope.

More differences between the samples can be seen when looking at their shapes, although they may not be drastic differences. In MCB1, all starch grains still had a recognisable shape, in MCB2 two starch grains were too damaged to see and in MCB3 three had lost their shape. However, even after boiling the maize for 30 minutes, a majority of starches still showed a describable and characteristic shape. This is different for the Maltese crosses. After cooking the maize for 10 minutes, only 2 clear crosses remain. The other eight grains still had birefringent properties though. In MCB2, only one clear Maltese cross can be seen and four have lost all their birefringence. For MCB3, no clear crosses remain, but only three grains have no birefringence left at all.

6.3.2 Boiling loose maize kernels

As with the samples of maize boiled on the cob, the loose kernels also show an increase in size of their starch grains. This increase is bigger than the maize on the cob. Already after boiling the kernels for ten minutes the sizes have gone above the known size range with a mean twice as large than the registered mean in this thesis. Table 6.5 presents an overview of the damages, means and size ranges encountered in this sample. Figure 6-6 presents a selection of starch grains showing different types of damages.

Experiment ID	MKB1	MKB2	MKB3
Size range	16.9 - 54.4	14.4 - 60.4	28.7 - 54.2
Mean	28.6	33.6	39.0
Undamaged	x	x	x
Central depressions	x	x	1
Bright ring	x	1	1
Surface cracking	5	4	1
Empty or flat	1	1	x
Enlarged	7	9	10
Wrinkled surface	8	8	10
Gelatinisation	5	7	9
Melting	2	1	5
Crust	x	x	x
Fissures	x	x	x

Table 6.5
This table presents the results from samples taken from roasting loose Zea mays *kernels with various roasting times. MKB1 was boiled for 2 minutes, MKB2 for 5 minutes, and MKB3 for ten. The size range and mean, as well as various damage patterns are noted. Whenever an X is noted, no presence of this category was documented in the samples.*

The increase in range and mean can also be seen when looking at the damage specifically. In the samples several starch grains are enlarged. Not only do the grains enlarge more and faster, but they also gelatinise more when boiled as loose kernels. This pattern can also be seen in other damage, such as melting, which occurred more in the loose kernels, as well as wrinkled surfaces. One thing that is striking however, is that the longer the loose kernels were boiled for, the less surface cracking was documented. In MKB1 five grains showed surface cracks, four in MKB2, and only one starch grain was documented in sample MKB3. In the case of the cob, six starch grains per sample showed surface cracks. This can mean that due to the faster gelatinisation rate, the grains with cracks get gelatinised faster.

An upward trend can also be seen when looking at the rate of molten grains. This suggests it takes some time to reach the melting point. Additionally, MKB1 and MKB2 both have one grain that appears flat, possibly from the knife cutting them off and emptying them. In contrast to the starch grains boiled on the cob, there is a significant loss of both shape and Maltese Cross. In MKB1, only three grains retained a recognisable shape, while the grains only displayed vague birefringence without crosses. In MKB2, only one grain shows a shape, and two grains completely lost their birefringence. Lastly, MKB3 has no recognisable shapes left, three grains completely lost their birefringence, and one other kept a visible cross but it was too damaged to document it as either straight or bent.

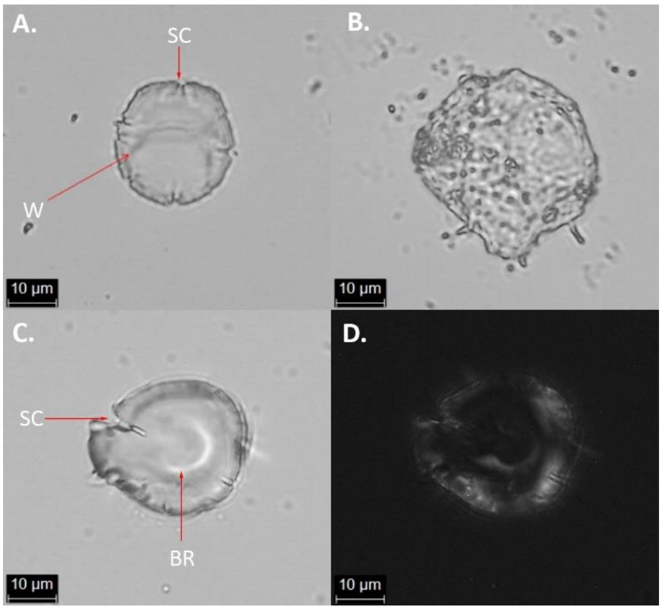

Figure 6-6
Starch grains encountered in the boiled loose kernels of Zea mays*. A: Starch grain MKB1-8 showing a fold or wrinkle in the surface, as well as surface cracks. No birefringence was encountered, so no view under polarised light is presented.*
B: Starch grain MKB2-4 being fully gelatinised and not showing any characteristics of starch grain morphology or damage patterns. No birefringence was encountered, so no view under polarised light is presented. C. Starch grain MKB3-10 showing a bright ring around the hilum, as well as surface cracks. D: Same as C., but under polarised light. A vague cross with straight arms can be discerned.
BR: Bright ring around the hilum area; SC: Surface cracks; W: Wrinkling of the surface;
Photos taken by Anika Hellemons with a Leica DM 2700 P (630x) microscope.

6.4 DAMAGE PATTERNS IN PAN DE MAÍZ

Several steps were taken that potentially leave traces on the starch grains. First the kernels were taken off the dried cobs, the loose kernels were soaked in water for one hour and most of the husks were removed by rubbing the kernels together by hand. They were dabbed dry and sampled. After this, the kernels were ground into flour for 10, 20 or 30 minutes and samples. Following this, each ground sample was either fried on a griddle for 2, 5 or 10 minutes, or boiled for the same amount of time. The results are presented below.

6.4.1 Soaking and grinding dried maize kernels

As stated before, the kernels were soaked for one hour and then ground for 10, 20 or 30 minutes. The results are presented in table 6.6, and a selection of photos is shown in figure 6-7. Interestingly enough, no big change in size can be seen. All the ranges fall within the previously described ranges and means. Only one starch grain seems to be enlarged, which came from the sample that was merely soaked (PdMS). PdM1 of the ground grains shows central depressions, which PdM2 and PdM3 do not. PdMS however shows four grains with depressions, and one which seems to release particles. The amount of starch grains with a cracked surface seems to not differ much between samples, only PdM1 shows a lower amount. Bright rings around the hilum are only present in the ground samples, which makes sense as it is described as a characteristic of grinding. The amount of wrinkled surfaces seems to increase from PdMS to PdM1, to descend again in PdM2 and PdM3. It could be that the amount of wrinkled starches and the amount of cracked surfaces can be linked, with less cracks in wrinkled starch grains. Additionally, all samples have grains with fissures, but are most common in sample PdM2 and PdM3.

Overall, there is little damage to the shapes of the grains. In PdMS, PdM1 and PdM3, only one grain lost its shape. In PdM2, no starch grains without recognisable shape were recorded. Interestingly enough, the soaked grains lost their Maltese Crosses more than the samples that were ground after soaking. Three grains only had birefringent properties on the outside of the grain, while the other only displayed a vague cross. The other samples all showed clear Maltese Crosses in nine grains, however some were damaged on one or more arm.

Experiment ID	PdMS	PdM1	PdM2	PdM3
Size range	5.9 - 25.6	4.4 - 12.9	4.6 - 17.3	8.0 - 17.1
Mean	11.6	9.6	11.5	11.2
Undamaged	x	1	x	1
Central depressions	4	3	x	x
Bright ring	x	3	3	4
Surface cracking	6	4	7	6
Empty or flat	1	x	x	x
Enlarged	1	x	x	x
Wrinkled surface	2	5	4	1
Gelatinisation	x	x	x	x
Melting	x	x	x	x
Crust	x	x	x	x
Fissures	1 stellate fissure	1 stellate fissure	2 y-fissures; 1 stellate fissure; 1 linear fissure	2 stellate fissures, 1 linear fissure

Table 6.6
This table presents the results from samples taken from soaked Zea mays *kernels (PdMS), as well as ground samples. PdM1 was ground for 10 minutes, PdM2 for 20, and PdM3 for 30 minutes. The size range and mean, as well as various damage patterns are noted Whenever an X is noted, no presence of this category was documented in the samples.*

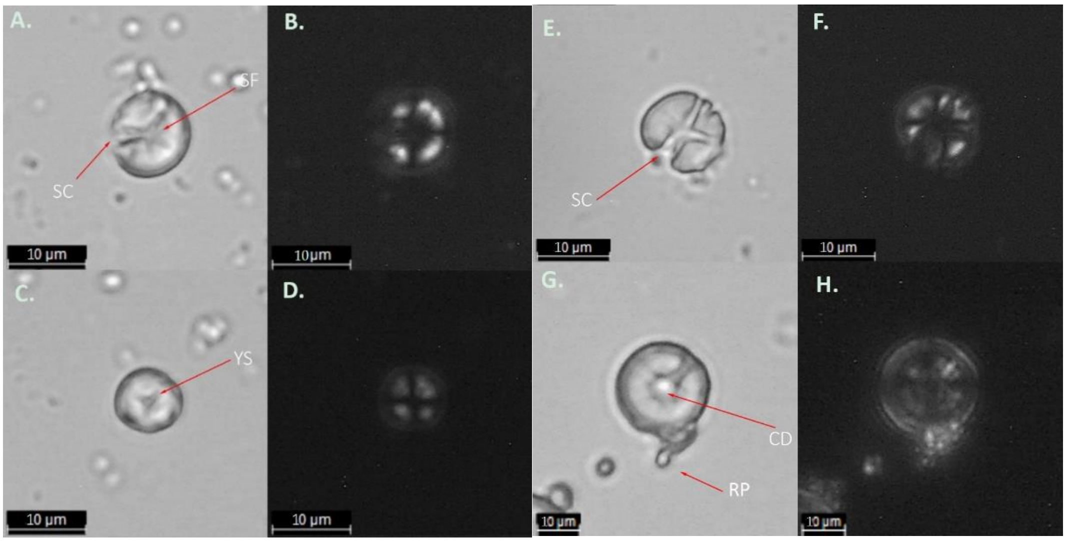

Figure 6-7
Starch grains encountered in the soaked and ground kernels of Zea mays. *A: Starch grain PdM1-9 showing an enhanced Stellate fissure and surface cracking. B: Same as A., but under polarised light. A shadow can be seen in the middle of the Maltese cross, and arm is damaged. Still a cross shape can be discerned. C: Starch grain PdM2-5 showing a Y-shaped fissure. No other damage can be discerned. D: Same as C., but under polarised light. A cross shaped Maltese cross with straight arms can be seen. E: Starch grain PdM3-10 showing surface cracks. F: Same as E., but under polarised light. The Maltese cross is damaged due to the surface cracks. G: Starch grain PdMS-10, showing a central depression and the release of particles. H: Same as G., but under polarised light showing a vague cross with straight arms.*
CD: Central depression; RP: Release of particles; SF: Stellate fissure; SC: Surface cracks; YF: Y-shaped fissure. Photos taken by Anika Hellemons with a Leica DM 2700 P (630x) microscope.

6.4.2 Damage from frying Pan de Maíz

This part will present the results of frying the maize dough on a griddle in oil. As aforementioned, the ground samples were baked for either 2, 5, or 10 minutes. This resulted in nine samples.

6.4.2.1 Experiment PdMF1

Table 6.7 presents the results, see figure 6-8 as well for a selection of photos illustrating the damage patterns. What is immediately striking when looking at the results are the size ranges and means of the starch grains. All of the samples yield starch grains that are far out of the previously described ranged, either in this thesis or in the previously published sources. This is also the case when looking at the means. When looking at the grains that are marked as enlarged, there is an ascending trend the longer the grains were heated. There is also an ascending trend when looking at the rate of gelatinisation in the grains and the appearance of wrinkled surfaces.

Experiment ID	PdMF1.1	PdMF1.2	PdMF1.3
Size range	11.6 - 47.3	12.1 - 55.0	22.5 - 60.9
Mean	22.2	26.9	38.5
Undamaged	x	x	x
Central depressions	5	8	2
Bright ring	2	x	x
Surface cracking	7	8	1
Empty or flat	x	x	x
Enlarged	1	4	8
Wrinkled surface	4	2	6
Gelatinisation	4	2	8
Melting	8	2	x
Crust	x	3	x
Fissures	x	x	x

Table 6.7
This table presents the results from samples taken from the fried Zea mays *dough, which was ground for ten minutes. PdMF1.1 was fried for two minutes, PdMF1.2 for five minutes, and PdMF1.3 for ten minutes. The size range and mean, as well as various damage patterns are noted. Whenever an X is noted, no presence of this category was documented in the samples.*

An ascending trend can be seen in the grains that show melting. Central depressions and surface cracking are most prominent in PdMF1.1 and PdMF1.2. Melting is only found in these two samples, while only PdMF1.2 yielded grains with crusting. There seems to be a correlation between the appearance of central depressions and surface cracking and the appearance of gelatinisation. The latter seems to obscure the other two types of damages.

Most of the starch grains do not display clear and identifiable shapes anymore. Only one is identified in PdMF1.1, two in PdMF1.2, and two in PdMF1.3. Maltese Crosses are also mostly absent. Only three grains in PdMF1.1 show crosses. PdMF1.2 yields four grains with Maltese Crosses, and one grain without birefringence. PdMF1.3 only yields two grains with identifiable crosses. The others still display properties. This means that after 10 minutes of grinding and 10 minutes of frying, grains still have some characterising properties, but they are rare.

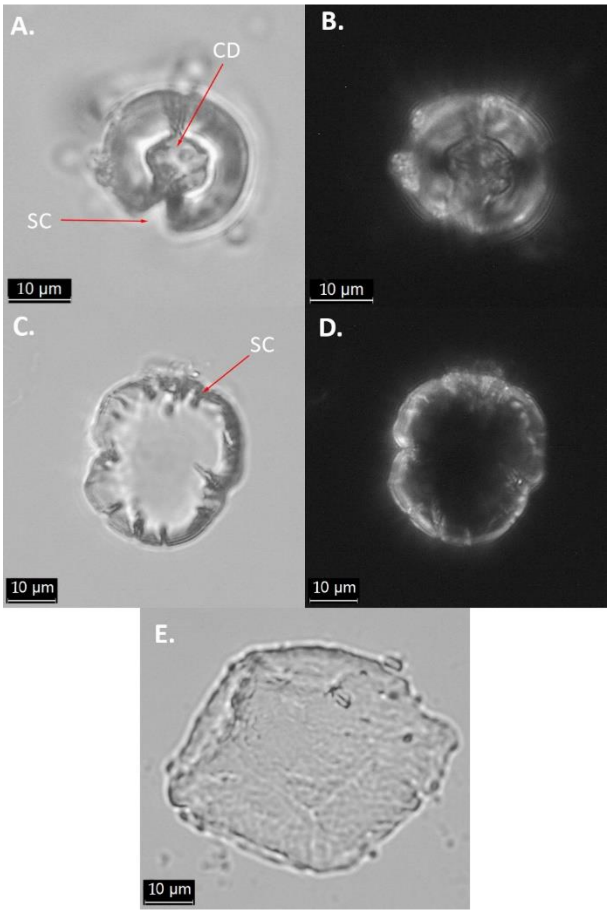

Figure 6-8
Starch grains encountered in Zea mays *dough ground for ten minutes and fried afterwards. A: Starch grain PdMF1.1-5 showing both a central depression and surface cracks. B: Same as A., but under polarised light. The central depression is visible in the Maltese cross, obscuring most of it. A vague cross can still be discerned. C: Starch grain PdMF1.2-9 showing surface cracks. D: Same as C., but under polarised light. Only some vague birefringence on the outside can still be seen. E: Starch grain PdMF1.3-3 being fully gelatinised and showing no starch grain characteristics or other damage patterns. No birefringence was encountered, so no view under polarised light is presented.*
CD: Central depression; SC: Surface cracks;
Photos taken by Anika Hellemons with a Leica DM 2700 P (630x) microscope

6.4.2.2 *Experiment PdMF2*

Curiously enough, the size ranges of experiment PdMF2.1 and PdMF2.2 (see table 6.8) fall within the known ranges of maize starch grains. However, they are outside of the recorded ranges of sweet corn in this thesis. The mean and range of PdMF2.3 are larger than the previously described ranges and means. This means that some enlargement is definitely present, however only a few enlarged grains were recorded in the samples.

Experiment ID	PdMF2.1	PdMF2.2	PdMF2.3
Size range	15.7 - 28.2	13.5 - 27.6	22.0 - 41.2
Mean	20.3	19.2	22.3
Undamaged	x	x	x
Central depressions	4	3	2
Bright ring	x	2	x
Surface cracking	10	6	5
Empty or flat	x	x	x
Enlarged	2	1	3
Wrinkled surface	1	3	6
Gelatinisation	3	3	5
Melting	2	3	1
Crust	1	3	1
Fissures	x	1 linear fissure	x

Table 6.8
This table presents the results from samples taken from the fried Zea mays *dough, which was ground for 20 minutes. PdMF2.1 was fried for two minutes, PdMF2.2 for five minutes, and PdMF2.3 for ten minutes. The size range and mean, as well as various damage patterns are noted. Whenever an X is noted, no presence of this category was documented in the samples.*

A descending trend can be observed when looking at the central depressions. It is in small steps however, and might not mean much. There is also an descending trend in the amount of surface cracking present. In other experiments this seems to correlate with the amount of gelatinised starch grains which can obscure other traces, but only a small increase can be seen there. Additionally, an ascending trend in the presence of wrinkled surfaces can be observed, which can explain the presence of less surface cracks, Melting and crust are present in all samples, most prominently in PdMF2.2. PdMF2.2 also has one grain with a linear fissure. Photos of these types of damage can be seen in figure 6-9.

Most of the grains have no identifiable shape anymore due to damage they have taken. All grains still show birefringent properties, but not all show identifiable Maltese Crosses. PdMF2.1 has four vague crosses with straight arms. PdMF2.2 shows three vague crosses with straight arms and one clearer cross with straight arms, while PdMF2.3 yields two vague crosses with straight arms. This sample also shows a cross that is partially damaged and an X-shaped cross with straight arms.

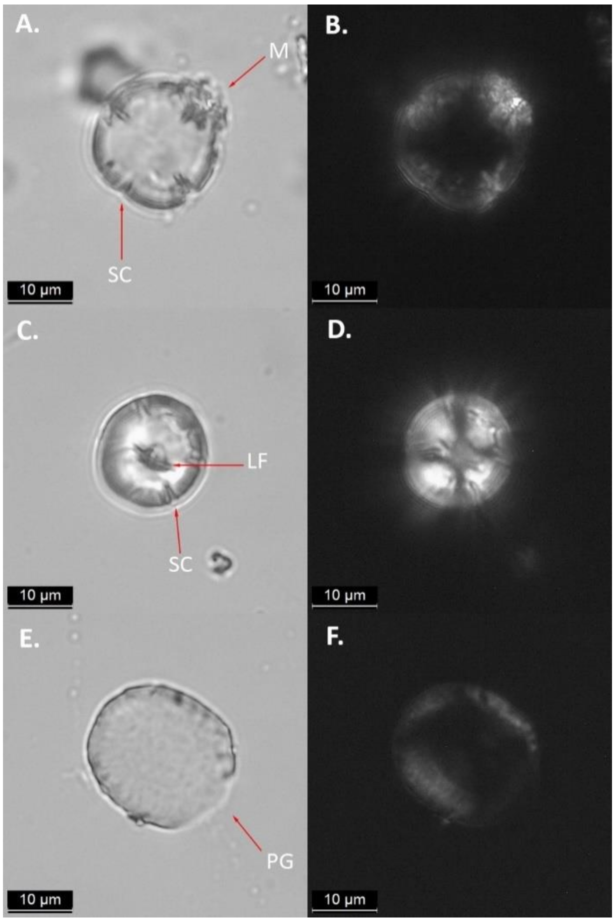

Figure 6-9
Starch grains encountered in Zea mays *dough ground for 20 minutes and fried afterwards. A: Starch grain PdMF2.1-3 showing both surface cracks, as well as signs of melting. B: Same as A., but under polarised light. A vague cross with straight arms can still be discerned. C: Starch grain PdMF2.2-5 showing surface cracks, as well as a linear fissure. D: Same as C., but under polarised light. A cross shape with straight arms can be seen, but the middle part is damaged. E: Starch grain PdMF2.3-2 being partially gelatinised. F: Same as E., but under polarised light. Some birefringent properties remain, but no clear Maltese cross can be discerned. CD: Central depression; M: Signs of melting; LF: Linear fissure; PG: Partial gelatinisation; SC: Surface cracks; Photos taken by Anika Hellemons with a Leica DM 2700 P (630x) microscope*

6.4.2.3 Experiment PdMF3

In contrast to PdMF2, PdMF3 shows starch grain size ranges and means outside of the known ranges (see table 6.9). Next to this, all means also exceed the known means of both the previously published sizes and the recorded sizes in this thesis. PdMF3.3 has an extreme outlier, which measured 85,5 by 78,8 µm. When omitting this grain in the calculation of the mean, it comes down to 27.8 µm. The range then becomes 9.4 to 49.5 µm. This is still far above the known ranges, but less extreme. No real trend can be seen in the enlargement of the grains. Interestingly enough both PdMF3.1 and PdMF3.3 also yield an undamaged starch grain each. Figure 6-10 shows a selection of photos taken from the samples, showing different types of damage.

Experiment ID	PdMF3.1	PdMF3.2	PdMF3.3
Size range	6.9 -30.7	8.8 -58.7	9.4 - 85.8
Mean	21.0	29.5	33.2
Undamaged	1	x	1
Central depressions	x	1	1
Bright ring	x	x	x
Surface cracking	9	7	7
Empty or flat	x	x	x
Enlarged	3	8	6
Wrinkled surface	5	5	4
Gelatinisation	7	9	7
Melting	2	x	x
Crust	x	x	x
Fissures	x	x	x

Table 6.9
This table presents the results from samples taken from the fried Zea mays *dough, which was ground for 30 minutes. PdMF3.1 was fried for two minutes, PdMF3.2 for five minutes, and PdMF3.3 for ten minutes. The size range and mean, as well as various damage patterns are noted. Whenever an X is noted, no presence of this category was documented in the samples.*

The amount of surface cracks stays high in all three of the samples, something that is descending in the other frying experiments. Gelatinisation is also highly present in all the samples, showing no ascending trend. Melting is only present in PdMF3.1, with no crust, while central depressions were only recorded in PdMF3.2 and PdMF3.3. All samples yielded approximately the same amount of wrinkled surfaces. No fissures were recorded.

In all samples, two grains still show identifiable shapes. Most grains in PdMF3.1 still show an identifiable Maltese Cross. PdMF3.2 however, only has two vague Maltese Crosses, while four show no properties at all. In PdMF3.3, only two grains have no properties, while five do still display birefringence but no clear Maltese Cross. This again shows that even after 30 minutes of grinding and 10 minutes of indirect heat can result in starch grains which still show diagnostic characteristics.

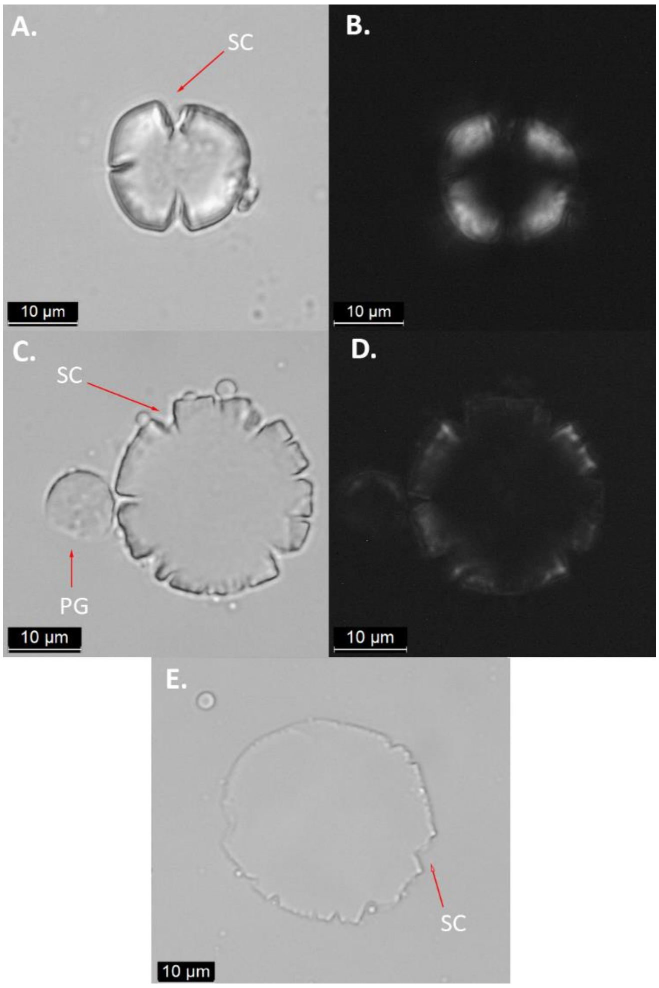

Figure 6-10
Starch grains encountered in Zea mays *dough ground for 30 minutes and fried afterwards. A: Starch grain PdMF3.1-9 showing cracks in it surface. B: Same as A., but under polarised light. A vague cross with straight arms can be discerned, even though the middle is gone. C: Starch grains PdMF3.2-8 and PdMF3.2-9. PdMF3.2-8 is partially gelatinised and losing its integrity. PdMF3.2-9 is swollen and shows surface cracks. Some gelatinisation is also happening. D: Same as C., but under polarised light. Only some vague birefringence is still present. E: Starch grain PdMF3.3-4 being fully gelatinised and showing surface cracks. No birefringence was encountered, so no view under polarised light is presented.*
CD: Central depression; M: Signs of melting; LF: Linear fissure; PG: Partial gelatinisation; SC: Surface cracks; Photos taken by Anika Hellemons with a Leica DM 2700 P (630x) microscope

6.4.3 Damage from boiling Pan de Maíz

Not only were the samples ground and fried, they were also ground and boiled. This was done by putting them in a clean cheese cloth so the dough would not fall apart. They were boiled for 2, 5 and 10 minutes. The results are presented below.

6.4.3.1 *Experiment PdMB1*

From sample PdMB1.1, thirteen instead of ten starch grains were documented since PdMB1.10, PdMB1.11, PdMB1.12, and PdMB1.13 are clustered together. The size range and means of all samples are above the known ranges and means. When omitting the clustered grains from the equation, the range stays 12.6 to 51.1 um, but the mean increases to 27.8µm. This enlargement can also be seen in the starch grains that were marked as enlarged. None of the cluster in PdMB1.1 were marked as enlarged. Table 6.10 presents the ranges and means from the experiments, as well as the different damage patterns. Additionally, figure 6-11 displays a selection of photos illustrating the types of damages.

Experiment ID	PdMB1.1*	PdMB1.2	PdMB1.3
Size range	12.6 - 51.1	19.5 - 64.8	25.0 - 58.9
Mean	24.6	37.6	41.4
Undamaged	x	x	x
Central depressions	2	x	1
Bright ring	x	x	x
Surface cracking	9	4	x
Empty or flat	x	x	x
Enlarged	5	8	10
Wrinkled surface	6	6	9
Gelatinisation	10	6	7
Melting	x	x	5
Crust	x	x	x
Fissures	x	x	x

Table 6.10
This table presents the results from samples taken from the boiled Zea mays *dough, which was ground for ten minutes. PdMB1.1 was boiled for two minutes, PdMB1.2 for five minutes, and PdMB1.3 for ten minutes. The size range and mean, as well as various damage patterns are noted. Whenever an X is noted, no presence of this category was documented in the samples.*

** Thirteen instead of ten starch grains were documented in this sample.*

All samples show high amounts of gelatinised starch grains. When omitting the cluster, the amount of gelatinised grains in all the samples stays approximately the same. A decrease in surface cracking can be detected. However, when omitting the cluster, only five of the nine grains show surface cracking in PdMB1.1. This is still a majority. Central depressions are present in both PdMB1.1, and PdMB1.3 in low quantities. Only PdMB1.3 yields starch grains that started melting. Grains with wrinkled surfaces are present in the majority of the grains. However, when not considering the cluster only two of the nine grains in PdMB1.1 have wrinkled surfaces.

Most of the starch grains lost their shapes due to damage. Only four grains still showed visible shapes: an oval and a spherical grain in PdMB1.1; and two oval grains in PdMB1.3. The majority of the grains also lost their birefringent properties. Seven grains in PdMB1.1 lost their properties, while in PdMB1.2, three starch grains kept their properties. PdMB1.3 also yields three grains with properties of which one shows a vague cross with straight arms.

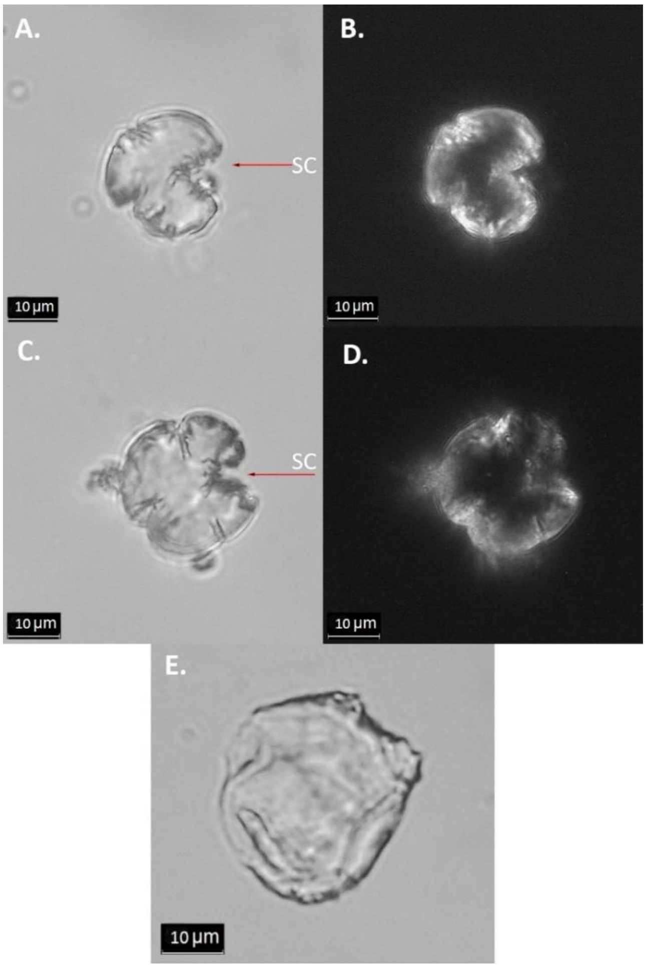

Figure 6-11
Starch grains encountered in Zea mays *dough ground for 10 minutes and boiled afterwards. A: Starch grain PdMB1.1-9 showing cracks in it surface. B: Same as A., but under polarised light. Some birefringent properties remain. C: Starch grain PdMB1.2-3 showing cracks in its surface. D: Same as C., but under polarised light. Only some vague birefringence is still present. E: Starch grain PdMB1.3-9 being fully gelatinised. No birefringence was encountered, so no view under polarised light is presented.*
SC: Surface cracks
Photos taken by Anika Hellemons with a Leica DM 2700 P (630x) microscope.

6.4.3.2 *Experiment PdMB2*

As with PdMB1, all ranges and means lie far above the recorded means and ranges of maize starch grains. There seems to be a descending trend however, which is both visible in the means and the ranges. This is interesting as in other experiments there seems to be a ascending trend in size. It can be that the largest grains dissolved faster, leaving the smaller starch grains to be documented. There is also a small decrease visible in the grains marked as enlarged, as can be seen in table 6.11. It must be noted that even though ten grains were registered in sample PdMB2.1, only nine were measured and photographed due to the range of the camera. A selection of these photos is presented in figure 6-12.

Experiment ID	PdMB2.1	PdMB2.2	PdMB2.3
Size range	20.8 - 65.4	20.6 - 59.7	16.0 - 57.9
Mean	37.1	36.1	30.3
Undamaged	x	x	x
Central depressions	x	2	2
Bright ring	x	x	x
Surface cracking	10	9	9
Empty or flat	x	x	x
Enlarged	7	6	5
Wrinkled surface	3	6	3
Gelatinisation	10	8	9
Melting	x	x	1
Crust	x	x	x
Fissures	x	x	x

Table 6.11
This table presents the results from samples taken from the boiled Zea mays *dough, which was ground for 20 minutes. PdMB2.1 was boiled for two minutes, PdMB2.2 for five minutes, and PdMB2.3 for ten minutes. The size range and mean, as well as various damage patterns are noted. Whenever an X is noted, no presence of this category was documented in the samples.*

All three the samples show high amounts of surface cracking and gelatinisation. No trend can be seen and the amounts stay approximately the same. A peak in the amount of wrinkled surfaces can be seen in PdMB2.2, which yield six grains while the other two samples both yield three. Only in PdMB2.3 a starch grain with signs of melting was documented. This sample and PdMB2.2 also both showed two grains with central depressions each. No fissures were recorded.

Again, the majority of the starch grains has no discernible shape anymore. Only three grains could be documented as being oval in shape. The majority of the starches also show no Maltese crosses. Only four grains in PdMB2.1 still show birefringent properties. In sample PdMB2.2, another four starch grains are still birefringent, and in PdMB2.3, three grains kept their birefringence.

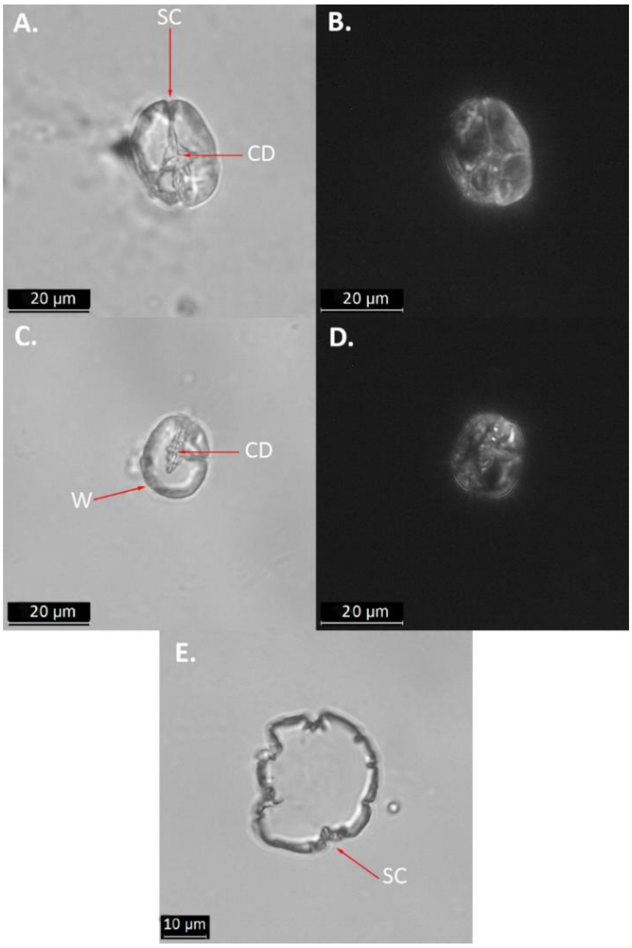

Figure 6-12
Starch grains encountered in Zea mays *dough ground for 20 minutes and boiled afterwards. A: Starch grain PdMB2.2-5 showing cracks in it surface, as well as a central depression. B: Same as A., but under polarised light. Some birefringent properties remain, but no clear cross can be discerned. C: Starch grain PdMB2.3-5 showing cracks in its surface, as well as a slight wrinkling of the surface. D: Same as C., but under polarised light. Only some vague birefringence is still present. E: Starch grain PdMB2.1-5 showing surface cracks. No birefringence was encountered, so no view under polarised light is presented.*
CD: Central depression; SC: Surface cracks; W: Wrinkled surface
Photos taken by Anika Hellemons with a Leica DM 2700 P (630x) microscope.

6.4.3.3 Experiment PdMB3

As with the other two boiled Pan de Maíz experiments, the size ranges and means are far outside of the previously recorded ranges. Strikingly enough, the grains are smaller than the ones documented in PdMB2. As one can see in table 6.12, the amount of enlarged grains has an increase between PdMB3.1 and PdMB3.2. This is more than what is documented in experiment PdMB2. It might mean that more smaller grains were enlarged after 30 minutes of grinding and boiling, or that the biggest starch grains were so enlarged they fell apart.

Experiment ID	PdMB3.1	PdMB3.2	PdMB3.3
Size range	21.0 - 50.6	15.7 - 56.6	12.4 - 52.5
Mean	28.5	41.0	30.0
Undamaged	x	x	x
Central depressions	2	x	2
Bright ring	x	1	x
Surface cracking	10	10	6
Empty or flat	x	x	x
Enlarged	5	8	8
Wrinkled surface	x	10	3
Gelatinisation	8	9	7
Melting	4	2	2
Crust	x	x	x
Fissures	x	x	1 linear

Table 6.12
This table presents the results from samples taken from the boiled Zea mays *dough, which was ground for 30 minutes. PdMB3.1 was boiled for two minutes, PdMB3.2 for five minutes, and PdMB3.3 for ten minutes. The size range and mean, as well as various damage patterns are noted. Whenever an X is noted, no presence of this category was documented in the samples.*

Next to the sudden increase in enlargement, there is a sudden decrease in grains with surface cracking (see figure 6-13 for a selection of photos displaying this and other types of damage). This trend is not reflected in the gelatinisation of the starch grains, which can obscure other damage patterns. The amount of gelatinised grains, while high, stays quite stable. A decrease in starch grains with signs of melting can be seen. It is not a big decrease, but a decrease nevertheless. Both PdMB3.1 and PdMB3.3 yield two starch grains with central depressions, while only PdMB3.2 shows a grain with a bright ring around the hilum area. One starch grain in PdMB3.3 shows a linear fissure. Interestingly enough, only PdMB3.2 and PdMB3.3 yield grains with wrinkled surfaces.

Of the 30 analysed grains, only five kept identifiable shapes. As with the other experiments involving boiling, most of the starch grains do not display a Maltese Cross anymore. In PdMB3.1, no Maltese Crosses were documented, and only four starch grains still showed birefringent properties. In PdMB3.2, only three still showed birefringent properties. PdMB3.3, however, showed two grains with crosses with straight arms, and one grain which did display a cross, but with an extra arm. Five other grains also still showed birefringent properties. It is interesting to see that the sample which was exposed to heat the longest, still shows the most crosses and identifiable shapes.

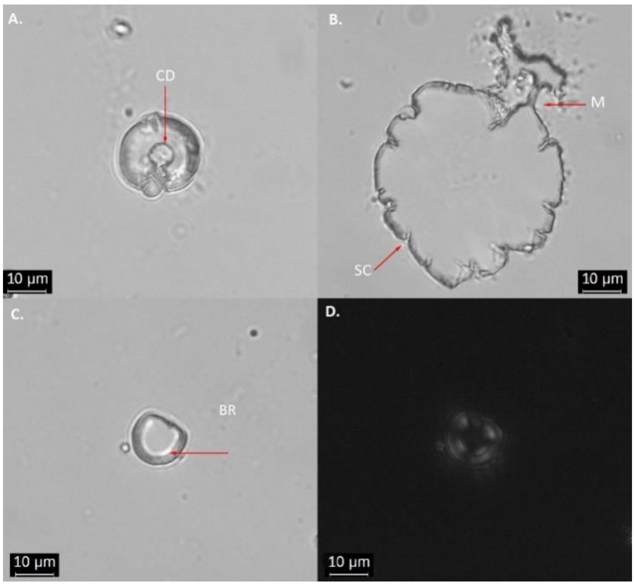

Figure 6-13
Starch grains encountered in Zea mays *dough ground for 30 minutes and boiled afterwards. A: Starch grain PdMB3.1-7 showing a central depression. No birefringence was encountered, so no view under polarised light is presented. B: Starch grain PdMB3.2-10 being swollen, showing surface cracks, and signs of melting. No birefringence was encountered, so no view under polarised light is presented. C: Starch grain PdMB3.3-2 showing a bright ring around the hilum area. D: Same as C., but under polarised light. A cross can be discerned, but one of the arms is damaged.*
BR: Bright ring around the hilum area; CD: Central depressions; M: Signs of melting; SC: Surface cracks
Photos taken by Anika Hellemons with a Leica DM 2700 P (630x) microscope

6.5 UNDAMAGED *MANIHOT ESCULENTA*

To understand the damage patterns after the experiments and compare them to undamaged grains, not only were previously published sources consulted, but samples were taken of the undamaged manioc as well. These will be presented here. Table 6.13 presents an overview of the size and damages, while figure 6-14 shows a selection of photos illustrating the results.

6.5.1 Shape:

Eight of the ten grains are truncated in shape. An additional one is slightly truncated. The tenth grain is spherical.

6.5.2 Size:

The size range of the starch grains lies between 7.3 and 26.6µm. This lies between the recorded ranges of 6,7 and 37.7µm. The mean of the grains in this thesis is 14.2µm. This falls between recorded means of 13.0 and 17.0 µm in other works.

Experiment ID	Man.
Size range	7.3 - 26.6
Mean	14.2
Undamaged	2
Central depressions	1
Bright ring	3
Surface cracking	6
Empty or flat	x
Enlarged	x
Wrinkled surface	1
Gelatinisation	x
Melting	x
Crust	x
Fissures	x

Table 6.13
This table presents the results from samples taken from the unprocessed Manihot esculenta. *The size range and mean, as well as various damage patterns are noted. Whenever an X is noted, no presence of this category was documented in the samples.*

6.5.3 Maltese cross:

Even though the grains were not processed before taking samples, it is possible that during the sampling process some of the grains were damaged. This is visible when looking at the Maltese crosses of the grains. Three grains still display birefringence, but have lost their crosses. An additional five grains do have vague crosses, with straight arms, but are damaged in some way. For example Cas-5 seems to have an extra arm, and Cas-2 shows a cross with a missing middle part. There is one grain which has no damage, this cross is cross shaped with wavy arms.

6.5.4 Damage patterns:

Of the ten grains, six display cracks in their surface. Additionally, three have a bright ring around the hilum, and one grain shows a central depression. Another one has a slightly wrinkled surface. This shows that taking the samples must have damaged the grains in a way. It most likely happened when peeling the manioc. The interaction with the knife might have caused the cracking and bright rings around the hilum. The pressure of peeling and ‘cutting’ parts out to be sampled might have resulted in these types of damages.

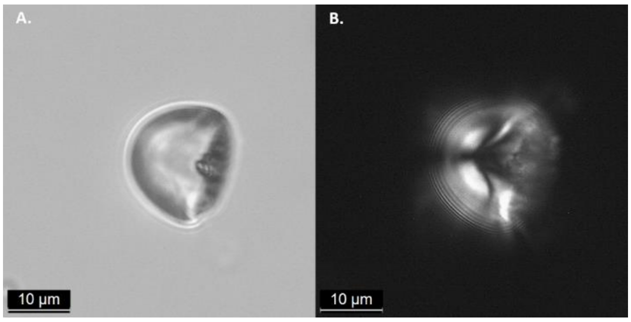

Figure 6-14
Starch grains documented in the unprocessed Manihot esculenta *samples. A: Starch grain Man-3 showing some damage on the right side. B: Same as A, but under polarised light, showing a warped Maltese cross.*
DB: Double border; DMC: Damaged Maltese cross; SF: Stellate fissure.
Photos taken by Anika Hellemons with a Leica DM 2700 P (630x) microscope

6.6 DAMAGE PATTERNS FROM BAKING CASSAVA BREAD

When baking the cassava bread, several steps were taken that will be taken into account when discussing the damage patterns. First the damage through grating will be compared to see if a more intensive, or longer, grating leads to more or different damage. Following this, the damage per experiment will be discussed. After that the samples that were heated for the same amount of time, but grated for different periods will be compared to see if the grating time influences the heating time.

6.6.1 Experiment PdC1

Experiment PdC1 was grated for ten minutes and then sampled after two, five and ten minutes of baking on a griddle. The size ranges, means, and damage patterns can be seen in table 6.14. Figure 6-15 presents a selection of photos taken in this sample, showing different types of damage. One should keep in mind that for PdC1.3, eleven instead of ten starch grains were documented. The first thing that can be noticed is the slight enlargement of the size ranges. When comparing both the ranges and means, an increase can be seen between the different stages of the experiments. The ranges still lay between the previously reported range, but some of the means exceed the described sizes. One can therefore argue for enlargement of the starch grains.

Experiment ID	PdC1	PdC1.1	PdC1.2	PdC1.3
Size range	4.8 - 29.7	9.2 - 33.5	14.1 - 29.8	18.0 - 31.0
Mean	12.3	16.8	21.7	23.7
Undamaged	x	x	x	x
Central depressions	7	7	9	9
Bright ring	5	3	8	x
Surface cracking	5	x	4	9
Empty or flat	x	x	x	x
Enlarged	2	3	2	2
Wrinkled surface	x	2	2	3
Gelatinisation	x	2	1	4
Melting	x	x	x	1
Crust	x	x	x	x
Fissures	x	x	x	x

Table 6.14
This table presents the results from samples taken from the baked Manihot esculenta *dough, which was grated for ten minutes (PdC1). PdC1.1 was heated for two minutes, PdC1.2 for five minutes, and PdC1.3 for ten minutes. The size range and mean, as well as various damage patterns are noted. Whenever an X is noted, no presence of this category was documented in the samples.*

Starting with the grated sample, one can already see central depressions in the starch grains. These central depressions can be found in all samples. A slight increase can be seen in the presence of bright rings around the hilum area in the first three samples. PdC1.3, however, does not show any starch grains with a bright ring. It could be that other damage, such as central depressions or wrinkled surfaces obscured this type of damage. In the case of surface cracks, an interesting thing can be seen as well: not only does the amount of grains with cracks rise a lot, but PdC1.1 does not seem to yield any. This could, of course, be a coincidence, but the rise between PdC1.2 and PdC1.3 could also display some sort of threshold for grains after which they start to 'crack' more.

All samples have signs of enlargement, but only the heated starch grains show signs of a wrinkled surface and gelatinisation. This last damage is of course related to heat, so this is only logical. Additionally, only one sample and one grain show signs of melting. Only six grains lost their shape and all samples still show clear crosses, but also yield grains that only have partial birefringent properties. Nevertheless, after grinding manioc for 10 minutes and baking it for 10 minutes, starch grains with clear crosses still can be observed.

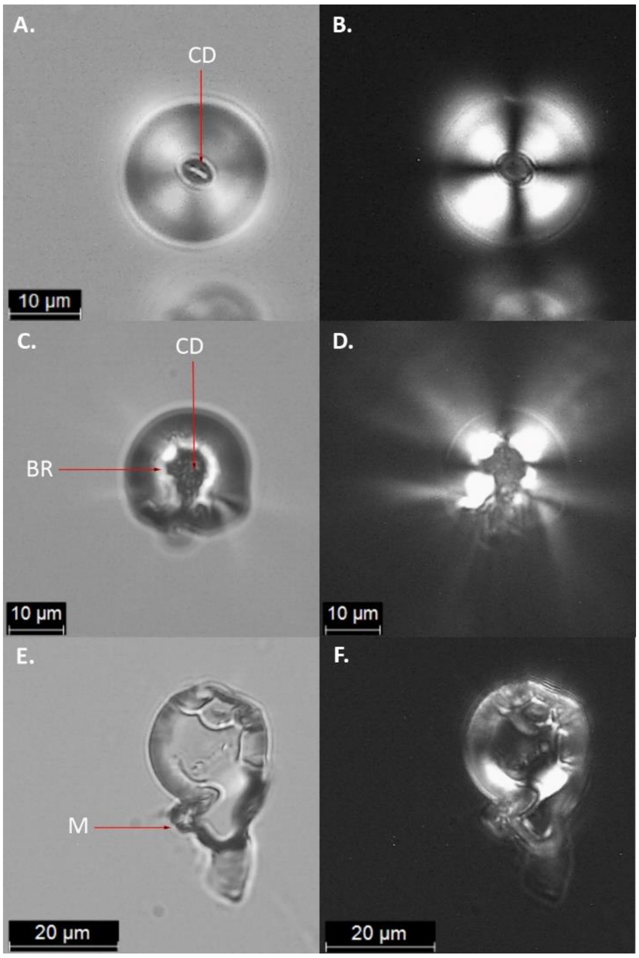

Figure 6-15
Starch grains encountered in Manihot esculenta *dough grated for 10 minutes and baked afterwards. A: Starch grain PdC1.1-10 showing a central depression. B: Same as A., but under polarised light. A central depression can be seen, but still a cross shape with straight arms can be discerned. C: Starch grain PdC1.2- 5 showing a bright ring around the hilum area, as well as a central depression. D: Same as C., but under polarised light. A cross with straight arms can be discerned, but the inside is damaged. E: Starch grain PdC1.3-4 showing signs of melting. F: Same as E., but under polarised light. A vague cross shape can be discerned, but damage due to melting makes it hard to identify.*
BR: Bright ring around the hilum area; CD: Central depressions; M: Signs of melting
Photos taken by Anika Hellemons with a Leica DM 2700 P (630x) microscope

6.6.2 Experiment PdC2

During this experiment, the manioc mass was grated for 20 minutes and baked for two, five and ten minutes. The size ranges, means and other damage patterns documented in this sample can be seen in table 6.15. In figure 6-16, a selection of photos from the samples is presented, illustrating the types of damages present. Again an increase in size can be seen. When comparing this to previously documented ranges, none of the experiments exceeds the range. However, all of the means are higher. This suggests enlargement in several grains.

Experiment ID	PdC2	PdC2.1	PdC2.2	PdC2.3
Size range	12.1 - 28.5	13.1 - 28.7	15.6 - 22.9	10.9 - 28.5
Mean	19.6	19.0	19.5	20.1
Undamaged	x	1	x	x
Central depressions	7	8	7	9
Bright ring	9	9	9	6
Surface cracking	4	3	4	7
Empty or flat	x	x	x	x
Enlarged	x	x	x	x
Wrinkled surface	1	2	x	5
Gelatinisation	x	1	x	4
Melting	x	1	x	x
Crust	x	x	x	x
Fissure	x	1 Y-shaped	1 y-shaped	x

Table 6.15
This table presents the results from samples taken from the baked Manihot esculenta *dough, which was grated for 20 minutes (PdC2). PdC2.1 was heated for two minutes, PdC2.2 for five minutes, and PdC2.3 for ten minutes. The size range and mean, as well as various damage patterns are noted. Whenever an X is noted, no presence of this category was documented in the samples.*

What else is striking that sample PdC2.1 yields one seemingly undamaged starch grain. In none of the other samples were undamaged starch grains documented. Throughout the samples, central depressions can be seen. No real trend can be seen here, other than continuity. This is also the case with bright rings around the hilum. Next to this surface cracking is visible in all samples and a rise can be seen between baking for five and ten minutes in the amount of surface cracks registered.

Also interesting are the amount of wrinkled surfaces that are encountered, as well as gelatinised and molten starch grains. None of these are visible in all samples, not even in all heated samples. Wrinkled surfaces were only documented in PdC2, PdC2.1, and PdC2.3. Gelatinised starch grains were only found in PdC2.1 and PdC2.3. Only one grain seems to have molten, which was encountered in PdC2.1. It is interesting to see that so little grains are gelatinised as it is damage specifically associated with heating. It could be that the grains were protected by other grains in the dough during the heating and that other grains were more damaged or even lost.

Next to these damages, two starch grains show Y-shaped fissures. In only one sample (PdC2.3) there are grains that lost their shape due to damage, of which four lost their shape due to gelatinisation and one due to other damage. All samples show several grains with clear crosses, and only one starch grain has almost completely lost its birefringence. This starch grain was not observed in a sample that was heated, but in PdC2. It seems that grating can be at least as damaging to birefringence as heating, which is important to keep in mind when doing archaeological starch grain analysis.

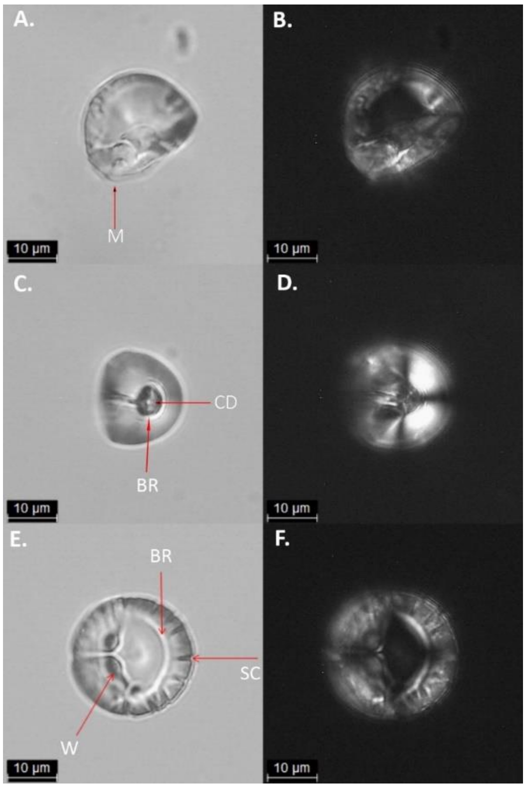

Figure 6-16
Starch grains encountered in Manihot esculenta *dough grated for 20 minutes and baked afterwards. A: Starch grain PdC2.1-9 showing signs of melting. B: Same as A., but under polarised light. Some birefringent properties remain, but no Maltese cross can be discerned. C: Starch grain PdC2.2-10 showing a bright ring around the hilum area, as well as a central depression. D: Same as C., but under polarised light. A cross can be discerned, but the left side of the grain is too damaged. E: Starch grain PdC2.3-10 showing a bright ring around the hilum area, as well as surface cracks and a fold or wrinkle in the surface. F: Same as E., but under polarised light. A vague cross shape can be discerned, but damage due to wrinkling makes it hard to identify. BR: Bright ring around the hilum area; CD: Central depressions; M: Signs of melting; W: Wrinkling of the surface*
Photos taken by Anika Hellemons with a Leica DM 2700 P (630x) microscope

6.6.3 Experiment PdC3

The manioc was grated for 30 minutes before the mass was heated on a griddle. Samples were taken after two, five and ten minutes. The results are presented in table 6.15, while figure 6-16 presents a selection of photos illustrating the different types of damage. Unfortunately, the results of PdC3.1 are not presentable, as they were too dried out to analyse, only one grain was encountered. As with the other samples, an increase in size can be seen in the starch grains. Only PdC3.3 exceeds the previously described range, however again all means are higher than the documented suggesting an increase of size.

Experiment ID	PdC3	PdC3.1	PdC3.2	PdC3.3
Size range	14.5 - 28.9	19.3 - 20.5	15.6 - 29.2	15.8 - 40.0
Mean	20.3	19.9	22.2	24.6
Undamaged	x	x	x	x
Central depressions	9	1	6	2
Bright ring	6	1	2	3
Surface cracking	6	x	9	7
Empty or flat	x	x	x	x
Enlarged	x	x	2	5
Wrinkled surface	3	x	4	6
Gelatinisation	x	x	8	8
Melting	x	x	x	1
Crust	x	x	x	1
Fissures	4 linear	x	x	x

Table 6.16
This table presents the results from samples taken from the baked Manihot esculenta *dough, which was grated for 30 minutes (PdC3). PdC3.1 was heated for two minutes, PdC3.2 for five minutes, and PdC3.3 for ten minutes. The size range and mean, as well as various damage patterns are noted. Whenever an X is noted, no presence of this category was documented in the samples.*

Also interesting is the occurrence of central depressions. In PdC3, these are very present with nine grains, however after this an descending trend can be observed. This is also the case with bright rings around the hilum, which show an descending trend as well. As with the other samples, an increase in surface cracks can be seen, but the spike between five and ten minutes of baking documented in PdC1 and PdC2 does not seem to happen here. Instead, PdC3.2 seems to have the most starch grains with surface cracks, which decreases in PdC3.3. It could be that other damage such as gelatinisation or melting obscured these cracks.

All samples display starch grains with wrinkled surfaces, which shows a slight increase. Next to this, all heated samples show starch grains with signs of gelatinisation. Only PdC3.3 shows a grain with signs of melting and a crust, which occurs in the same grain. Additionally, only PdC3 yields starch grains with fissures, which are all linear in shape. When looking at the Maltese crosses, all samples show at least one grain with a visible and identifiable shape. PdC3 has eight clear crosses, and two other grains with birefringent properties. PdC3.2 still has five grains with clear crosses, the other five starch grains still have properties on the outside. Lastly PdC3.3 still has one cross, but the other grains all also still show birefringence. However, most of the heated grains lost their shape due to damage.

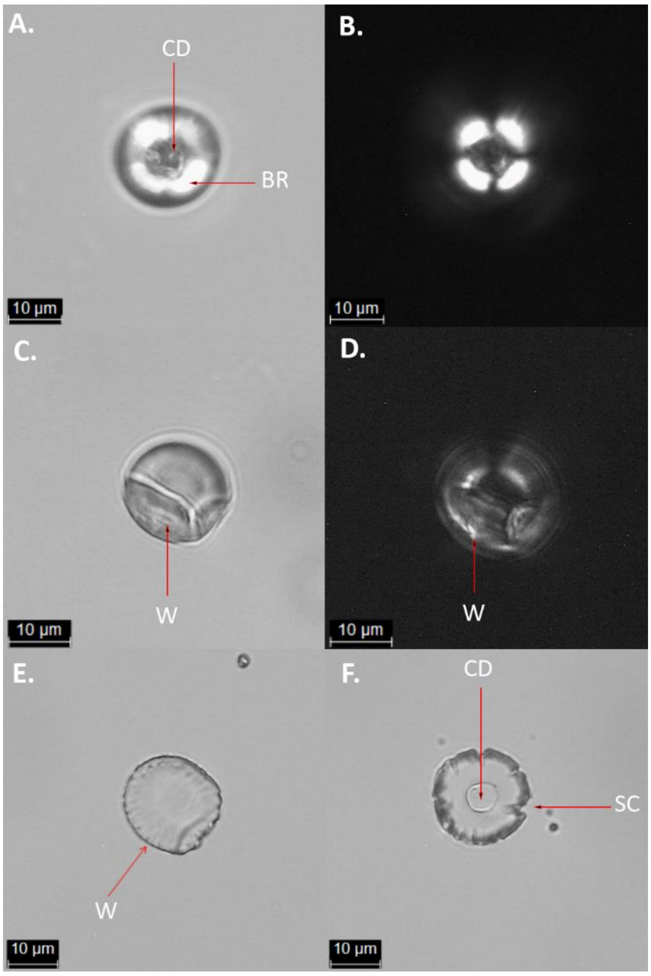

Figure 6-17
Starch grains encountered in Manihot esculenta *dough grated for 30 minutes and baked afterwards. A: Starch grain PdC3.1-1 showing both a central depression, as well as a bright ring around the hilum area. B: Same as A., but under polarised light. A straight cross can be discerned, even though the central depression damaged it. C: Starch grain PdC3.2-6 showing wrinkling of the surface. D: Same as C., but under polarised light. A vague cross can be discerned, but the wrinkling of the surface leaves it too damaged. E: Starch grain PdC3.3-2 showing wrinkling in the surface. No birefringence was encountered, so no view under polarised light is presented. F: Starch grain PdC3.3-4 showing both a central depression, as well as surface cracks. No birefringence was encountered, so no view under polarised light is presented.*
BR: Bright ring around the hilum area; CD: Central depressions; SC: Surface cracks; W: Wrinkling of the surface
Photos taken by Anika Hellemons with a Leica DM 2700 P (630x) microscope

6.6.4 Carbonised cassava bread

Next to the analysis done on the grated and heated dough, samples were taken of the carbonised cassava bread stuck to the used griddle. As can be seen in table 6.17, the size range is on the higher side but still falls within the 5.0 to 37.3 µm described. The mean however is higher and exceeds the common means between 13.0 and 17.0 µm. A high amount of surface cracking and gelatinisation can be seen in the sample. Other damages visible are central depressions, bright rings, and grains with wrinkled surfaces. Of the ten grains, eight lost their shape due to gelatinisation or other damage. Only one clear Maltese cross could be found. The other nine grains still display vague birefringence on the outside. Figure 6-18 shows a selection of photos illustrating the various types of damages.

Experiment ID	PdCB
Size range	13.4 - 30.4
Mean	23.5
Undamaged	x
Central depressions	4
Bright ring	2
Surface cracking	9
Empty or flat	x
Enlarged	4
Wrinkled surface	4
Gelatinisation	7
Melting	x
Crust	x
Fissures	x

Table 6.17
This table presents the results from samples taken from the carbonised Manihot esculenta *dough. The size range and mean, as well as various damage patterns are noted. Whenever an X is noted, no presence of this category was documented in the samples.*

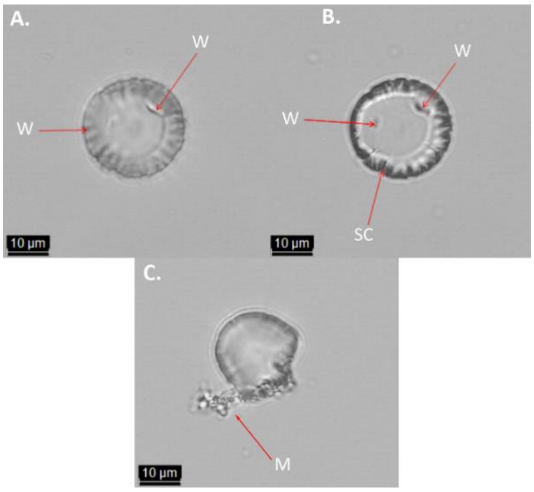

Figure 6-18
Starch grains encountered in Manihot esculenta *dough left to carbonise. A: Starch grain PdCB-1 showing different wrinkles in the surface. No birefringence was encountered, so no view under polarised light is presented. B: Same as A., but with different focus, now also showing surface cracks. C: Starch grain PdCB-2 showing signs of melting. No birefringence was encountered, so no view under polarised light is presented. M: Signs of melting; SC: Surface cracks; W: Wrinkling of the surface*
Photos taken by Anika Hellemons with a Leica DM 2700 P (630x) microscope.

6.7 Concluding remarks

As we have seen in this chapter, several types of damages occur due to different preparation techniques. Some damages occur due to more than one preparation technique, while others seem to occur only due to one. Next to this, differences within species can be seen when taking slightly different steps. What these damages can say about processing techniques, and how they can be identified in the archaeological record will be discussed in more detail in the next chapter, which will conclude this thesis.

7 DISCUSSION AND CONCLUSION

As we have seen in this thesis, foodways are an interesting and helpful way of studying the daily lives of people of the past. It is a part of the culture and identity of individuals and groups (Atkins and Bowler 2001, 1; Beaudry 2016, xxix; Ciofalo *et al.* 2019, 1633; Twiss 2019, 1). There are different ways of studying these foodways, including consulting ethnohistorical and ethnographical sources, but also studies into artefact use, and botanical macro- and microremains (Hastorf 2016, 4, 7, 83-84; Twiss 2019, 1, 16). The latter category includes starch grains, which can not only tell us about which plants were processed with what artefact, but also can give insight into how the plants were processed (Gott *et al.* 2006, 35, 40; Hellemons 2018, 19; Kooyman 2015, 525; Messner 2008, 111; Pagán-Jiménez 2011a, 325; Pagán-Jiménez and Oliver 2008, 144). Through conducting experiments, this thesis aims to gain a better understanding of the damages done by processing certain crops.

It has been argued by Binford (1981), that this type of actualistic research can help with interpreting the archaeological record and through it understanding the social dynamics of the past. This chapter will therefore combine the discussed theories, methodology and results to come to an conclusion, answering the main question of this thesis:

> *To what extent is it possible to identify the cultural processes involved with ancient food preparation in the circum-Caribbean area through recreating these processes and subjecting the residues to starch grain analysis?*

7.1 BRIDGING THE GAP: DISCUSSING THE THEORY AND METHODS

When looking at the archaeological record, one sees a static record created by organisation dynamics of the past. These dynamics, however, are not observable anymore. To understand *how* the archaeological record became the way it is today, middle-range theories can be applied. The idea of middle-range theory, as well as actualistic research in the form of ethnography, ethnohistory, and experimental archaeology, lead to the research conducted in this thesis.

As argued, a bridge is needed between the static material record and the dynamics of the past. In order to create this bridge, middle-range theory aims to identify the processes leading to a certain pattern. This is done by studying situations in which both the static, as well as the dynamics leading to its creation, can be observed. This is called actualistic research, and amongst others includes studying ethnographic and ethnohistoric sources, as well as conducting experimental archaeology (Binford 1981, 22, 27; Pierce 1989, 2; Tschauner 1996, 4). When the observation of the dynamic leads to an understanding of patterns occurring in the archaeological record, inferences can be made. This step can be seen as the translation process of the archaeological record, converting the observations from the present to arguments and concepts about the past. Middle-range theory can arguably be seen as the Rosetta stone in this translation process (Binford 1981, 26-28; Pierce 1989, 3). This sounds very promising, but one must be careful with using analogies, especially law-like uniformitarian ones. Analogies can never be tested with a hundred percent accuracy, and that is why they are interpretations, not truths.

What can be done, however, is strengthening (or weakening) analogies with additional research supplementing the used data. This is done in this thesis by comparing multiple sources and datasets. The experiments are based on ethnohistorical and ethnographical descriptions of food processing techniques in the Antilles and Amazonia. The experiments were conducted to see which damage patterns were occurring due to which preparation technique. Previously published researches into damage patterns were consulted as well to create a better understanding, and in order to see if the archaeological record also presents this type of damage, previously published starch grain analysis was consulted as well. In combining these datasets, this thesis contributes to a better understanding of plant processing in the past, as it presents possible techniques that can be used. Especially as it combines previous research, as well as new research.

Throughout this research, the notion that analogies are there to broaden the horizon of interpretations was kept in mind. We can never truly replicate the circumstances that lead to the archaeological record, but we can aim to create a better understanding of it. This is what this thesis aimed to do. Especially through the experimental research conducted. However, some critical notes must be given on this approach. As said, one can never truly recreate the occurrences which lead to the formation of the archaeological progress, therefore one can also never recreate the foodstuffs that were cooked on the ceramics we encounter in the archaeological record. Experimental archaeology and its results will therefore definitely shed light on possible techniques used to create food, or an artefact, or even a house. But we can never confirm that this is the way it was done. There might be influences that were not considered, or techniques that result in the same damage patterns or use-wear. This does not mean that experimental archaeology is useless, on the contrary it can be quite useful as it helps us gain new perspectives. The results however, should be approached with the same caution one approaches other analogies.

To summarize, the research in this thesis uses multiple approaches to gain a better understanding of processing techniques in the past. The idea of the middle-range theory as a bridge between present and the past, or a way of translating the archaeological record into arguments and ideas carrying meaning, is the basis for this research. To create this bridge, experiments based on ethnohistorical and ethnographical approaches were conducted, of which the results were compared to previously done research into damage patterns, as well as archaeological starch grain analysis. This will be discussed in the next part of this chapter. The results of this thesis are approached with caution, and this is where we differ from the middle-range theory. No notion of law-like, uniformitarian assumptions are used, as analogies or inferences can never be tested with a hundred percent accuracy. This should be kept in mind for the next part of this chapter, which will give an overview of the main results from the experiments.

7.2 DISCUSSING THE RESULTS

In order to create a better understanding of the different damage patterns occurring due to different processing techniques, the author feels that a brief comparison between experiments must be made and discussed. Additionally, a comparison with previously published experiments will be made. This will make it possible to answer two of the three sub-questions posed in the introduction of this thesis:

1. *What damage patterns can be observed per processing technique, and how can these be correlated to the culinary processes involved in preparing food?*
2. *What are the different damage patterns observed per used starchy plant?*

7.2.1 Comparing grating and grinding

Both the experiments with manioc and maize involved pressure. The manioc samples were grated, while the maize samples were ground. Visible trends in grating the manioc for 10, 20 and 30 minutes include the presence of central depressions and bright rings around the hilum area, as well as surface cracking. A wrinkling in the surface can be observed as well. Most shapes are still identifiable, and most starch grains still show birefringent properties. Some Maltese crosses are damaged however. Nevertheless, after 30 minutes of grating starch grains with identifiable shapes, sizes and Maltese crosses are still present and no identifying differences can be seen between different times of grating.

In the ground maize, bright rings around the hilum and surface cracks are observed. Additionally, all samples show wrinkled surfaces. Interesting are also the amount of fissures observable. It seems that most of the grain shapes were smoothed out, as a high amount of rounded or oval grains was encountered. Most Maltese crosses were still identifiable. No striking differences between the samples was observed, so one would not be able to distinguish between starch grains ground for longer or shorter periods of time. However, when considering the damages, there is a good chance of recovering recognisable starch grains. Identification should be possible to at least genus level, but possibly also to species level.

When comparing the grated manioc samples versus the ground maize samples it is interesting to see that the latter shows less to none central depressions, while manioc does show these features. All samples however show bright rings around the hilum, more so in the manioc samples. Surface cracking and wrinkling of the surface is also present in all. Fissures are more present in maize samples. Other than this, no big differences can be seen. The presence of bright rings around the hilum can be identified as characteristic of grating or grounding in manioc or maize, and can help with the identification in the archaeological record. The other damage patterns occur in the other non-ground samples as well, and can therefore not be used.

In the published literature discussing experiments on grated manioc or ground maize, several similarities can be found. Both grating and grounding has been argued to have effect on the birefringent properties of maize and manioc, which can be seen in this thesis as well (Babot 2003, 77; Chandler-Ezell *et al.* 2006, 110). The appearance of surface cracks has also been mentioned in literature concerning both species (Babot 2003, 76, 78; Chandler-Ezell *et al.* 2006, 110; Pagán-Jiménez *et al.* 2017, 35. No mentions of bright rings, central depressions or wrinkled surfaces are made in the literature concerning manioc, but they did appear in this thesis research. These types of damages are howver mentioned in the literature concerning maize (Babot 2003, 76; Chandler-Ezell *et al.* 2006, 110; Mickleburgh and Pagán-Jiménez 2012, 2483). Additionally, Babot (2003), and Mickleburgh and Pagán-Jiménez (2012) mention the homogenisation of starch grain shapes, also observed in this thesis.

To summarise, both grinding and grating leave similar traces including surface cracks, central depressions, a lowered birefringence, and bright rings around the hilum. The latter can be named as a characteristic as this is only observed in grated or ground samples. Additionally, even though there are several similarities between the damages observed in previous research and the experiments, there are also differences. This shows the importance of thorough research and consulting more than one source, as well as using ones own observations.

7.2.2 Comparing boiling and frying

In the experiments including maize, several samples were either boiled or fried. Both samples include kernels on the cob, loose kernels, and ground dough samples. Firstly, the author wants to briefly mention the difference between the cob, loose kernels and ground samples. When looking at the boiled cob versus the boiled kernels both samples seem to show the same types of damages. However, the loose kernels seem to enlarge and gelatinise faster than the kernels from the cob. When the kernels are still packed together on the cob, they seem to be protected by both the cob and each other from the heat. Being packed together also seems to suppress starch grain enlargement, as the kernels are pushed against each other and the starch grains have less space to actually expand. Nevertheless, when one would encounter starch grains from both mixed together on an artefact, the chance is small that they can be properly assigned to either being boiled loose or on the cob.

This is also the case with the roasted samples. A high amount of gelatinisation and enlargement can be seen in both the cob and the kernels, but the loose kernels seem to take more damage and also take it faster. However, as one does not know what the preparation times were in the archaeological record or if the grains were even part of the same preparation, it would be hard to differentiate between starch grains that were prepared on the cob versus the grains that came from loose kernels. Additionally, even though the amount of different damages is higher in the grains from the loose kernels, this only becomes clear when a comparison can be made between the preparation techniques. Next to this, the samples that were ground first seem to take the same damages, and in similar amounts as the loose kernels. The only difference is the sparse presence of bright rings around the hilum which indicate either grinding or grating.

When comparing roasting or frying, and boiling, at a first glance no real differences can be observed. All samples show enlarged, as well as gelatinised grains and show signs of melting. However, when looking closer, one can see that heating unground maize in low humidity results in a higher amount of central depressions. It also results in the appearance of encrusted grains, which is not encountered in the boiled samples. However, when grinding the maize, central depressions occur in similar amounts in both the boiled and fried samples, with only a slightly higher amount in the fried grains. Central depressions can therefore not be used to indicate low humidity heating. Additionally, gelatinisation seems to occur more frequently in ground samples. Lastly, more grains keeping their birefringent properties were encountered in the roasted samples than the boiled grains.

When comparing the results to the previously published sources, gelatinisation, enlargement, central depressions, melting and encrustation were all mentioned by previously done research on roasted or toasted maize (Babot 2003, 73; Chandler-Ezell *et al.* 2006, 110; Henry *et al.* 2009,). However, surface cracking, enlargement, melting, crust and wrinkled surfaces have not been mentioned by other research into roasting and toasting maize, even though these damages are prevalent in the samples. As far as the author is aware, no research was published discussing the change in starch grains due to boiling maize specifically. Research on other species has been published though. Again gelatinisation and enlargement have been mentioned, as well as central depressions (Henry *et al.* 2009, 918). The boiled maize however, shows less central depressions than the roasted maize. Again differences and similarities can be observed, showing the importance of more research.

In summary, most of the damage registered in both boiled and roasted maize cannot be used to distinguish one from the other. However, the presence of central depressions together with crusts around the starch grains is an indicator for heating starch grains in an environment with low humidity and can thus signify roasting or frying other than boiling. However, as central depressions occur in both humid and dry cooking environments, as well as after grinding, this type of damage alone cannot be used to determine the culinary practices, when assuming ancient cooking processes followed the same steps as in this thesis. A higher amount of starch grains with recognisable Maltese crosses and birefringent properties can help with this though. When grinding the maize beforehand, higher levels of gelatinisation can obscure other damages, which makes differentiation harder. Additionally, grinding before heating makes the identification of the starch grains to species level nearly impossible.

7.2.3 Comparing Pan de Maíz and Pan de Casabe

As the Pan de Casabe was only toasted, only the toasted samples of the Pan de Maíz will be considered here. Both the manioc samples, as well as the maize samples show increases in size. However, the increase in size is significantly higher in the maize samples than the manioc samples. The increase is also occurring more rapid in the maize samples versus the manioc samples. This could be because grinding damages the starch grains more, which makes them more vulnerable to heat. Gelatinisation also seems to occur more and faster in the maize samples. Only in the manioc samples that were heated for 10 minutes is there a similarity with the maize samples. This is also the case for wrinkled surfaces. The amount of surface cracking seems to be approximately the same amount, but more melting and encrustation is occurring in the maize samples. However, not all damage types are more prevalent in the maize samples. The manioc samples show a higher amount of central depressions, as well as a higher amount of bright rings around the hilum. In the maize samples, only some grains showed this characteristic of grinding, making it hard to identify samples which were ground before heating. In manioc, this can quite easily be discerned when looking at the experiments.

When looking at the shapes and Maltese crosses, the manioc samples that were grated for 10 and 20 minutes show a majority of starch grains with discernible shapes and birefringent properties. After 30 minutes of grating combined with heating, a majority of the grains lost its shape and Maltese cross. In the maize samples however, most grains already lost their shape and recognisable cross after 10 minutes of grinding and two minutes of heating. It seems that the starch grains from maize take more damage, and take it faster than the samples from manioc. It might be that manioc grains are more resilient, or that grating is less damaging to the integrity of the starch grains than grating. Nonetheless, manioc grains that were grated and heated have a higher chance of being identified than maize grains.

7.2.4 Answering the questions

As we have seen, most damage patterns occur in both unheated ground samples, heated ground samples, as well as unground heated samples. Central depressions for example occur in high amounts in toasted and roasted samples, but also in grated manioc, ground maize, and in low amounts in boiled samples. This is the same for surface cracking. Both of these types of damages can therefore not be used to determine any specific type of processing. Additionally, gelatinisation occurs in all heated samples, but encrustation is almost only visible in samples that were heated in low humidity. This makes crust a good identifier for toasting, roasting or frying. Bright rings around the hilum also only occur in ground or grated samples, making this characteristic for these processing techniques. However, damage from heating can obscure this type of damage, making it harder to identify ground or grated starch grains. Nevertheless, two characteristic damages have been observed, which can aid in identifying processing techniques in archaeological starch grains.

Grinding or grating for longer periods of time damages the integrity of the starch grain more. This makes them fall apart faster when heated, leading to less secure, or no, identification. This occurred more in ground maize samples than manioc samples, suggesting than manioc grains are a bit more resilient. Manioc grains seem to keep their birefringent properties longer then maize starch grains, this is also the case for their shapes. Grated and fried manioc grains are more susceptible to central depressions however, but seem to be less prone to enlarging drastically. Other than this, all types of damage are similar in maize and manioc.

Even though only small differences occur between the processing techniques and the different crops, still two characteristic types of damages could be seen. These types of damages are the same in both maize and manioc, and can therefore at least help in identifying heating in low humidity, and grating or grinding. More research might shed more light on the matter.

7.3 SITUATING THIS THESIS IN THE ARCHAEOLOGICAL RECORD

As aforementioned, a comparison with the archaeological record can help with gaining a better understanding of the results, but also help with gaining a better understanding of plant foodways as a whole. This section will therefore compare the results from the experiments to the results from three studies conducted on shell tools and ceramic artefacts from El Flaco and La Luperona. In doing this, it will answer the third and final subquestion:

3. How do these damage patterns compare to the archaeological record, and can we identify different food preparation sequences in archaeological samples?

In total, 47 starch grains were documented. Unfortunately, the ratio between the grains per site is not even. In total, 26 damaged grains from El Flaco were encountered in the literature, while only four were noted from La Luperona.

Three types of damage were noted in both El Flaco and La Luperona: encrustation, central depressions and surface cracks. As previously argued, both central depressions and surface cracks occur due to multiple types of food processing techniques, and this means that they can unfortunately not be used to determine the type of technique used. Encrustation, however, occurs when the starch grains are exposed to heat in a dry environment. They were therefore either toasted, roasted or fried. The identified plants with encrustation include: maize, zamia (*Zamia* spp.), chili pepper (*Capsicum* sp.), the ginger family (Zingiberaceae), and the bean family (Fabaceae). In total, eleven grains from El Flaco, and two from La Luperona, showed encrustation. It can be said with some certainty that these grains were damaged with dry heat.

Additionally, two maize grains were documented in El Flaco that showed a-symmetrical striations or a deepening of their fissures. These are considered as ground samples. One of these maize starch grains was encrusted as well, showing that even in the archaeological record certain damage patterns can survive. As this maize was scraped or slightly ground, it might have been made into a dough and toasted as done in this thesis when preparing pan de maíz. This is interesting to see as in the experiments little of this type of damage remained after heating the maize. Six grains showed central depressions, including starch grains from maize and sweet potato (*Ipomea batatas*), which can occur due to multiple types of processing techniques. It is however most prevalent in heating in a dry environment. This can support toasting or roasting, but cannot confirm it. The same applies to the two starch grains with surface cracks.

Other damage types were documented, but only in the case of El Flaco. This includes seven fully gelatinised, and two partially gelatinised starch grains which could not be identified. These can only confirm the presence of heat at some point. This also applies to the one grain that showed signs of melting, which was unidentified as well, as does it apply to the sweet potato grain with folds in the surface. Two starch grains reportedly had roughened surfaces, which is described by several sources to be the result of grinding. One of these grains was identified as maize, the other was unidentified. This again shows grinding. There are reportedly no signs of heating, so it is unsure if this was made into a dough or not.

As can be seen, several types of damage, which have been documented through the experiments and previous literature, occur in the archaeological record as well. However, not knowing exactly how the starchy crops were prepared does make it harder to safely identify damage patterns. The starch grains encrusted in particles, and with striations and roughened surfaces are an exception, as these damages were found in this thesis to quite characteristic for heating in low humidity and grinding. It is interesting to see similarities in the experiments and archaeological record though, as it does help with the interpretation. A comparison between the two is therefore valuable to make.

7.4 FUTURE RESEARCH

As previously described, a total of 504 starch grains were analysed in the different samples. Per sample, ten random grains were described and photographed. This did result in a visualisation of damage patterns, but the differences observed sometimes were quite low. The approach is good, but more intensive analysis is needed to create an even better picture of the types of damages, and the patterns, that might occur. Next to this, only maize and manioc were analysed. As we have seen from the archaeological starch grain analysis, these two crops were not the only crops which were eaten and processed. It would therefore be valuable to do more experiments with a variety of crops. Combining recipes with multiple crops might also shed light on different ratios of survival after damaging.

Not only should more time be put in analysing the results, the author also believes that repeating the same experiments multiple times can help with recording more types of damages, or seeing different amounts of damage in the samples. When looking at the previously published researches, both similarities and differences can be seen between the recorded damages. This could mean that sometimes certain types of damages do not occur, while within the same processing technique but in different settings, it does occur. As was argued earlier, different processing techniques might also lead to the same type of damage. It would also be interesting to research this, so that our interpretations will become stronger.

Next to this, merely conducting experiments does not factor taphonomic processes after the discard of the artefacts we analyse. Experiments by Hutschenreuther *et al.* (2017) show that enzymes and taphonomic processes significantly decreases starch counts on artefacts (Hutschenreuther *et al.* 2017, 95, 99, 104-105). It would therefore also be valuable to conduct experiments and expose the artifacts to these enzymes in the soils to determine what type of damage this does to the starch grains, and how it affects the survival rate of processed versus unprocessed starch grains in post-depositional contexts.

As one can see, there is ample room and necessity for future research into starch grain damage patterns. As argued, food plays an enormous part in the daily and social lives of peoples. It is part of culture and identity. Gaining a better understanding of different processing techniques can shed light on similarities and differences between areas, or even within different social settings. More research into damage patterns is therefore an interesting step into gaining a better understanding of the daily lives of peoples of the past.

7.5 Conclusion

Throughout this thesis, the preparation of foodstuffs has been central. It has been argued that ethnographic, ethnohistoric, and experimental research can help bridge the gap between the static archaeological record, and the social dynamics of the past. By doing this, we can create a better understanding of the preparation techniques used in the past. The experiments conducted in this thesis, as well as the comparisons made to previously published experiments and archaeological starch grain analysis sought to answer the main question of this thesis:

> *To what extent is it possible to identify the cultural processes involved with ancient food preparation in the circum-Caribbean area through recreating these processes and subjecting the residues to starch grain analysis?*

As we have seen, several types of damages can be labelled as characteristic for certain processing techniques. The presence of a bright ring around the hilum argues for either grating or grinding and encrustation of starch grains indicate heating in low humidity, either frying, roasting or toasting. Next to this, other damage patterns cannot signify specific processing techniques in this thesis, but give a more general overview. This includes the presence of enlarged starch grains, and signs of melting, which all occur when heating starch grains. Additionally, the presence of gelatinised starch grains hints at heating in a moist environment. However, one needs to keep in mind that we cannot replicate the specific steps taken in ancient cooking processes, which might result in different damage patterns.

When comparing the results from the experiments to the archaeological record, it became clear that even after hundreds of years starch grains with different types of damage survived and were retrieved. These include, but are not limited to, maize (*Zea mays*) grains with signs of grinding, as well as toasting, steps similar as the preparation of *Pan de Maíz* in this thesis. This is interesting as this preparation is rarely described as being used on the Caribbean islands at the time of the Spanish arrival. This shows that a combination of experimental research, as well as archaeological starch grain analysis can shed light on preparation techniques. However, in order to gain a better understanding of all the cultural processes involved in food preparation, such as gathering, cooking, consuming, and discarding foodstuffs and the tools involved, more research needs to be done, and more research needs to be combined and compared.

8 ABSTRACT

Food and its preparation are part of everyone's daily life, and the interaction and usage of plants has always been deeply imbedded in human history. Therefore, by gaining a better understanding of how plants were processed and prepared, we can gain a better understanding of the daily lives of peoples of the past. To reconstruct the dietary practices of peoples of the past, different parts of the diet and their proxies, such as animal remains, faunal lipids, botanical lipids, isotopes and botanical macro- and microfossils can be analysed. Additionally, historical and ethnographical accounts may prove useful as a basis for these researches. However, as historical accounts are often incomplete or less clear due to the lack or prior knowledge of native plants and their preparation and consumption, these accounts could better be used as a basis for further research.

One of the microfossils that can be analysed are starch grains. They are considered the only type of botanical microfossil remains which can be directly correlated with both the usage as well as the preparation of plants by humans from the past. The grains can be identified to species level based on their specific characteristics. However, he preparation of food and beverages by, for example, heating, grinding or fermenting starchy plants can damage the starch grains within. These preparation techniques do leave specific damage types however, which may be used to identify damage patterns in the archaeological record. It is therefore important to gain an understanding of these damages.

This thesis aimed to research these damage patterns through conducting experiments on two crops native to the Americas, maize (*Zea mays*), and manioc (*Manihot esculenta*), and to get an answer to the research question:

> *To what extent is it possible to identify the cultural processes involved with ancient food preparation in the circum-Caribbean area through recreating these processes and subjecting the residues to starch grain analysis?*

The experiments were based on ethnographic and ethnohistoric sources mentioning the foodways after the arrival of the Europeans to the New World. The results were then compared to previously published experiments, as well as archaeological starch grain analysis from two sites at the Dominican Republic. It was assessed that even though heating starch grains in humid or dry environments obscures certain damage types, some characteristic damage types could be observed. These types of damages were also encountered in the archaeological case studies, showing preparation techniques not

mentioned by the ethnographic and ethnohistoric sources. This therefore shows the importance of conducting more experiments to gain a better understanding of food processing techniques in the past. More research will help with gaining a better understanding of past foodways and subsequently the daily life’s of peoples of the past.

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Appendix A.

Appendix A consists of various clips of the author conducting experiments. These clips are uploaded separately to a file sender with the following link:

https://filesender.surf.nl/?s=download&token=e01a6230-5a51-4206-87de-bd982afa4eae

This link can be used to download the files anonymously until 19/08/2021.

A short description of the clips will be given here:

Appendix A.1

In the clip containing Appendix A.1, one can see the author prepare maize (*Zea mays*) in order to roast it. First the husks are taken off. Following this, several grains are carefully taken off to be samples as undamaged maize. After the sampling, the cob is washed with demineralised water and cut in half. One half was used for roasting a whole cob, while the other has its kernels sliced off. The sliced off kernels are sampled as well. After this, the loose kernels were roasted for two, five, and ten minutes and sampled in between.

Appendix A.2

In Appendix A.2, one can see the author grind maize kernels in order to make flour. The kernels were soaked for one hour prior to the clip. One can see that the kernels are getting rubbed together to separate the endosperm from the pericarp. After this, the maize kernels are blotted dry and ground for 10, 20, and 30 minutes and samples in between. Following this, the flour was mixed with water and heated on a griddle.

Appendix A.3

Appendix A.3 shows the author grating manioc. First the manioc was grated into a mass (not shown in the video). The mass was grated for 10, 20, and 30 minutes after that, and samples in between. The masses were then heated on a griddle for two, five and ten minutes, which is also not shown.

APPENDIX A.4

In appendix A.4, one can see how the sampling process works after taking the sample from the foodstuffs. The prepared food is mixed with demineralised water, and left to soften. Following this, the sample is mixed with the water and decanted through a clean cloth into another container. This container is agitated, after which a pipette is used to place a small amount of sample on a microscope slide.

APPENDIX B.

Appendix B contains the sample logbook of the author with all the measurements, descriptions and damages recorded per starch grain. However, as this is an excel workbook, it cannot be added to this document. It was therefore uploaded separately.