The Potentiality of Phytoliths in the Study of Roman Spices:
An Investigation into the Nature of Phytoliths in *Piper nigrum* and *Piper longum*.

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Evan McDuff

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ABSTRACT

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A thesis presented to the Graduate Program in Ancient Greek and Roman Studies

Graduate School of Arts and Sciences
Brandeis University
Waltham, Massachusetts

By Evan McDuff

Written sources tell us the pepper species of *Piper nigrum* and *Piper longum* played a significant role in ancient Roman cuisine, however, physical evidence of their culinary use in the form of macrobotanical remains is rare. Phytoliths, due to their possible taxonomic significance and survivability, could be used to understand Roman culinary applications of pepper in contexts where the preservation of macrobotanical remains is poor. To gauge their usefulness in the study of pepper, phytoliths were isolated from modern botanical samples of white pepper (*Piper nigrum*), black pepper (*Piper nigrum*), and long pepper (*Piper longum*). Phytoliths were found to be absent in samples of white pepper, but keystone morphologies of the oblong psilate and polyhedral irregular types were found in long and black pepper respectively. These keystone morphologies indicate that phytoliths could possibly be used to identify these forms of pepper in certain Roman archaeological contexts. In addition to morphological research an experiment was undertaken that found that ground forms of all varieties of pepper and all preparations of long pepper were susceptible to mold in a climate of varying temperature and humidity.
# TABLE OF CONTENTS:

<table>
<thead>
<tr>
<th>Page</th>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>VI</td>
<td>List of Tables</td>
</tr>
<tr>
<td>VII</td>
<td>List of Figures</td>
</tr>
<tr>
<td>1</td>
<td>Introduction</td>
</tr>
<tr>
<td>5</td>
<td>Chapter 1: Spices and the Nature of Phytoliths</td>
</tr>
<tr>
<td>15</td>
<td>Chapter 2: A History of Pepper in the Ancient Mediterranean</td>
</tr>
<tr>
<td>33</td>
<td>Chapter 3: Laboratory Procedures and Data</td>
</tr>
<tr>
<td>48</td>
<td>Chapter 4: Results</td>
</tr>
<tr>
<td>58</td>
<td>Conclusions</td>
</tr>
<tr>
<td>61</td>
<td>Images</td>
</tr>
<tr>
<td>79</td>
<td>Appendix A: Pepper in Ancient Texts</td>
</tr>
<tr>
<td>80</td>
<td>Bibliography</td>
</tr>
</tbody>
</table>
TABLES:

38   Table 3.1: Number of Phytoliths Per Morphology in Each Variety of Pepper
39   Table 3.2: Percentage of Morphology Present in Each Variety of Pepper
43   Table 3.3: Weights and Measures for Each Variety of Pepper
44   Table 3.4: Number of Phytoliths Per Gram of Sample (Sample Density)
44   Table 3.5: Number of Phytoliths Per Gram of Pepper (Density Per Gram)
47   Table 3.6: Changes in Mass Associated with Decay in Each Variety of Pepper
FIGURES:

61 Figure 1: *Piper nigrum* Plant
62 Figure 2: *Piper nigrum* Fruit
63 Figure 3: *Piper longum* Plant
64 Figure 4: Black and White Peppercorns
65 Figure 5: Long Pepper Catkins
66 Figure 6: *Piperatorium*
67 Figure 7: Phytolith Processing
68 Figure 8: Polyhedral Irregulate Phytolith Type, Black Pepper (1)
69 Figure 9: Polyhedral Irregulate Phytolith Type, Black Pepper (2)
70 Figure 10: Polyhedral Irregulate Phytolith Type, Black Pepper (3)
71 Figure 11: Oblong Psilate Phytolith Type, Long Pepper (1)
72 Figure 12: Oblong Psilate Phytolith Type, Long Pepper (2)
73 Figure 13: Oblong Psilate Phytolith Type, Long Pepper (3)
74 Figure 14: Taphonomic Experiment, Set Up
75 Figure 15: Taphonomic Experiment, Before
76 Figure 16: Taphonomic Experiment, Running
77 Figure 17: Taphonomic Experiment, After
78 Figure 18: Tracheid Phytoliths
Introduction

Paleoethnobotany, a subfield of archaeology, is concerned with identifying plant remains in the archaeological record and contextualizing these finds culturally in order to elucidate the past relationships between plants and humans.⁴ Paleoethnobotany is also concerned with how botanical resources and environmental pressures impact the development of cultures. In short, the field studies how plants, culture, and environment all act on and react to each other. This research, however, is entirely dependent on the survivability of plant materials. Like most carbon-based organisms, plants are highly susceptible to decay after death. Yet, where decaying animals leave behind mineralized tissue in the form of bones, plants leave behind a mineralized skeleton in the form of phytoliths.

Phytoliths are microscopic mineral bodies composed of silica that form within and around the organic structure of a plant’s cells. Archaeobotanical research is particularly interested in these opal silica forms for three reasons. First, phytoliths, as a by-product of their production, are indicative of the producing plant’s cellular structure. Because of this, phytoliths can be diagnostic of taxa and can be used to identify the producing plant long after its organic components have decayed away.² Second, since they are composed of inorganic silica, phytoliths are resilient to break down in most types of soil. Thus, in a relatively stable environment

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² Taxa is a generic term to describe taxonomic groupings, like kingdom, genus, and family, within which organisms belong. For instance, the olive known by its botanical name *Olea europaea* belongs to the genus *Olea*, the family Oleaceae, and the clade Eudicotidea.
phytoliths will remain diagnostic to their producing plant for extended periods of time. Finally, the preservation of phytoliths is not dependent on human activity or happenstance. Unlike most macrobotanical remains that often require mineralization in the form of burning to remain stable over long periods of time, phytoliths require no such human processing or natural phenomenon to ensure preservation. Because of these three factors, phytoliths are a revolutionary tool for the study of past plant use. For example, Deborah Pearsall, a pioneer of phytolith research, was able to devise a methodology to distinguish maize from wild grasses in the archaeological record based on the measurements of one morphologically significant phytolith type. This technique would be later used to distinguish domesticated maize and its wild relatives in the archaeological record and helped understand the process of maize domestication in the New World.

Given the value of phytoliths in the study of past plant use, my primary research interest is to explore the possible effectiveness of phytolith analysis in identifying the archaeological remains of spices. This study focuses particularly at Roman archaeological contexts, since the Romans were avid users of spices and imported great quantities of aromatics from the east. Of the spices imported into the Roman world none carried quite as high a significance as pepper, which was traded from the Indian subcontinent. Pepper bore significant cultural, medicinal, culinary, and economic value to the Romans. Despite its value, pepper was, according to literary sources, abundant and accessible throughout the Roman world. Pepper is a prime candidate for

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7 Andrew Dalby, Food In the Ancient World From A to Z (London; New York: Routledge, 2003), 254–55.
phytolith analysis because of the unique dichotomy between its exotic origin and common application in the Roman world. Thus, this study focuses on the potential use of phytoliths in identifying pepper remains in the archaeological record, and the research areas surrounding pepper that could be investigated using phytolith methodologies.

In order to evaluate this potential, I designed and ran an experiment to isolate phytoliths from the three types of pepper found in the Roman Empire. The results of this experiment, laid out in this thesis, establish that two of the three pepper varieties common in the Roman world do in fact accumulate distinctive phytoliths that would be left behind after complete organic decay. This investigation establishes and describes the morphologies of these distinctive phytoliths and sets the groundwork for using these morphologies as comparatives to identify pepper remains in the archaeological record. The experimental basis for this research is common for phytolith analysis because an archaeological sample cannot be understood taxonomically without a laboratory comparative.

Additionally, this study looks into the possibility that taphonomic forces, those forces that cause the decay and fossilization of organic material, are responsible for the absence of certain varieties and preparations of pepper in the archaeological record. To do this, the three Roman pepper varieties were left to decay for seven months in an environment of fluctuating temperature and humidity in order to see if any particular variety was more resilient to organic breakdown than the others. The varieties of pepper were tested in both whole and ground forms in order to determine if such distinctions affected susceptibility to decay.

I discuss the findings of this research in four topic-focused chapters. The first chapter addresses the standards, uses, and limitations of phytolith research in general. This chapter also discusses the physical properties and formation of phytoliths in vascular plants. The second
chapter focuses on the types of pepper investigated in this research and the archaeological and ethnohistoric evidence for their use and importation into the ancient Mediterranean world. The third chapter outlines the experimental procedures undertaken as part of this research and presents the data obtained through my experiments. The final chapter discusses the results of the experiments and places them in the greater context of pepper research and classical archaeology.

In total, the goal of this project is to assess the historical and archaeological evidence around Roman pepper consumption and determine if phytoliths can be used to better understand these practices. This research, as an initial investigation into the nature of phytoliths and pepper, aims to contribute to future research concerned with distinguishing whether different varieties of pepper held particular significance in different spheres of society, different parts of the Mediterranean, and at different periods of time. Such evidence would render it possible to create a timeline for the importation of different varieties of pepper, which could test previous scholastic assumptions about land and sea routes of trade and Roman preference for one type of pepper over the others. In doing this, there will be a better understanding of one of the first globalized trading economies and one of the most important goods traded in that economy.
Chapter 1: Spices and the Nature of Phytoliths

A spice, in a broad sense, is a substance of botanical origin which is valued for its qualities of scent and taste. Frequently these qualities are the result of volatile chemicals that give spices their aroma, taste, and, in some cases, sizzle. Unlike herbs, which share these volatile qualities, spices convey an exotic air. The association of ‘being from afar’ attached to spices likely derives from the words Latin root *species*, which in late Latin denoted those commodities and products that were of great importance and expense, like frankincense, silk, cinnamon, cotton, and pepper, all of which originate far beyond the shores of the Italian peninsula. Of course, there is no equivalent Latin or even Greek word that conjures the culinary connotations that the word *spice* now holds in English. The same spices that are now used predominantly in the kitchen were used in a myriad of fashions in addition to their function as a condiment during the Roman period. Spices were used as medicines, in dried bundles as air fresheners, in victory crowns, in dyes for fabrics, perfumes, and in religious ceremonies. Spices were an integral part of Roman society, cuisine, and religion; however, finding archaeological evidence to establish the relation between the Romans and their spices is not always easy.

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9 *Species, speciei f; display, spender, show, sort.*
11 Dalby, *Food In the Ancient World From A to Z*, 309.
12 Miller, 1–2.
The archaeological study of spices in the ancient Roman world has been challenging because plant tissue is so rarely preserved. As such, most research concerned with Roman importation and use of spice has been confined to rare archaeological finds of charred or desiccated macrobotanical remains or historical studies through written sources. Botanical materials may be preserved if they are subjected to mechanical or chemical processes that prevent organic decay; however, these processes are subject to a high degree of chance. In other words, plants themselves are only preserved en masse under extremely fortuitous circumstances, like the exceptional conditions met at Pompeii and Herculaneum.\(^\text{13}\) This degree of chance results in the preservation of only a small fraction of the plant species used by humans in the archaeological record.\(^\text{14}\) Despite the near-total decay of plant organics, non-carbon bodies produced by plants, namely the phytolith, have been used in paleoethnobotany to study human-plant relations and may serve useful in the study of Roman spices.

*Phytolith*, in a loose sense, can be used to describe any hard-mineral substance secreted by plants. The strictest archaeological parameters, however, define a phytolith as a body of silica deposited into and around the cellular structure of higher-level plants. Phytolith production is a common and ubiquitous feature of the kingdom Plantae,\(^\text{15}\) and archaeological research has already found that some spice-deriving plants, such as *Alliaria petiolalata*, produce phytoliths.\(^\text{16}\) The archaeological utility vested in phytoliths derives from the process of their formation, which begins with the botanical absorption of silica. Silica, as one of the most abundant elements, is

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\(^\text{13}\) Robinson and Rowan, 106.


found in the earth’s crust in silicate minerals like quartz and feldspar. As these minerals are weathered, solid silica reacts with ground water in a hydration reaction to create soluble silica in the form of monosilicic acid. Monosilicic acid is absorbed by plant roots as they uptake water in the process of transpiration.

Upon absorption, monosilicic acid is transported upward toward the aerial organs of the plant via the water conductive tissue of the xylem as a result of transpiration. Through both passive and active transport mechanisms, monosilicic acid is circulated throughout the plant. As water transpires out of the plant the silica becomes more concentrated until it precipitates out of solution and forms solid opal silica within the cellular structure of the plant. Silica deposits can inhabit fully or partially both intercellular and intracellular spaces and can create either solid cast of cellular spaces or produce thin coatings of the cellular linings. Phytolith formation is particularly concentrated in the epidermal tissue of the stem and leaves, though they can form in the inflorescence, as well. As particular cells and cellular structures have characteristic forms, so too do phytoliths, which display a variety of morphologies dictated by the cells they form in and around. This is important, because the impression of the plants cellular structure on to the silica body gives a phytolith its shape, which can in some cases be taxonomically

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significant. These taxa-related keystone phytoliths allow archaeobotanists to associate phytolith assemblages with their plants of origin.

The morphologies of silica bodies are divided into two groupings. The first group of phytoliths includes those with variable morphologies that are highly irregular and unclassifiable. This grouping consists of amorphous forms of silica that cannot reasonably be broken into categories of like and dislike shapes. Most plants tend to produce such silica bodies. The second phytolith group is that which exhibit characteristic morphologies that are repeated and easily categorized.\textsuperscript{26} It is this second category on which archaeobotanical inquiries and botanical research focus. Unique or diagnostic shapes are often associated with particular cell types while other unique shapes are characteristic of taxonomic groupings.\textsuperscript{27} For instance, members of the family *Orchidaceae*, to which orchids belong, are easily identified by their conical phytoliths.\textsuperscript{28} Some regular morphologies are of limited taxonomic value such as tracheid phytoliths, which occur in numerous dicotyledons (Figure 18).\textsuperscript{29} Some keystone phytoliths are distinguishable to family level, others are diagnostic enough for more nuanced taxonomic distinctions like genus, species, and subspecies.\textsuperscript{30} For instance, the decoration on the conical phytoliths of the *Orchidaceae* family can sometimes be used to distinguish different species of orchid.\textsuperscript{31}

Under a microscope, phytoliths usually appear as clear bodies of varying shapes and sizes that range from 2 µm to 1000 µm, although sizes between 20 µm and 200 µm are most

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\textsuperscript{27} Rovner, “Plant Opal Phytolith Analysis: Major Advances in Archaeobotanical Research,” 228.


\textsuperscript{29} Piperno, *Phytolith Analysis: An Archaeological and Geological Perspective*, 103.

\textsuperscript{30} Pearsall, “Phytolith Analysis: Applications of a New Paleoethnobotanical Technique in Archeology,” 862.

common. Given the variation of morphologies and the interdependence between biological tissue and morphology, a considerable amount of research has been done tying phytolith morphology to taxonomy. Generally, taxonomic groupings have consistent morphologies around the world and, thus, plants of the same species have the same morphologies despite being continents or centuries apart. Phytolith morphology, however, can be affected by external factors such as soil composition and plant maturity, but these external factors rarely affect diagnostic phytoliths. In some cases these fluctuations in morphology can elucidate climatic changes like the research done at the Israeli site of Grar, which found that the northern Negev received more annual rainfall during the Chalcolithic than it currently does.

When describing phytoliths in an analytical setting, morphology is broken down into shape, texture, and decoration. Because phytoliths come in every imaginable configuration, from spherical masses to perfectly formed cubes, shape is usually described using comparable geometric terms. Decoration is independent from shape and describes the surface texture or ornamentation of a phytolith. A combination of shape, texture, and ornamentation are used to describe the morphology of a phytolith. Up until the early 2000s the description of phytolith morphology was dependent on individual researchers. This made comparative studies nearly impossible, since there were no strict definitions for each descriptor. This issue was partially remedied in 2005 with the publication of the “International Code for Phytolith Nomenclature 1.0,” which set out guidelines for phytolith nomenclature established by a group of scientists.

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Plants with normally high phytolith accumulation have been observed to produce less phytoliths in soils where monosilicic acid is unabundant.
known as the International Working Group on Phytolith Nomenclature.35 This publication calls for a standardization of naming conventions and set names for several common shapes and decorations. Subsequent publications on phytoliths use these conventions for naming, however, these conventions do not fully cover the staggering amount of diversity in phytolith morphology.36 As such, there is still a large area of interpretation that is unregulated.

Phytoliths are a valuable asset to archaeology not only because of their taxonomic significance but their survivability as well. A plant continues phytolith production throughout its lifetime and ceases with death.37 As the organic components of the plant decay the inorganic phytoliths are deposited in the soil. Once deposited into the archaeological record phytoliths resist breakdown. As they are not composed of carbon, phytoliths are not adversely affected by the same factors that would allow macrobotanical remains and pollen to decay. Furthermore, phytoliths, for unknown reasons, are resilient to dissolution and reformation in the silica cycle upon being deposited in soil. As such, phytoliths can remain stable and identifiable in soils for extended periods of time, with the exception of climates with a high pH of nine and above, usually found in those locations endowed with an excess of sodium,38 or temperatures hot enough to melt silica.39 Given these factors, phytoliths have a high degree of survivability in

39 Silica has a melting point of 1,713°C according to the *CRC Handbook of Chemistry and Physics*. 

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most soil types, however, they are susceptible to mechanical breakage and weathering which can effect some morphologies more than others. Their survivability and ability to be taxonomically identifiable make phytoliths extremely useful at elucidating past interactions between plants and humans, especially in contexts where there are no other archaeobotanical remains like macro-remains and pollen, which are only preserved under special conditions.

Phytoliths are of particular use in the study of ancient diet as many food remains are reduced to macroremains through processing, cooking, mastication, and digestion. The ability to connect phytoliths with diet and cuisine is dependent mostly on context. In regard to diet, phytoliths can be found in both direct and indirect contexts. A direct context would constitute those that show a direct connection between the human body and the consumption of plant matter. This correlation can be found within soils associated with articulated human corpses as phytoliths in the human digestive system are deposited into the area around the viscera. Likewise, phytoliths accumulate in plaque deposits on teeth as a result of mastication and can be used to show a direct correlation with plant materials and consumption, such as the 1990 study that found phytoliths bonded to the teeth of a Gigantopithecus blacki that indicate that the extinct ape subsided on a varied diet of grasses and fruits. Similarly, phytoliths in coprolites—desiccated or mineralized fecal matter—can also be used to illuminate these relations. For example, phytoliths identified in coprolites from Dust Devil, Utah, indicate that the defecator had eaten prickly pear. Indirect contexts are those that might demonstrate the consumption of plant

material but do not directly show a correlation between the human body and plant materials. These contexts include storage jars, kitchen floors, cooking wares, eating utensils, and trash dumps. It is feasible, given their taxonomic significance and survivability, that phytoliths can be used within both primary and secondary contexts to study spice in the diet and cuisine of the Romans.

There is no precedent for the use of phytoliths in the study of spices in a Roman context, and there is only one published study that uses phytoliths in the analysis of spices. The sole study, published in the article “Phytoliths in Pottery Reveal the Use of Spice in European Prehistoric Cuisine,” by Saul et al., not only explores the potentiality for phytoliths in the analyses of spices, but also positively established the identification of spice phytoliths in an archaeological deposit. In this study analysts headed by Saul isolated phytoliths from 26 deposits of carbonized material affixed to the insides of sherds obtained from the museum collections of Holbeak, Kalunborg, and Schleswig-Holstein. The sherds were excavated from three sites in Denmark and Germany ranging in age from 6100 and 5750 cal B.P. (Calibrated years before Present).45 Carbonized materials from inside the vessels were thought to be burned food and this was confirmed by a greater relative abundance of phytoliths compared to charred materials found on the outer surfaces of the sherds. The high relative abundance indicates that the inner deposits were, in fact, a direct result of culinary action.46 Phytoliths obtained from the innermost portions of these deposits were compared to phytolith samples from the stems, leaves, and seeds of 120 plants from Asia and Europe. Eight of the deposits were found to contain globular sinuate phytoliths typical of seed epidermal tissue and were morphologically equivalent to phytoliths

45 Saul et al., 1.
46 Saul et al., 2.
found in the seeds of modern garlic mustard (*Alliaria petiolata*).\textsuperscript{47} Garlic mustard ranges from Europe to central Asia and is characterized by a strong flavor caused by volatile aglycones in both the leaves and seeds.\textsuperscript{48} The inclusion of garlic mustard seeds in these ancient dishes is not a result of human nutritional needs, since garlic mustard seeds have little to no caloric value. Therefore, according to Saul et al., the inclusion of garlic mustard seeds reflects a desire for added flavor, as they contain volatile aglycones which cause a peppery garlic taste.\textsuperscript{49} This study clearly demonstrates that some spices produce unique phytolith morphologies and that these morphologies can be identified in the archaeological record.

Despite potential usefulness, phytoliths have their limitations since not all plants or plant parts produce phytoliths.\textsuperscript{50} Phytolith analysis, moreover, may not be useful on some spices. For instance, decayed cinnamon and cassia might not show up in the archaeological record because they are derived from the bark of woody dicotyledons, which have been shown in studies to produce a low amount of phytoliths in their wood and bark.\textsuperscript{51} Likewise, phytolith analysis would be useless on spices and aromatics like silphium, asafoetida, and frankincense because these are derived from saps and resins bled from botanicals. Since these dried resins and saps are from outside the cellular structure of the plant and are themselves liquid, the presence of phytoliths is likely only in very low numbers and only in impure samples. Since some taxa do not deposit silica within their flowers or fruit, some spices derived from inflorescences, such as pepper, juniper, and myrtle, may or may not produce phytoliths depending on the individual species.\textsuperscript{52}

\textsuperscript{47} Globular sinuate phytolith; Spherical phytolith marked with an uneven surface with alternating but uneven concavities and convexities.
\textsuperscript{48} Saul et al., 3.
\textsuperscript{49} Saul et al., 3.
\textsuperscript{51} Albert and Weiner, 265.
Since phytolith production is not a guaranteed biological process in the plant kingdom, the initial step that must be undertaken in the study of phytoliths and Roman spices is the identification of those plant species and parts that do and do not produce phytoliths.

Phytoliths can be indicative of taxonomic distinctions, they have a high survivability in the archaeological record, and the archaeological context of their finding can give a direct or indirect connection to culinary practice. The Saul et al. study has already demonstrated that it is possible to identify spices in the archaeological record using phytoliths. Because these techniques have been utilized in prehistoric cuisine, so too might they be used in the archaeological study of Roman spices. For archaeological investigations to be done, comparative phytoliths must be extracted from plants identified as likely to contribute to phytolith assemblages in Roman contexts. Thus, researchers must first distinguish plants used as spices by the Romans as phytolith accumulators and non-accumulators. In part of this effort, it is the goal of this project to ascertain the nature of phytolith accumulation in pepper in this regard. Pepper was selected as the focus of this project due to its importance to Roman culture, which will be discussed at length in chapter two. The aspiration of this study is to identify whether or not the three varieties of pepper used in the ancient Mediterranean produce taxonomically significant phytoliths within their fruits.
Chapter 2: A History of Pepper in the Ancient Mediterranean

In order to fully establish the potential of phytoliths in the study of Roman pepper and to best determine how phytoliths analysis can be used for maximum effect in this study, it is necessary to understand the spices’ place in the cultural and historic landscape of the ancient Mediterranean. This chapter explores the historic use of pepper based on traditionally available evidence including written sources and archaeological finds associated with pepper. As well, this chapter outlines the factors, mainly its widespread availability due to mass importation, which marks pepper a prime candidate for phytolith analysis. This chapter also examines the botanical peculiarities of *Piper nigrum* and *Piper longum* and focus on the development of their fruits, which after variant forms of processing are used as the spices long, black, and white pepper.

2.1, White, Black, and Long Pepper:

Three kinds of pepper were known to the ancient Mediterranean and are noted in ancient literary sources. In English these peppers are denoted as white pepper (*Piper nigrum*), black pepper (*Piper nigrum*), and long pepper (*Piper longum*). All three kinds of pepper originate from the Indian subcontinent and were traded via land or sea routes into the Mediterranean at great cost. Additionally, they are all from the plant family Piperaceae and the genus *Piper*, which contains over 1000 species spread across the globe.53

In order to explain the variation of phytolith morphologies in Roman forms of pepper, it is essential to understand the biology and development of the fruits of *Piper nigrum* and *Piper longum* and the subsequent processing of these fruits because it is these structures which were traded into the Mediterranean as black, white, and long pepper. White and black pepper are both derived from the fruits of *Piper nigrum* and should theoretically both produce the exact same phytolith morphologies; however, this was proven to be false early in my morphological investigation. Piper nigrum is a perennial climbing vine and is indigenous to the forest of the Western Ghats along the southwestern coast of the Indian subcontinent. The flowers of *Piper nigrum* are produced in clusters on spikes and pollination occurs via wind, rain, and insect interaction (Figures 1 and 2). Upon fertilization the ovary containing a single ovule develops into a drupe. Each individual flower will produce one drupe which will in turn produce one single peppercorn. The drupes are slow growing and will not attain maturity for 6 to 8 months. The drupes are globular, green, and cluster on a spike similar to small grapes. Clusters usually contain 20 to 30 peppercorns. It is these peppercoms which are traded as the spices of white and black pepper.

The basic methods used for producing black and white pepper respectively have not changed since the classical period. Black pepper is produced when nearly ripened yet still green *Piper nigrum* drupes are harvested, dried in the sun, and removed from their spikes. This drying causes the outer fruit wall or pericarp to turn black and wrinkle, thus the name black pepper. White pepper is produced when fully ripened red drupes are collected, and the pericarp is

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54 My research has found that the parts of the *Piper nigrum* drupe which constitute white pepper are devoid of phytoliths. For more information please see the results in Chapter 3 and 4.
56 Ilyas, 275.
removed to harvest the white seed within (Figure 4). Since they are of the same species both white and black pepper have similar chemical compositions and flavors. Essential oils found in the fruit of the *Piper nigrum* plant are concentrated within the outer flesh. This means the removal of the pericarp leaves white pepper with a smaller volume of volatile oils than black pepper. Essential oils make up 1% of white pepper’s total mass and 5% of black pepper’s total mass. The major chemical contributing to the flavor of black and white pepper is the alkaloid piperine, which, unlike the essential oils found in the pericarp, is found in the core of the peppercorn. Thus, weight for weight white pepper contains more piperine than black pepper.

The third type of pepper known to the ancient Greeks and Romans was long pepper (Figure 3). Long pepper is derived from the plant species *Piper longum*. *Piper longum* is indigenous to the northern evergreen forest of the Indian subcontinent, where it still grows wild. Like *Piper nigrum*, *Piper longum* is a perennial climbing vine with cordate leaves and a jointed nodular stem. Unlike *Piper nigrum*, where each flower produces one fruit, the fruit of the *Piper longum* plant consist of one spike of aggregated drupelets formed from the merging of several pollinated female flowers. This aggregation forms a thin conical spike-like fruit with a hatched texture. The fruit of the *Piper longum* plant is harvested when it is nearly matured but still green. After harvesting long pepper is dried in the sun until the fruit takes on a grey appearance (Figure 5). Like *Piper nigrum*, *Piper longum*’s bitter peppery taste is a result of piperine. *Piper longum* also includes the compound zingiberene, which gives long pepper the heat and the mouth numbing effects associated with ginger.

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57 Cappers, 111.
59 Ilyas, 277; McFadden, 69.
60 McFadden, 69.
The English term *pepper* is derived from the Latin *piper*, which is in turn derived from the Greek τὸ πέπερι, a corrupted loan word from Sanskrit, an ancient language that was spoken in the northern Indian subcontinent. The word origin, anglicized as *pippali*, is used to denote the spice derived from the species *Piper longum* and does not include the spices derived from the species *Piper nigrum*, which is identified in Sanskrit as *maricha*. It is logical to speculate that the term τὸ πέπερι was coined with the introduction of long pepper to the Greek world. The adoption of this term for all three kinds of pepper suggests that long pepper was the default to which the other forms of pepper were compared, at least at first. Based on this interpretation of the expansion of τὸ πέπερι to mean white and black pepper it is possible that long pepper was introduced to the Mediterranean world earlier than the other forms of pepper. Perhaps long pepper was more likely to be transported west due to its origin point closer to the mainland trade routes connecting the Greek world with Asia. White and black pepper, originating in the most southern part of the subcontinent, would have been much farther from the overland trade routes and thus less likely to reach Greek lands. In this case, the definition of τὸ πέπερι was extended to include black and white pepper upon their later introduction due to their similar flavor to long pepper. This is all speculative because questions concerned with the availability and preference for the varieties of pepper cannot be fully evaluated with current evidences, but perhaps there is phytolith evidence out there which might let future research broach such topics.

2.2, Pepper Before Rome

Pepper and spices were known and used in the Greek world, but were often applied to food

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62 Dalby, *Food In the Ancient World From A to Z*, 254–55.
with restraint and only for medical purposes, as the strong flavors associated with spices were thought to ruin food.\textsuperscript{64} Hippocrates, \textit{c. 400 B.C.E.}, is one of the earliest authors to write regarding pepper and he, like many ancient authors writing about pepper, suggests its use in several medical preparations including the use of a cloth suppository soaked in a concoction of pepper, honey, and vinegar which was intended to draw out menstrual blood.\textsuperscript{65} Hippocrates also suggests a mixture of pepper, laurel, myrtle, castor, cassia, myrrh, rosemary, and Egyptian ointment for quartan fever.\textsuperscript{66} Later, sometime after 310 B.C.E., Theophrastus describes pepper as an effective antidote against hemlock poisoning\textsuperscript{67} and offers one of the earliest surviving physical descriptions of two varieties of pepper saying, “one is round like bitter vetch, having a case and flesh like the berries of bay, and it is reddish: The other is elongated and has seeds like those of the poppy.”\textsuperscript{68}

Diphilius of Siphnos, in the early third century, is the oldest surviving source to speak of pepper as a condiment in food.\textsuperscript{69} As preserved by Athenaeus, Diphilius suggests the use of pepper paired with cumin on scallops, for the combination of botanicals aided with the digestion of the bivalve.\textsuperscript{70} Diphilius’ inclusion of pepper seems to be strongly related to the medical qualities of the spice rather than overall taste of the dish. This exemplifies the relationship between the ancient Greeks, pepper, and food: the culinary use of pepper is a product of the spice’s medicinal use, in so far as it was often taken with food in order to aid in digestion and

\textsuperscript{64} Dalby, \textit{Food In the Ancient World From A to Z}, 309.
\textsuperscript{66} Miller, 82.
\textsuperscript{67} Andrew Dalby, \textit{Dangerous Tastes: The Story of Spices} (Berkeley: University of California Press, 2000), 89.
\textsuperscript{68} Cappers, 112.
\textsuperscript{69} Dalby, \textit{Food In the Ancient World From A to Z}, 254.
appetite rather than being eaten solely for its flavor. Furthermore, in On Odors, Theophrastus stresses the Greeks’ disdain for the use of aromatics in food, saying “One might wonder why exotic and other fragrances improve the taste of wines when, so far from having that effect on food—whether cooked or uncooked—they invariably ruin them.” It is clear from these texts that, at least for a time, pepper was valued for its medical properties rather than its culinary or economic importance; however, during the Hellenistic and Roman period these other cultural aspects of pepper became greater in importance.

2.3, Pepper in the Roman Period

The Romans, brought into closer contact with eastern “luxury” goods during their military campaigns of the third and second century B.C.E., departed from the Greek culinary tradition and adopted the use of eastern spices from Arabia, Asia, and the Far East into their cuisine. Soon, a new Roman cuisine and banqueting culture were born and new spices never before tasted on the Italian peninsula were making their way to Rome.

By the early Imperial period, the demand for spices, considered luxuries due to their foreign nature, reached a height previously unseen in the Mediterranean. The Roman cookbook Apicius, calls for the use of over sixty aromatic herbs and spices. Of these sixty botanicals, only fifty grew within the regions of the Roman Empire. The remaining ten spices originated far

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71 Andrew Dalby, Siren Feast: A History of Food and Gastronomy in Greece (London; New York: Routledge, 1996), 137.
74 John F. Donahue, Food and Drink in Antiquity: Readings From the Graeco-Roman World (London; New York: Bloomsbury Academic, 2015), 167.
75 Livy, 225.
outside of the Empire’s borders and required extensive trade networks between the Roman heartland and the Far East. These foreign spices were imported at a steep price that the Romans gladly paid, for not only were spices a necessary component to Roman cuisine, but they were in and of themselves status symbols due to their expensive and exotic nature. As such, spices played a lively role in Roman society, cuisine, and economic affairs. Of the exotic eastern spices, pepper was unique in that it was a luxury spice from afar but was relatively affordable for most Romans and appears to have been dispersed throughout the Empire.

The Romans, with their great desire for pepper, went out of their way to acquire it and sent Roman merchants across the Indian ocean with large supplies of gold in order to purchase the spice in Indian ports. The Tamil poet Erulkaddur Tayan-Kannanar wrote of Roman merchants observed at the Port of Muziris: “The thriving town of Muziris where the beautiful large ships of the Yavanas bring gold… and return laden with pepper.” By the time of the Flavians, the trade between Rome and the Indian subcontinent was so fruitful and the influx of pepper so great that special warehouses were erected by Domitian for the housing of pepper. These large warehouses, called Horrea Piperataria, abutted the forum of Vespasian and the Temple of Peace in the heart of Rome. The pepper stored in the Horrea Piperataria acted as a currency rather than a condiment and was held by the state like silver and gold and other valuable assets as part of the strategic reserve. In fact, this reserve was called upon in the twilight years of the western Roman Empire, when, in 408 C.E., three thousand pounds of pepper

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76 Dalby, Siren Feast: A History of Food and Gastronomy in Greece, 137.
77 Dalby, Dangerous Tastes: The Story of Spices, 91; V Kanakasabhai, The Tamils Eighteen Hundred Years Ago (New Delhi: Asian Educational Services, 1904), 16. Yavanas is a Tamil term used to refer to Romans.
80 Miller, 83.
were used as tribute along with 5,000 pounds of gold and 30,000 pieces of silver to dissuade King Alaric of the Visigoths and his barbarian army from sacking the city of Rome.\textsuperscript{81} Although Rome eventually fell to Alaric two years later, the anecdote provides the relatively high value of pepper since it is included in the same transaction with some of the most interculturally valuable metals.\textsuperscript{82}

Alaric’s sack of Rome illuminates the other half of pepper’s uniqueness—despite the cost, it was abundant enough to be stored \textit{en masse}. Strabo highlights the magnitude of the Roman effort to acquire Indian goods by comparing the massive Roman fleet sent from Myos Hormos to the small number of ships sent to the Indian subcontinent under Ptolemaic rule. He writes, “I learned that as many as one hundred and twenty vessels were sailing from Myos Hormos to India, whereas formerly, under the Ptolemies, only a very few ventured to undertake the voyage and to carry on traffic in Indian merchandise.”\textsuperscript{83} The vessels of this merchant fleet were not only numerous but were large and incredibly durable in order to withstand the gale force winds of the monsoon. Such a fleet of vessels would have required a major endowment of capital to build and maintain and so the fleet was likely financially backed by the Roman government in part or in whole.\textsuperscript{84} The Roman merchant fleet, considering the number of vessels and necessary vessel size needed for ocean travel, would have brought a significant amount of pepper into the Roman Empire on a yearly basis.

\textsuperscript{81} Turner, 86. \\
\textsuperscript{82} Steven E. Sidebotham, \textit{Berenike and the Ancient Maritime Spice Route} (Berkeley; Los Angeles; London: University of California Press, 2011), 226. \\
\textsuperscript{84} Marijke Van Der Veen, \textit{Consumption, Trade, and Innovation: Exploring the Botanical Remains From Roman and Islamic Ports at Quseir Al-Qadim, Egypt} (Frankfurt: Africa Magna Verlag, 2011), 7.
Pepper’s value and its abundance in the Roman world mark it as unique. Pepper was prized in its foreign nature, but its mass importation caused it to be available to many Romans. Thus, of all the exotic spices from the east that made their way across Asia by land and sea to Rome, black pepper was the cheapest. Pliny the Elder writes on the expense of each type of pepper; “By pound, long pepper is bought for 15 denarii, white pepper for seven, and black pepper for four.” Around the time of Pliny’s writing, one pound of black pepper, the cheapest of the three, was equivalent in cost to 40 pounds of wheat. Comparatively, a pound of ginger was sold for six denarii and varying grades of cinnamon oil could cost anywhere from 35 to 300 denarii per pound in rough forms and between 1,000 to 1,500 denarii per pound in its purest. Thus, in terms of luxury goods, pepper, especially black pepper, was financially available to almost everyone in the Roman Empire, with the exception of the poorest. In fact, several wooden tablets found at fort Vindolanda in England just south of Hadrian’s Wall record the purchasing of pepper by common soldiers stationed at the fort. Thus, it was possible for a spice originating in the Far East to be transported from the Indian subcontinent to the very most northern extent of the Empire and still be within the price range of humble soldiers. Furthermore, an early Roman lead tablet found in Trier, Germany, mentions a supply of fresh pepper (novellum piper) in the amount of eight Roman pounds. This supply, corresponding to almost six modern imperial pounds, does not seem like a large shipment, but would be equivalent to

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85 Pliny refers to white pepper using candidum in some instances and album in others. Pliny always refers to black pepper as piper nigrum and long pepper as piper longum.


87 Turner, 73.

88 Turner, 73.

89 Turner, 57–58.

nearly one quarter of all the pepper uncovered in archaeological samples. This makes it a significant sum of pepper in light of the actual amount of physical evidence of the spice available. Furthermore, this lead label only indicates one shipment of pepper on the far-flung border of the Empire. Thus, it is highly likely that shipments of pepper, of comparable or even larger sizes, were made through the empire on a regular basis. As such, not only was pepper available to non-elites on the edges of the empire, it was available in quantity, further supporting pepper’s status as a luxury of the people. This widespread availability and exoticism make pepper a prime candidate for phytolith research because it has significant economic and cultural implications but is not so rare as to go unencountered in the archaeological record like those exotic spices only available to the richest among the Romans, like cinnamon.

2.4, Culinary Evidence for the Use of Pepper in the Roman Period

Much of Rome’s appetite for pepper stemmed from the spice’s use in cuisine. The greatest evidence for the culinary application of pepper comes from the aforementioned Roman period cookbook referred to as *Apicius*, after the famous Roman gourmet, or as *De Re Coquinaria*. The cookbook is the only one of its kind to survive antiquity and it is believed, based on the amalgamation of different styles of Latin and many idiosyncratic grammatical forms, to be a collection of several individual author’s works. Due to its collective nature, it is difficult to accurately date *Apicius*; however, it is speculated to be from the early second century, during the reign of Trajan. Pepper is called for in 349 of the 468, recipes found in *De Re Coquinaria*. This means that pepper is included in nearly 75% of the dishes assembled in the work. These

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91 Cappers, 114.
93 Dalby, *Food In the Ancient World From A to Z*, 17.
94 Turner, 70.
dishes incorporating pepper are not only numerous but varied, as the spice is featured in recipes for sauces, roasted pork and hare, vegetable purees, and even mulled wines. The large number of culinary applications of pepper and the sheer number of applications presented in *Apicius* clearly indicate that pepper was a significant contributor to Roman cuisine. Furthermore, the text does not seem as concerned with the medical properties of each spice, as there is often no mention of such properties. Thus, the use of herbs and spices used in *De Re Coquinaria* is most likely the result of a desire for flavor rather than an aid for digestion.95

In addition to pepper’s employment in the kitchens of the Roman world, the spice appeared on the tables of Roman banqueters as a condiment to be added to dishes after being served. It is theorized that, in elite contexts, this table pepper was distributed by the use of specialized vessels known in modern scholarship as *Pipertoria* (Figure 6). These *Pipertoria*, or pepper pots, were small decorative figurines designed, as there are no milling components, to hold a ground substance, speculated to be pepper. The vessel could then be used to sprinkle its contents onto food through holes shaped into the bottom of the vessel, much like the modern-day salt and pepper shaker.96 Few examples of these *Pipertoria* exist, but those that do are generally manufactured out of precious materials like silver or gold formed into a statuette depicting either people or animals. These statuettes are hollow and often feature a simple contraption which allows the vessel to be opened and closed at will.97 Scholars have long suspected that these devices were used for table distribution of pepper, but there does not appear to be any physical evidence that the containers carried pepper. As a result of this uncertainty of function, *Pipertoria* would be prime test subjects for phytolith analysis, as there is a possibility that such

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96 Van Der Veen and Morales, 62.
vessels contain trace amounts of decayed pepper or other botanical substances. Such analyses could confirm or dispute the vessel use and association with pepper. Additionally, if pepper phytoliths were found in *Piperatoria* it might be possible to identify which type of pepper was used in the elite context associated with the vessel or vessels. Such information could elucidate whether or not long pepper had associations with wealth that the less costly black pepper did not. This would support the currently disputed hypothesis that long pepper was favored in contexts where it was available and affordable.

2.5, Archaeological Evidence of Pepper

Despite the abundance of literary attestations to the Roman use of pepper, physical evidence of pepper is rare, especially in the case of long pepper which has not, thus far, been encountered in the archaeological record. This rarity is due likely to two factors. First, in domestic contexts pepper was likely only purchased in small quantities due to its cost. These small quantities were probably consumed in their entirety leading to little waste and little physical evidence of the spice’s presence. As much of the archaeological record is the result of abandonment, the presence of pepper is unlikely as it would have been too expensive to waste, as other more common botanicals such as barley, grapes, and olives are found in far greater quantity. Second, the preservation of plant materials is subject to favorable conditions. Botanicals, as biologic organisms, are vulnerable to organic decay in ordinary archaeological conditions. Plant preservation does occur under extraordinary conditions including the intense dry heat found in desert areas or waterlogged conditions present in marshlands and bogs. If these

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99 Cappers, 91, 102, 134.
conditions are not met and botanical samples are exposed to variant temperature and humidity, they will not preserve. It is under these conditions of waterlogging or desiccation that the rare specimens of pepper have been uncovered.

The earliest find of pepper associated with Roman contexts comes from the fort of Oberaden in western Germany, which was occupied by the Romans between 11 and 7 B.C.E. Eight peppercorns, thought to be a mixture of black and white pepper, were found in the cesspits on the grounds of the fortress. The presence of these peppercorns in the frontier, in conjunction with Strabo’s observations of the Roman pepper fleet at Myos Hormos, suggests that the Roman importation of black pepper from the Indian subcontinent via sea routes began shortly after the annexation of Egypt by Augustus in 30 B.C.E. Fifty-two peppercorns, likely lost while loading off from cargo ships, were found in the harbor of Straubing located on the Danube of Southern Germany. Another twelve peppercorns were found in a well in Hanau, Germany. The pericarp on nine of the twelve peppercorns recovered was intact. This could indicate that either the assemblage is a mixture of white and black pepper or that it was entirely composed of black pepper and over time the pericarps of some peppercorns rotted away to resemble white pepper. The rotting of the pericarp possibly affected samples from Oberaden as well. This is important because white and black pepper were purchased at different prices and so the presence of one over the other could be an indication of economic status. A single peppercorn was found in both Biesheim-Kunheim, France and Bath, England. All samples from Germany, Great Brittan and

100 Robinson and Rowan, 105–6.
101 Peppercorns of white or black pepper are often difficult to distinguish throughout the Roman archaeological record. Some specimens lack the wrinkled pericarp that mark a peppercorn as being black pepper; however, this does not necessarily mean the specimens are white pepper. The lack of the wrinkled flesh is possibly a result of preservation conditions and this is likely as these unwrinkled specimens are always mixed with wrinkled specimens. This mixing may also be a result different stages of ripening of the peppercorns, as not all the fruit on one spike ripen at the same time. Regardless, whether the peppercorns represent black or white pepper they are both the fruit of *Piper nigrum*, which is the only species of Indian pepper represented in the archaeological record in the form of macrobotanical remains.
France were waterlogged and represent unintentional deposits.\textsuperscript{102} Permanently waterlogged sediments prevent the diffusion of oxygen from the air into an archaeological deposit which creates an anoxic environment that preserves the lignin and cellulose of plant tissues.\textsuperscript{103} A collection of fewer than ten peppercorns were found in the Cardo V sewer of Herculaneum. The remains found in the standing water sewer were accumulated before the A.D. 79 eruption of Vesuvius. The underground sewers were protected from the heat of the eruption and were encased and preserved in the subsequent ash fall.\textsuperscript{104} Though it is found far less compared to common botanicals like olives, pepper is by far one of the most frequently occurring spices found in Roman archaeobotanical contexts in Europe.\textsuperscript{105} This makes sense since black pepper was the most affordable of the eastern imports and was likely of more interest to archaeological investigations of the last century than locally grown herbs and spices.

The highest concentration of pepper in the archaeological record originates in Egypt where a dry arid climate has led to the superb preservation of many botanicals, and economic centers of pepper trade have created large well-preserved assemblages.\textsuperscript{106} The site of Quseir al-Qadim, situated at Myos Hormos, yielded a significant number of black peppercorns originating from the northern side of the harbor, where pepper would have been transferred from ships to animal caravans headed to the Nile valley and beyond to Rome. At Quseir al-Qadim no peppercorns were strongly associated with domestic structures.\textsuperscript{107} Two desiccated peppercorns were found at

\textsuperscript{102} Cappers, 119.
\textsuperscript{103} Robinson and Rowan, 106.
\textsuperscript{104} Robinson and Rowan, 107–9.
\textsuperscript{105} Van Der Veen and Morales, 60.
\textsuperscript{106} Cappers, 2.
\textsuperscript{107} Van Der Veen and Morales, 55–59.
an Egyptian site situated 100 km northwest of Quseir al-Qadim known as Mons-Claudianus, while, one single peppercorn was found at the site of Qasr Ibrim in southern Egypt.  

The highest concentration of pepper in all of Egypt and the Roman Empire in totality occurs at the city of Berenike and its hinterland settlement of Shenshef. Berenike, which was inhabited between the first and sixth centuries A.D., served as one of the central conduits with which Rome conducted trade with the world outside its borders. Over 3,000 black peppercorns have been excavated between Berenike and Shenshef, with an overwhelming majority coming from Berenike. 1000 peppercorns were found prior to 1999 in many different Roman contexts spread throughout Berenike, mostly concentrated in warehouses, other storage facilities, and dump areas. It is unclear whether these were lost in transit through to the inter-imperial trade routes or if they were simply lost during the course of daily life.

In 1999 the most significant archaeological assemblage associated with pepper was made when a dolium containing 7.55 kg of peppercorns was uncovered in the courtyard floor of the Temple of Serapis at Berenike. The dolium, which was Indian in manufacture, appears to have been placed in the courtyard floor in the late first century B.C.E or early first century C.E. It is theorized by Cappers and Sidebotham that the deposit had some religious significance, given its location on the temple grounds and the fact that a large amount of the peppercorns found in Berenike are charred, a likely result of ritual sacrifice and not of culinary use as pepper was often ground before cooking. Cappers hypothesizes that pepper was used as an offering to the gods.

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108 Cappers, 117.  
110 Cappers, 114.  
111 Sidebotham, 225.  
112 *Dolium*, pl. *dolia*: a large earthenware vessel used for the transport of goods. For more information about pepper storage and transport vessels see note 90.  
113 Cappers, 115.  
114 Cappers, 116; Sidebotham, 226.
for safe voyages and as thanks for safe returns because of its role in the Roman-Indian spice trade, the abundance of pepper flowing through Berenike, and the risky nature of voyages on the Indian Ocean.\textsuperscript{115} At Berenike, an excavation confined to the Shrine of the Palmyrenes, a sacred area with worship to the Imperial cult and the Palmyran sun god Yarhibol, unearthed 200 charred peppercorns. The proximity of so many charred peppercorns to a holy district support the hypothesis that pepper was used as a sacrifice in Berenike. No charred peppercorns, however, appear in a shrine in the northern region of Berenike, indicating that the use of pepper in ritual is likely a practice linked to certain local cults.\textsuperscript{116}

Physical evidence of pepper in the archaeological record from Europe and Egypt indicates that pepper was present in several provinces outside of the heartland. This evidence is significant as an indicator that black pepper was not a rare good only available and used in Rome. Black pepper was, as written evidence has shown, available and affordable for soldiers stationed along the borders and for people living under Roman governance in the outer provinces. Physical evidence also supports the importation of black and possibly white pepper via sea routes on the Indian Ocean due to the amount of pepper found in maritime trading contexts, which include ports along the Red Sea and the Danube River. This evidence further shows the movement of black and possibly white pepper from the Indian subcontinent, through Egypt, and out to the far reaches of the Empire, just as literary evidence has indicated. Though it is clear from archaeological evidence that black, white, or both types of pepper were being imported into the Empire, the extent and magnitude is still unclear, as evidence from a majority of the Roman Empire is lacking. Likewise, physical evidence of pepper in domestic and culinary contexts, where pepper use is expected, is lacking. This could indicate a past tendency in archaeology to

\textsuperscript{115} Cappers, 116.
\textsuperscript{116} Sidebotham, 226–27.
ignore domestic contexts or it could indicate an absence due to difficulties in identifying ground forms of pepper because most pepper for domestic use was sold in a ground form.\textsuperscript{117} Furthermore, there is a lack of physical evidence supporting the presence of long pepper in Roman contexts. In fact, \textit{Piper longum} is the only non-liquid food product to appear in written sources that has not been identified in the archaeological record.\textsuperscript{118} This is important to note as written evidence seems to support the theory that long pepper was used alongside black and white pepper, and linguistic evidence even seems to support that long pepper was more prevalent than black or white pepper at one time. Yet physical evidence overwhelmingly supports the sole use of \textit{Piper nigrum} products. This means that either long pepper was so rare in the Roman world it has yet to be encountered in archaeological excavations, or decay has essentially erased macrobotanical remains of long pepper. The archaeological evidence of pepper is important because it is divergent from what written evidence has told us about pepper use and importation and raises questions about the availability and preferences for different types of pepper in the ancient world.

The opposition of literary evidence and physical evidence indicates one of two things. The first option is that pepper, particularly long pepper, did not play as important a role in Roman society as written evidence has led scholars to believe. This means that encounters with pepper are so rare and limited to certain geographic areas because the spice itself was hardly present in the Roman world or was only used in certain regions or by select groups of people. This seems unlikely due to the wealth of written sources which contradict this theory. The second, and more likely option, is that this discrepancy indicates either an academic or a taphonomic bias.

\textsuperscript{117} According to Pliny the Elder long pepper was adulterated with Alexandrian mustard. Such adulteration must have happened in the ground form, and so, at least some pepper intended for culinary use was sold in a ground form. (\textit{Naturalis Historia} 12.15)

\textsuperscript{118} Cappers, 116–17.
case of academic bias, physical evidence of pepper has been ignored or unanalyzed due to a focus on other research. In modern research this bias is less of an issue as a greater number of excavations undertake archaeobotanical research. A taphonomic bias, on the other hand, is harder to understand and account for. Decay may cause some forms and preparations of pepper, say ground black pepper or whole long pepper, to be essentially erased from the macrobotanical record. Phytolith analysis is the best analytical tool to be able to illuminate which factors are creating this divergence between physical and written evidence. The experimental portions of this research aim to demonstrate that phytoliths can be used to identify pepper in Roman contexts and that the adoption of phytolith analysis in classical archaeology will expand vastly our ability to study pepper as it is usable in environs which would normally prohibit the preservation of any and all forms and preparations of pepper.
Chapter 3: Laboratory Procedures and Data

Based upon literary evidence supporting the large-scale consumption of pepper in the ancient Roman world and the comparatively small physical evidence of such consumption it is hypothesized that phytolth analysis might be an effective way of studying the Roman use of pepper and reconciling the discrepancy found in these sources of data. The central goal of this thesis is to provide a proof of concept for using this new approach in Roman archaeology to supplement investigations into the prevalence and use of pepper in the Roman world. A guiding question of this goal is whether the three types of pepper commercially available in the Roman world produce distinct phytoliths of taxonomic significance. Additional considerations include what amount of phytoliths each type of pepper produces and whether this number of phytoliths is significant enough for detection in the archaeological record. This thesis also seeks to determine if taphonomic biases are responsible for the spice’s rarity in the archaeological record. Phytolith-centric methodologies and experimental archaeology were undertaken in order to approach these questions.

This chapter is divided into three sections. Each section represents one of the three procedures undertaken in order to test one of the three main questions outlined above. The first procedure, in section one, looks into the productive and morphological nature of phytoliths within the three varieties of pepper used in the Roman world: long pepper (Piper longum), white pepper (Piper nigrum), and black pepper (Piper nigrum). This first section outlines how phytoliths were extracted from modern pepper samples and the methodologies used for
identifying, classifying, and counting the morphologies of the three peppers. Section two outlines the procedure used for preparing samples in order to calculate the phytolith density in each type of pepper. The final section describes an experimental set up aimed at understanding how taphonomic processes may affect different varieties and preparations of pepper in order to explain the aforementioned discrepancy between written and physical evidence related to pepper.119

Section 1: Morphological Investigation

1.1. Introduction

To identify varieties of pepper in the archaeological record using phytoliths it is necessary to create comparative references using modern samples of pepper in order to isolate the taxonomic relations between varieties of pepper and the morphologies associated with them. This procedure starts with a regular sample of recently deceased botanical material and breaks it down using a combination of acid and incineration until solely silica and trace amounts of acid-insoluble minerals remain. In the end the phytoliths extracted from the modern botanical specimens are mounted on a slide and studied through a microscope in order to distinguish their morphological features. Because the nature of phytolith production in Piper nigrum and Piper longum has not been studied previously, this processing of comparative materials will clarify whether phytoliths are produced within the fruits of these peppers. Furthermore, morphological analysis will

119 For this study the varieties of pepper were acquired from commercial sellers. The black pepper was purchased from the Target in Central Square in Cambridge, Massachusetts. The whole black peppercorns were purchased in a 1.24-ounce container distributed by Market Pantry, a Target brand. The Environmental Archaeology Laboratory at Boston University provided the white pepper, which was collected by Kaoru Ueda in a spice market in South East Asia. 1.5 ounces of long pepper were procured in the form of whole spikes from Gryffon Ridge Spice Merchants at the Brunswick, Maine winter farmers market. These samples of long, white, and black pepper served as the sources of modern botanical material for each procedure and each trial undertaken in this project.
indicate whether these phytoliths are indicative of taxa. In other words, can samples of pepper in the archaeological record be identified solely by phytolith morphology?

1.2. Phytolith Isolation Procedure

1. Five grams of white, long, and black pepper were weighed out and were each placed in labeled 15 ml centrifuge tubes. Each tube was then filled with 2% liquinox detergent solution and was allowed to soak overnight.

2. After soaking the samples were moved to an ultrasonic bath for 15 minutes.

3. After sonication the samples were rinsed with DI water and were allowed to dry overnight in a desiccator at 30°C.

4. Once dried, the samples were removed from the desiccator. Approximately 0.1 grams of sample was portioned off into labeled ceramic crucibles, which were placed in a muffle furnace and incinerated for seven hours at 450°C.

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120 The phytolith extraction procedure is based on the standard phytolith reference collection processing procedure used by the Enviromental Archaeology Laboratory in the Department of Archaeology at Boston University. The EAL’s procedure is a combination and adaption of procedures found in Pearsal (2015) Paleoethnobotany: A Handbook of Procedures 3rd edition and Piperno (2006) Phytoliths: A Comprehensive Guide for Archaeologist and Paleoecologist and was created by the E.A.L.’s Laboratory Manager Kali Wade. The E.A.L. procedure was followed as the final slides would be entered into the lab's comparative phytolith collection.

121 In the process of sonication, ultrasound traverses a liquid and causes micro-bubbles to form and collapse causing the destruction of free-floating contaminating particles.


123 Due to time constraints and the small size of the ashing furnace, all nine samples could not be processed simultaneously. Thus, three samples were tested at a time in three runs over a period of several weeks.

124 The crucibles were covered in aluminum foil to limit phytolith contamination between the different forms of pepper. Small holes were poked into the aluminum foil to insure air circulation and complete combustion.

125 This temperature is hot enough to burn away organic materials but not hot enough to melt silica.
5. After burning the cooled ash was transferred into labeled 1.5 mL plastic conical microcentrifuge tubes which were then filled with hydrochloric acid at a normality of one in order to dissolve carbonate minerals (Figure 6).

6. The samples were centrifuged at 6000 rpm for five minutes. The supernatant was decanted using a pipette leaving a solid pellet at the bottom of the tube intact. DI water was added, and the tubes were centrifuged at 6000 rpm again for five minutes after which the DI water was decanted. Rinsing with DI water was undertaken three times for each sample. Once the washing was complete the samples were allowed to dry overnight in a desiccator at 30°C.

7. After the samples were dry, a glass pipet was used to place a dime-sized amount of Cargille Immersion Oil B on one microscope slide per sample. The samples were then added to each appropriate slide and thoroughly mixed with the immersion oil.

8. After mixing, a 25x25mm cover slip was placed on top of the oil, which was then allowed to spread evenly under the slide. Once the oil had spread to the edges of the coverslip, the edges were painted with clear nail polish to seal the slide. Once the nail polish was dry the samples were ready for microscopic analysis.

1.3. Phytolith Counting

The slides produced in the phytolith isolation procedure were analyzed using a Leica DM 750p microscope with polarized light filter and attached Leica DFC290 HD camera, on which all

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microscopic photography was taken. Alternating between a 20x objective and a 40x objective, the morphologies of 200 or more phytoliths were observed and recorded. Studies have shown that counts of 125 phytoliths are sufficient to represent all major morphologies, but that counts of over 200 are shown to increase accuracy. Alternatively, if samples were found to have an absence of phytoliths, then six or more transects of the slides were viewed at the 10x objective to verify the non-accumulation of phytoliths.

Phytolith clusters of eleven or more phytoliths were counted as one phytolith. This was done in order to negate the possibility that artificially processed phytoliths do not disperse as well as phytoliths obtained in archaeological sediments. As well the shapes of phytoliths present in large clusters cannot be as accurately determined as easily as the shapes present in individual phytoliths or small clusters of phytoliths. The phytoliths of clusters consisting of ten or fewer phytoliths were counted as individuals. In the case of black pepper, which contained a mixture of clear phytoliths and dark-stained phytoliths, characteristic morphologies were broken into light groupings and dark groupings. Phytolith morphologies of long pepper were not divided by color, but it would be prudent in future research to divide long pepper and white pepper phytoliths into comparable dark and light groupings like those of black pepper. The summary of morphologies observed in each trial and variety of pepper is summarized in Table 3.1 and Table 3.2.

---

127 Three slides of each pepper were prepared in the phytolith isolation process. Two slides of each variety of pepper were used in the counting procedure, one slide was set aside as an alternate. Originally all three slides were to be used in the morphological analysis, but this was determined to be unnecessarily repetitive.

128 Albert and Weiner, 258.

129 The estimated size of the phytolith cluster was demarcated on the counting sheet. Clusters estimated to be between 11 and 25 phytoliths were counted as small, between 25-50 were medium, between 50-100 were large. Clusters that could not be viewed in one field at 20x objective were considered extra-large.
### Table 3.1

<table>
<thead>
<tr>
<th>Morphology</th>
<th>Piper nigrum (Black)</th>
<th>Piper nigrum (White)</th>
<th>Piper longum</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Trial #1</td>
<td>Trial #2</td>
<td>Trial #1</td>
</tr>
<tr>
<td>Globular Psilate</td>
<td>14</td>
<td>13</td>
<td>0</td>
</tr>
<tr>
<td>Globular Granulate</td>
<td>0</td>
<td>11</td>
<td>0</td>
</tr>
<tr>
<td>Oblong Psilate</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Tracheid</td>
<td>10</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>Articulated Tissue(^{130})</td>
<td>9</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Oblong Cluster Small</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Oblong Cluster Medium</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Oblong Cluster Large</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Oblong Cluster XL</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Oblong Cluster Total</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Polyhedral Irregular Dark</td>
<td>70</td>
<td>112</td>
<td>0</td>
</tr>
<tr>
<td>Polyhedral Irregular Light</td>
<td>71</td>
<td>102</td>
<td>0</td>
</tr>
<tr>
<td>Polyhedral Irregular Dark Cluster Small</td>
<td>8</td>
<td>11</td>
<td>0</td>
</tr>
<tr>
<td>Polyhedral Irregular Dark Cluster Medium</td>
<td>4</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>Polyhedral Irregular Dark Cluster Large</td>
<td>3</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Polyhedral Irregular Dark Cluster XL</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Polyhedral Irregular Dark Cluster Total</td>
<td>16</td>
<td>19</td>
<td>0</td>
</tr>
<tr>
<td>Polyhedral Irregular Light Cluster Small</td>
<td>13</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>Polyhedral Irregular Light Cluster Medium</td>
<td>3</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Polyhedral Irregular Light Cluster Large</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Polyhedral Irregular Light Cluster XL</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Polyhedral Irregular Light Cluster Total</td>
<td>17</td>
<td>14</td>
<td>0</td>
</tr>
<tr>
<td>Total Number of Phytoliths Counted</td>
<td>207</td>
<td>295</td>
<td>0(^{131})</td>
</tr>
</tbody>
</table>

\(^{130}\) Most of the observed articulated tissues were composed of tracheid morphologies.

\(^{131}\) Six transects of the slide were scanned at the 10x objective with no phytoliths detected.

\(^{132}\) Eight transects of the slide were scanned at the 10x objective with no phytoliths detected.
<table>
<thead>
<tr>
<th>Table 3.2</th>
<th>Percentage of Morphology Present in Each Variety of Pepper</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><em>Piper nigrum</em> (Black)</td>
</tr>
<tr>
<td>Morphology</td>
<td>Trial #1</td>
</tr>
<tr>
<td>Globular Psilate</td>
<td>6.76%</td>
</tr>
<tr>
<td>Globular Granulate</td>
<td>0%</td>
</tr>
<tr>
<td>Oblong Psilate</td>
<td>0%</td>
</tr>
<tr>
<td>Tracheid</td>
<td>4.83%</td>
</tr>
<tr>
<td>Articulated Tissue</td>
<td>4.35%</td>
</tr>
<tr>
<td>Oblong Cluster Small</td>
<td>0%</td>
</tr>
<tr>
<td>Oblong Cluster Medium</td>
<td>0%</td>
</tr>
<tr>
<td>Oblong Cluster Large</td>
<td>0%</td>
</tr>
<tr>
<td>Oblong Cluster XL</td>
<td>0%</td>
</tr>
<tr>
<td>Oblong Cluster Total</td>
<td>0%</td>
</tr>
<tr>
<td>Polyhedral Irregulate Dark</td>
<td>33.82%</td>
</tr>
<tr>
<td>Polyhedral Irregulate Light</td>
<td>34.30%</td>
</tr>
<tr>
<td>Polyhedral Irregulate Dark Cluster Small</td>
<td>3.86%</td>
</tr>
<tr>
<td>Polyhedral Irregulate Dark Cluster Medium</td>
<td>1.93%</td>
</tr>
<tr>
<td>Polyhedral Irregulate Dark Cluster Large</td>
<td>1.45%</td>
</tr>
<tr>
<td>Polyhedral Irregulate Dark Cluster XL</td>
<td>0.48%</td>
</tr>
<tr>
<td>Polyhedral Irregulate Dark Cluster Total</td>
<td>7.73%</td>
</tr>
<tr>
<td>Polyhedral Irregulate Light Cluster Small</td>
<td>6.28%</td>
</tr>
<tr>
<td>Polyhedral Irregulate Light Cluster Medium</td>
<td>1.45%</td>
</tr>
<tr>
<td>Polyhedral Irregulate Light Cluster Large</td>
<td>0.48%</td>
</tr>
<tr>
<td>Polyhedral Irregulate Light Cluster XL</td>
<td>0%</td>
</tr>
<tr>
<td>Polyhedral Irregulate Light Cluster Total</td>
<td>8.21%</td>
</tr>
<tr>
<td>Oblong Psilate Total</td>
<td>0%</td>
</tr>
<tr>
<td>Polyhedral Irregulate Total</td>
<td>84.06%</td>
</tr>
</tbody>
</table>

* The drops in the percentage of clusters represented between trial Trial#1 and Trial#2 may be a result of analyst improvement in identifying individual phytoliths.

133 Most of the observed articulated tissues were composed of tracheid morphologies.
Section 2: Density Calculations

2.1. Introduction

A plant’s phytolith density is a calculation of the amount of phytoliths contained in a given amount of a plant or plant part. For instance, a plant form with a high rate of phytolith accumulation would, after processing to remove organic compounds and non-silica mineral, have a substantial amount of phytoliths remaining, as many grasses do.\textsuperscript{134} Non phytolith accumulating plants or plant parts, conversely, would leave behind no phytoliths, since 100\% of their mass is comprised of organic and non-silica minerals. Phytolith density can be expressed as a number of phytoliths per gram of plant material or as a percentage of the plant’s dry mass.

Originally, an adapted form of the Katz Method was attempted to determine the density of phytoliths in each variety of pepper. This method is presented in the paper “Rapid Phytolith Extraction for Analysis of Phytolith Concentrations and Assemblages During an Excavation: An Application at Tell es-Safi/Gath, Israel,” and is usually utilized in the processing of phytolith-rich sediment samples. The adaptations undertaken in the processing of the pepper samples included the addition of hydrogen peroxide to remove organics and nitric acid to remove the more insoluble minerals present in the modern botanical samples. These additional steps were suggested in the publication itself, though these were never intended to be performed on modern samples.\textsuperscript{135} This method was chosen because the suspension of phytoliths in the processing liquid disperses them evenly across the slide. Such an even distribution allows an analyst to count fewer microscope fields, which shortens the time needed to count each slide. These counts, however, remain acceptably accurate in determining the density of phytoliths with a phytolith

\textsuperscript{135} Katz et al., “Rapid Phytolith Extraction For Analysis of Phytolith Concentrations and Assemblages During an Excavation: An Application at Tell Es-Safi/Gath, Israel,” 1557–63.
count spanning only 16 fields. Unfortunately, the slides produced from this method are unstable and are rendered useless after several hours due to the crystallization of the sodium polytungstate solution used in heavy liquid flotation.\textsuperscript{136} The reaction, however, between the organic materials in the modern pepper samples and the hydrogen peroxide created gas bubbles under the coverslips of the slides; this caused the slides to leak profusely and ruined any chance at accurate counts. The reaction did not abate until the crystallization process rendered the samples useless.

Since the use of the Katz Method in determining phytolith density was unsuccessful, a more traditional Acid Insoluble Fraction Protocol was undertaken. The Acid Insoluble Fraction is the portion of a sample, whether modern or archaeological, which is resistant to dissolution due to heat or strong acids.\textsuperscript{137} It is this portion of a plant, which contains minerals of silica, including phytoliths. The procedure used was adapted from an unpublished protocol supplied by Kristen Wroth, a recent graduate at Boston University who focuses on phytolith analysis. This Rapid Acid Insoluble Fraction Protocol, like the Katz Method, was originally intended for use on sediment samples. Because of this some steps have been adapted from the original procedure to eradicate the higher amount of organic materials present.

\subsection*{2.2. Rapid Acid Insoluble Fraction Protocol}

1. Approximately 0.300g of washed white, long, and black pepper were weighed and each was placed in labeled ceramic crucible.\textsuperscript{138} The three samples were heated to 450°C for two hours in a muffle furnace.

\textsuperscript{136} Heavy liquid flotation is the process in which a dense liquid is used to separate phytoliths from other materials by nature of their different densities.
\textsuperscript{137} Albert and Weiner, 251.
\textsuperscript{138} The procedure for washing samples with liquinox is seen in steps 1-3 of the \textit{Phytolith Isolation Procedure}. 
2. After burning, the cooled ash from each sample was transferred to a 1.5 mL labeled plastic microcentrifuge tube and the weight of each sample of ash was recorded.

3. Hydrochloric acid at a normality of 3.5 was slowly added to each centrifuge tube which was then vortexed to insure proper distribution.

4. After the reaction subsided, the samples were centrifuged at 6000 rpm for five minutes until the denser materials settle to the bottom of the tubes. Using a pipet, the supernatant comprised mostly of HCl was decanted and the samples were washed using DI water. Once the washing was complete the samples were allowed to dry overnight in a desiccator at 30°C.

5. After the samples were dry a glass pipet was used to place a dime-sized amount of Cargille Immersion Oil B on one microscope slide per sample. The weights of the oiled slides were taken and the contents of each microcentrifuge tube, at this point the Acid Insoluble Fraction, were placed on the corresponding slide. The weight for each Acid Insoluble Fraction, noted by the change in weight of the slide, was taken and recorded. The samples and immersion oil were then thoroughly mixed together.

6. After mixing, a 25x25mm cover slip was placed on top of the oil, which was then allowed to spread evenly under the slide. Once the oil had spread to the edges of the coverslip, the edges were painted with clear nail polish to seal the slide. Great precaution was taken to avoid leaks as they would undermine the density counts. Once the nail polish was dry the samples were ready for microscopic analysis.

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139 The procedure for washing samples with DI water is seen in step 6 of the Phytolith Isolation Procedure.
140 Acid Insoluble fraction weights lower than 0.0001 grams were rounded up to 0.0001 grams.
7. The phytoliths of each slide were counted using a Leica DM 750p microscope at the 20x objective. The number of fields required to reach 200 phytoliths of identifiable morphology on each slide were noted, as set out in the procedure of Albert and Weiner. If no phytoliths were detected after twenty fields the slide was deemed to have zero phytoliths.

2.3. Formulas and Calculations.

To find the number of phytoliths in the A.I.F. (Sample Density):\(^{141}\)

\[
\text{(number of fields counted)} \times \left( \frac{\text{total area of cover slip}}{\text{area counted}} \right) = \text{number of phytoliths on slide}
\]

Because the entirety of the Acid Insoluble Fraction was put on the slide, the number of phytoliths per slide represents the number of phytoliths in the A.I.F., which in turn represent the total amount of phytoliths in the starting sample.

<table>
<thead>
<tr>
<th>Table 3.3</th>
<th>Piper nigrum (White)</th>
<th>Piper nigrum (Black)</th>
<th>Piper longum</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Starting Sample Weight</strong></td>
<td>0.3049g</td>
<td>0.3024g</td>
<td>0.3071g</td>
</tr>
<tr>
<td><strong>Ash Weight</strong></td>
<td>0.0033g</td>
<td>0.0113g</td>
<td>0.0179g</td>
</tr>
<tr>
<td><strong>Acid Insoluble Fraction Weight</strong></td>
<td>&gt;0.0001g</td>
<td>0.0009g</td>
<td>&gt;0.0001g</td>
</tr>
<tr>
<td><strong>Area of Microscope Field at 20x Objective</strong></td>
<td>0.7853981mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Area of Cover Slip</strong></td>
<td>600mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Number of fields Counted</strong></td>
<td>20</td>
<td>19</td>
<td>14</td>
</tr>
<tr>
<td><strong>Area of Slide Counted</strong></td>
<td>15.707962mm</td>
<td>14.9225639mm</td>
<td>10.9955734mm</td>
</tr>
<tr>
<td><strong>Number of Phytoliths Counted</strong></td>
<td>0</td>
<td>219</td>
<td>223</td>
</tr>
</tbody>
</table>

### Number of Phytoliths per Sample of Pepper (Sample Density)

<table>
<thead>
<tr>
<th>Table 3.4</th>
<th>Piper nigrum (White)</th>
<th>Piper nigrum (Black)</th>
<th>Piper longum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Starting Sample Weight</td>
<td>0.3049g</td>
<td>0.3024g</td>
<td>0.3071g</td>
</tr>
<tr>
<td>Calculated Number of Phytoliths</td>
<td>0</td>
<td>8805</td>
<td>12169</td>
</tr>
</tbody>
</table>

To find the number of phytoliths per gram of pepper (*Density Per Gram*):

1. \[
\left( \frac{\text{#phytoliths in sample}}{\text{weight of sample}} \right) \times \left( \frac{x}{\#g \text{ pepper}} \right)
\]

2. \[(x) \text{ weight of sample} = (\text{#phytoliths in sample}) \times (\#g \text{ pepper})\]

3. \[
\frac{(\text{#phytoliths in sample}) \times (\#g \text{ of pepper})}{\text{weight of sample}} = \text{phytoliths per gram pepper}
\]

### Number of Phytoliths per Gram of Pepper (Density per Gram)

<table>
<thead>
<tr>
<th>Table 3.5</th>
<th>Piper nigrum (White)</th>
<th>Piper nigrum (Black)</th>
<th>Piper longum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Phytoliths in Sample</td>
<td>0</td>
<td>8805</td>
<td>12169</td>
</tr>
<tr>
<td>Number of Phytoliths in 1g Pepper</td>
<td>0</td>
<td>29119</td>
<td>39624</td>
</tr>
</tbody>
</table>

### Section 3: Taphonomic Experiment

#### 3.1. Introduction

Because written sources emphasize an apparent abundance of pepper in the Roman world, the relatively small amount of *Piper nigrum* macrobotanical remains found throughout Europe and Egypt, and the absence of long pepper remains in the archaeological record, it is feasible that
taphonomic processes are responsible for the erasure of macroremains of *Piper longum* in the archaeological record.\textsuperscript{142} It is possible that long pepper, which is reportedly susceptible to mold and decay in moist conditions, would essentially decay to the point of nonexistence except in the most fortuitous circumstances.\textsuperscript{143} If long pepper is susceptible to total decay, phytoliths might be the only possible way to identify long pepper remains in the archaeological record, as phytoliths even in small sums of botanical material are abundant, taxonomically identifiable, and resilient to organic decay.\textsuperscript{144}

Similarly, forms of *Piper nigrum* appear to be archaeobotanically rare despite being reported as the cheapest and most common of the Indian spices. This is possibly a result of black pepper being distributed in a ground form which inhibits the creation of the traditional form of macroremains which appear in the archaeological record.\textsuperscript{145} In the case of ground *Piper nigrum* varieties, it is possible that phytoliths could be used to identify ground remains, because microscopic phytoliths are generally not weathered in significant numbers due to the mechanical force of grinding.

Due to the possible taphonomic factors surrounding both species of pepper, a special experiment was conducted with the aim of assessing the susceptibility of each type of pepper to taphonomic processes in both ground and unground forms in addition to the general morphologic study of modern botanical varieties of white, black and long pepper. In this experiment the types and varieties of pepper were sealed in terracotta pots and were left in an environment subject to frequent changes in humidity and temperature for a period of seven months.

\begin{footnotesize}
\begin{enumerate}
\item[\textsuperscript{142}] Cappers, 117.
\item[\textsuperscript{143}] Sidebotham, 225.
\item[\textsuperscript{144}] Tsartsidou, 153.
\item[\textsuperscript{145}] Livarda, 158–60.
\end{enumerate}
\end{footnotesize}
3.2. Set up of the Taphonomic Experiment

The taphonomic experiment required six nearly identical terracotta plant pots measuring approximately 6.35 cm in height by 5.08 cm in diameter and their accompanying saucers, which were approximately 5.1 cm in diameter. Terracotta pots were chosen to replicate the conditions at Berenike, where black peppercorns were found stored in a large terracotta dolium.\(^{146}\) These small flower pots were selected for this experiment because they were of a comparable material to the dolium, were cost effective, and were small enough that several could be stored in a small area for an extended period of time (Figure 13).

A Sartorius M-Prove AY412 balance scale was used to take all weight measurements and a ThermoPro TP50 digital hygrometer and thermometer was used to take temperature and humidity readings; however, after several weeks the conditions of the greenhouse where the samples were kept caused the hygrometer to malfunction, leading to a corruption of several months of temperature and humidity data.\(^{147}\)

Three of the terracotta saucers were weighed on the scale, which was then zeroed. Approximately 3 grams of whole white pepper were added to the first saucer. Equal samples of whole black and long pepper were added to the second and third saucer. The weights of the samples alone were taken and recorded. Then the total weights of each sample and paired saucer were taken and recorded. An upturned flower pot was weighed and placed on each saucer to make a closed terracotta container. Each sample was labeled and the total weight for each assemblage (sample, saucer, and flower pot) was taken. This same process was repeated using samples ground to an even consistency by hand in a course mortar and pestle.

\(^{146}\) Cappers, 114.
\(^{147}\) Due to the loss of a significant amount of data the thermometer and hydrometer were not replaced as data from the first quarter of the trial would be missing and any averages calculated using the remaining data would not accurately reflect the conditions of the greenhouse throughout the experiments run.
The six samples and terracotta “mini-dolia” were placed on a tray in a random order and left in the northwest corner of Boston University’s rooftop greenhouse.\textsuperscript{148} The samples were left in the greenhouse from 5 February 2018 until 14 September 2018, a total of 222 days. Periodically, the position of the mini-dolia was rearranged (Figure 15).\textsuperscript{149}

After the 222-day run, the experiment was disassembled. Each mini-dolium was weighed and recorded. Then the mini-dolia covers were removed and each sample and saucer were weighed. Notes about the appearance of each type and varieties were taken. Finally, the samples were removed from the saucers and placed on a tared scale. The weight of the sample was taken and recorded in Table 3.3. The amount of change from the original mass of each sample was calculated in order to determine the amount of decay.

### 3.3. Taphonomic Experiment Data

<table>
<thead>
<tr>
<th>Changes in Mass Associated with Decay in Each Variety of Pepper in Ground and Unground Forms</th>
<th>White Pepper (Piper nigrum)</th>
<th>Black Pepper (Piper nigrum)</th>
<th>Long Pepper (Piper longum)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unground</td>
<td>Ground</td>
<td>Unground</td>
<td>Ground</td>
</tr>
<tr>
<td>Initial Weight (g)</td>
<td>3.05</td>
<td>3.04</td>
<td>3.02</td>
</tr>
<tr>
<td>Final Weight (g)</td>
<td>3.48</td>
<td>3.35</td>
<td>3.45</td>
</tr>
<tr>
<td>% of Original Sample</td>
<td>114.10%</td>
<td>110.20%</td>
<td>115.56%</td>
</tr>
<tr>
<td>% change from Original Sample</td>
<td>14.10%</td>
<td>10.20%</td>
<td>15.56%</td>
</tr>
</tbody>
</table>

\textsuperscript{148} Because there is no indication in any sources that the dolia found at Berenike had any internal linings of pitch, the pepper in the taphonomic experiment was left in contact with the bare ceramic surface of the “mini-dolia.” Pitch lining may affect the quality of preservation inside of ceramic vessels and this possible effect should be considered in future experimental runs.

\textsuperscript{149} This was done in order to randomize the treatment of each sample, so no sample was, because of position, exposed to conditions less favorable to preservation.
Chapter 4: Results

The results of the morphological investigation clearly show that both *Piper nigrum* and *Piper longum* accumulate phytoliths within the structures of their fruits. White pepper was the only pepper type to lack phytoliths. This absence is likely a result of the different procedures used to process black and white pepper. Because both black and white pepper are from the *Piper nigrum* plant, and black pepper accumulates phytoliths, the unprocessed fruit of the plant must also contain phytoliths. The likely cause for the presence and absence of phytoliths in these spices is the pericarp, which is removed in white pepper processing but not in the processing of black pepper.¹⁵⁰ The lack of the pericarp in white pepper is archaeologically significant because samples of the spice have no accumulated phytoliths to deposit into the archaeological record. Thus, phytoliths cannot be used to identify white pepper in the archaeological record.

Of the two pepper varieties to display phytolith accumulation, there is some overlap in displayed morphology. Both black pepper and long pepper displayed globular morphologies with both granulate and psilate decorations and textures, though in total number these globular morphologies make up less than 10% of either form of pepper’s phytolith signature. Tracheid morphologies (Figure 18), which are common across the plant kingdom and have little taxonomic value, were present in both samples of long and black pepper.¹⁵¹ Between 4.83% and 6.78% of the morphologies identified in black pepper and between 14.56% and 19.61% of the

¹⁵⁰ Cappers, 111.
morphologies identified in long pepper were tracheid. Both black and long pepper, however, contained distinctive keystone morphologies that the other did not.

Black pepper was found to contain a majority morphology designated as the polyhedral irregular type, in order to denote its rectangular shape and jagged interlocking decorations (Figures 7, 8, and 9).

This morphology, which was divided into dark and light categories reflecting possible staining due to the drying process of black pepper, comprises between 83.73% and 84.06% of the morphologies observed in total. Phytoliths of the light polyhedral irregular type represent between 39.32% and 42.51% of the phytoliths identified while the dark polyhedral irregular type represents between 41.54% and 44.41% of the identified black pepper phytoliths. Phytolith clusters—eleven or more linked phytoliths—of the dark polyhedral irregular type composed 6.44% to 7.73% of the phytoliths identified, while 4.75% to 8.21% were light polyhedral irregular clusters. Of the phytolith morphologies present in the samples of black pepper, the majority were of the polyhedral irregular type, which was the most characteristic morphology associated with black pepper phytoliths. No similar phytoliths were observed in long pepper specimens, meaning that between the two peppers the polyhedral irregular type phytolith is taxonomically significant and can be used to differentiate black pepper from long pepper in the archaeological record. The polyhedral irregular type phytolith resembles in appearance two groups of phytoliths identified by Piperno as anticlinal epidermis phytoliths and polyhedral epidermal phytoliths. These morphologies, however, lack the serrated and dendritic appearance associated with the polyhedral irregular type phytolith. A more in-depth study of the polyhedral irregular type phytolith geared to morphometric analysis must be undertaken to better

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152 Nomenclature was based of the guidelines established by the *International Code for Phytolith Nomenclature 1.0*, where gaps in the naming conventions arose the works of D. Pearsall and D. Piperno were used.  
understand the morphologies’ relation to taxonomy and establish its similarities and variances to other morphologies present in the plant kingdom.\textsuperscript{154}

Long pepper, on the other hand, was found to contain a majority morphology which consisted of smooth torpedo-shaped phytoliths (Figure 10, 11, and 12). This morphology was named oblong psilate to reflect its long-rounded shape and lack of decoration. This morphology comprises between 62.14\% and 63.73\% of the morphologies observed in total. Individual phytoliths of this morphotype comprised between 53.43\% and 57.28\% of the phytoliths identified in the samples of long pepper while clusters of this morphology made up between 4.85\% and 10.29 \% of phytoliths identified. The oblong psilate morphotype is the most common morphology observed in the samples of long pepper and did not appear in black pepper; this morphology, however, has been observed in the species \textit{Piper flagellicuspe}, another member of the \textit{Piperaceae} family.\textsuperscript{155} The hair cell phytoliths of \textit{Piper flagellicuspe} are nearly identical to the oblong psilate phytoliths observed in \textit{Piper longum}. As \textit{Piper flagellicuspe} is a new world species of pepper, the possibility of its presence in Roman contexts is highly unlikely and so the chance of misidentification between the two species is extremely low.\textsuperscript{156}

The similarity between \textit{Piper flagellicuspe} and \textit{Piper longum} phytoliths is likely a result of similar biological morphologies. Information regarding the fruit structure of \textit{Piper flagellicuspe}, however, is unavailable since research on this specific species is relatively obscure. If this is the case, then it is possible that other members of the \textit{Piperaceae} family with similar fruit structures to \textit{Piper longum} and \textit{Piper nigrum} may also engender similar phytolith

\textsuperscript{154} Morphometric analysis refers to the detailed study of the shape and measurement of a phytolith via the use of image capturing technology. This allows for a more accurate measures and three-dimensional modeling of phytolith morphology. Morphometric analysis allows for a more accurate definition of one phytoliths morphology over another.

\textsuperscript{155} Piperno, \textit{Phytolith Analysis: An Archaeological and Geological Perspective}, 236.

\textsuperscript{156} Jaramillo and Manos, 710.
morphologies. Since no members of the Piperaceae family are indigenous to the Mediterranean basin and only Piper longum and Piper nigrum were known to be traded to the ancient Mediterranean, similar phytolith morphotypes from plants within Piperaceae are not likely to cause issues in identifying samples from Roman contexts. Since this is the case, situations where pepper is suspected of being present in a context, such as a soil sample shown to contain chemical compounds associated with pepper, phytoliths can be used to confidently identify the sample as being from the fruits of Piper longum or Piper nigrum due to the presence of oblong psilate or polyhedral irregulate type phytolith morphologies respectively.

The uniqueness of long and black pepper phytoliths compared to other members of the plant kingdom remains to be seen. Uniqueness across the globe is unnecessary for a positive identification, since only a uniqueness within the sphere of Roman context would have bearing on archaeological analyses. Phytoliths have yet to be utilized in the study of Roman food beyond this work, and a comparative collection centered on phytoliths from Roman food sources is currently unavailable and is not likely to exist in the near future. Thus, a thorough comparison of similar morphologies from species likely to be found in a Roman context is currently impossible. The remedy for this lack of comparative samples is work like this thesis, in which samples of modern botanicals, historically attested in the written sources of the ancient Mediterranean, are tested for phytolith accumulation and morphologically analyzed. Such research gives archaeobotanists a database with which to compare their archaeological samples in order to taxonomically identify phytoliths. Future phytolith research on pepper should focus on a morphometric analysis of oblong psilate and polyhedral irregulate type morphologies. This includes categorizing each shape into subgroups based on like and dislike qualities such as variations in decorations and differences in size. A morphometric investigation will create a
more refined understanding of the link between taxonomy and phytolith morphology in *Piper longum* and *Piper nigrum*.

The results of the density investigations undertaken as part of this study further demonstrate the usefulness of phytoliths in the identification of spices in the archaeological record. During the density investigations it took only 14 microscopic fields at a 20x objective to reach a count of over 200 phytoliths in the sample of long pepper. The total number of repeating and identifiable morphologies counted reached 223, which makes for an average of 15.93 phytoliths per field. Given the area of one field and the number of fields per slide, the calculated number of phytoliths on the slide is 12,169. As the number of phytoliths on the slide represents the entirety of the Acid Insoluble Fraction this number represent the calculated total number of phytoliths in the original .3071g of long pepper. Thus, there are an estimated 39,624 morphologically identifiable phytoliths per gram of long pepper. Going through the same mathematical process gives an estimated 29,119 phytoliths per gram of black pepper, and an estimated zero phytoliths per gram of white pepper. Such high numbers of phytoliths would generally only accumulate in areas where large amounts of pepper were stored and transported.

According to the outlined calculations, long pepper accumulates the greatest number of phytoliths per measure of pepper. Black pepper accumulates a significant number of phytoliths but contains approximately 36% fewer phytoliths than long pepper. Because spices are usually used in small amounts, a high degree of phytolith accumulation is an asset in regard to the study of Roman spices. A higher amount of phytolith accumulation means a better chance of phytolith detection and identification in the archaeological record as even small samples produce viable amounts of phytoliths. For instance, the smallest amount of long pepper theoretically needed to
reach a count of 200 would be approximately 5mg while about 7mg of black pepper would be needed to reach this same count.

In terms of keystone phytolith types, long pepper contains 25 oblong psilate type phytoliths per mg of sample and black pepper contains 24 polyhedral irregulate type phytoliths per mg of sample. This means that black pepper and long pepper produce about the same amount of keystone phytoliths types per mg of sample. Comparatively, the keystone globular sinuate type phytolith used to identify samples of *Alliaria petiolate* in the work of Saul et al., the only currently published report using phytoliths to identify the culinary use of spices, was found to contain 50 phytoliths per mg of sample. Thus, the two types of pepper are not high accumulators when compared to the sample of *Alliaria petiolate*. In archaeological sampling, however, Saul et al. found keystone phytoliths of *Alliaria petiolate* to number between 1 and 32 per mg of deposit with an average of 27 phytoliths per mg.\(^{157}\) Considering how few phytoliths per mg were needed to identify *Alliaria petiolate* in samples of food crust, it is likely that keystone phytoliths of long pepper and black pepper will lead to positive identifications of pepper deposited in the archaeological record, even in minuscule amounts. Furthermore, because neither type of pepper is a more prolific producer of phytoliths than the other, phytolith analysis is equally valuable for identifying long and black pepper.

The results of the taphonomic experiment indicate that different varieties and preparations of pepper decay at different rates. It was hypothesized that the mass of each pepper susceptible to decay would decrease over the run of the experiment. Susceptible forms would undergo a significant decrease while less susceptible forms would lose less mass. Unexpectedly, however, some forms of pepper increased in mass over the 222-day run of the experiment,

\(^{157}\) Saul et al., 3.
including both forms of white pepper and the unground form of black pepper. The ground white pepper increased in mass by 10.2% while the unground form increased by 14.1%. The unground form of black pepper increased in mass by 15.56%. These unexpected increases in mass may be the result of the sample’s absorption of water. Because white and black pepper undergo dehydration as part of their processing, it is possible that the samples, stored in a humid environment, underwent a degree of rehydration. Due to this, there is no quantifiable way to express the possible degree of decay in these samples. This is important because the increases in mass differs from the expected results of the taphonomic experiment and shifts the focus of the experiment from a purely numerical investigation, to a purely empirical one depended on observations made on the degradation of the samples. This unexpected result indicates that tighter controls are needed to produce more accurate results. It is advisable in future experimental endeavors that all samples undergo dehydration in a desiccator before the experimental run and after being removed from the mini-dolia in order to remove any excess weight added by water absorption.

The remaining samples, both preparations of long pepper and the ground form of black pepper, experienced decreases in overall mass. The ground black pepper showed a slight decrease in mass of a magnitude of 2.33%. The unground long pepper, the only unground form to display a loss of mass, showed a decrease of 4.61% while the ground form displayed a loss of 13.11% of its total mass, the highest decrease in mass observed during this experiment. If a decrease in total mass can be used as a quantifiable display of rotting, then samples of long pepper show more decay than any other variety of pepper. Likewise, ground preparations of pepper also experience a higher amount of decay than whole forms. This may imply that ground

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158 Theoretically over a longer period of time the samples would eventually begin to lose a substantial amount of mass as they decay; however, in the short run of this experiment some samples only decayed slightly.
forms of pepper are less likely to preserve in the archaeological record. Again, the fact that some samples decreased in mass while others increased in mass shows the taphonomic experiment needs tighter controls and a longer run time to produce the best results.

Visual inspections of the unground white pepper found very little change from the appearance of the sample prior to the experimental run. The unground sample of black pepper was completely intact but appeared a bit darker and more wrinkled than the sample did prior to the experiment. Some of the peppercorns of this sample were spotted with whiteish-green mold. The sample of unground long pepper was entirely covered in a thick fuzzy black and white mold. Of the unground samples, the long pepper had clearly decayed the most as it was infested with mold. Despite the large amount of mold growth on the sample of long pepper, it still experienced a drop-in mass. This decrease in mass may be a result of the mold consuming and converting the organic material present in the long pepper into carbon dioxide as it respires. The whole long pepper’s dissolution by the mold implies that the sample would eventually be broken down to the point that no macrobotanical remains would be left. These results are important because they support the hypothesis that long pepper is lacking from the archaeological record not because of an absence in the Roman world but rather because of taphonomic forces, which eradicate long pepper remains.

All three samples of ground pepper had some degree of mold, with white pepper having a small amount of mold and both black and long pepper having a higher degree of mold incursion. Both white and black pepper were still recognizable in their ground form with the white pepper only being slightly moldy and the black pepper about 50% moldy. The long pepper was unrecognizable and was completely covered in green and black mold. The granules composing each sample of ground pepper coagulated into one mass due to mold or moisture. The three least
moldy samples experienced a rise in mass while the three moldiest samples experienced a decrease in mass. This evidence supports the hypothesis that ground forms of pepper are more likely to decay in low-preservation environs and that ground forms of pepper are thus less likely to be encountered in the archaeological record.

The qualitative and quantitative data gleaned from the taphonomic experiment seems to indicate that long pepper is more susceptible to decay in high moister environments with fluctuating temperature and humidity. These conclusions, however, should be treated as a preliminary result because the sample size of the experiment is quite low. It is recommended that further experimentation be undertaken to fully understand the rates of decay in each type of pepper. These future experiments should feature a control, set in a climate-controlled space, and multiple samples of each variety and preparation of pepper in a humid but controlled environment. Likewise, the samples of pepper should be tested in several environments set to different levels of humidity in order to determine the best- and worst-case scenarios for preservation. These experiments should also run until all forms of pepper display a significant decrease in mass in order to determine a more accurate timeline for the decay of pepper and the deposition of phytoliths into the archaeological record. Furthermore, after the experimental run phytolith samples should be taken from each form and variety of pepper to gauge the survivability of phytoliths in samples of decayed pepper.

In total, the taphonomic experiment undertaken here demonstrates that decay affects each type and preparation of pepper differently. Decay seems to particularly strongly affect all forms of long pepper and, to a lesser degree, all forms of ground pepper. The implication of these data

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159 Though an experimental run of 222 day or even 2 years seems insignificant to ancient timescales it is important to note that botanical decay will often occur rapidly after a botanical sample is placed in an environment hostile to preservation.
archaeologically, means that peppers in those forms are likely to go undetected in the archaeological record at the macrobotanical level. This is particularly important in domestic contexts where pepper was possibly stored in a ground form.\textsuperscript{160} A total decay of ground pepper would then explain why it is so rarely found in domestic contexts and found in industrial contexts in whole forms. Likewise, the total decay of long pepper in the archaeological record indicated by the results of the experiment explain the discrepancy between abundant representation of long pepper in the written and historic record and the absence of any physical remains. Fortunately, with the results of the morphological analysis, microbotanical remains in the form of phytoliths could be used to detect and identify these uninterpreted pepper remains.

\textsuperscript{160} According to Pliny the Elder long pepper was adulterated with Alexandrian mustard. Such adulteration must have happened in the ground form, and so, at least some pepper intended for culinary was sold in a ground form. (\textit{Naturalis Historia} 12.15)
Conclusions

It is clear from these experiments that the use of phytolith analysis in the study of Roman pepper would be a benefit to the field of classical archaeology since two of the three varieties, including the most underrepresented variety, long pepper, produce distinguishable phytoliths. Additionally, this research has shown how taphonomic forces could explain the discrepancy between the few physical remains of pepper uncovered in the archaeological record and the far spread nature of the spice found in ethno-historic sources. Most importantly this research has demonstrated investigative questions relating to the Roman use of pepper that could in the near future be approached using phytolith analysis.

Understanding the nature of phytoliths in the species of *Piper longum* and *Piper nigrum* opens up a completely new methodology to the study of Roman cuisine which has the potential to answer questions we could not begin to address with the limited amount of archaeological evidence previously available. For example, culinary vessels, like cooking pots and *Piperatoria*, which do not yield much in terms of physical evidence for their bygone contents, may yet yield phytoliths like those discovered in the food crust of prehistoric cookpots investigated by Saul et al. Testing cooking pots from different periods and contexts could elucidate the use of pepper at different economic levels and throughout the Roman period. The detection and identification of different peppers in the Roman world both geographically and temporally allows us to better reconstruct the history of an essential good in one of the world’s earliest globalized economies and trans-continental trading networks. Such reconstructions may lead us to a more nuanced perception of ancient globalization and cross-cultural exchange. Furthermore, knowledge of the
importation history of pepper and a broader scale understanding of its use and consumption makes it possible to investigate questions of Roman choice, preference, and individuality. Particularly, whether long pepper was favored by those who could afford it or whether long pepper was supplanted over time by the more affordable black pepper. It would be possible to construct a timeline of pepper preference to show which type of pepper was dominant before and after the opening of the Indian Ocean trade routes during the early imperial period. As well, it would be possible to investigate the opposition of literary evidence and physical evidence to find if pepper was as widespread as literary sources would have us believe.

This research, as a proof of concept, demonstrates the high potential for phytolith analysis in the study of Roman food and particularly the study of Roman spices. Yet, first a database of appropriate species must be made available so that archaeologists working in Roman and Greek contexts can compare phytoliths from their archaeological samples to morphologies tied to identified species. Such a resource would allow scholars of the classical world to use phytoliths to understand ancient food, diet, and cuisine in ways never before explored. Phytolith analysis brings us new methods, new questions and new ways of thinking about and understanding the foods of ancient peoples. Understanding how people ate elucidates a part of identity and culture that goes widely ignored in contemporary archaeology, not for lack of want, but for a lack of viable materials to study due to decay. At its deepest level this research is aimed at understanding the flavors of Roman cuisine and through this the cultural preference of Romans for certain flavors over others and the unifying effect of these Roman tastes. In essence, this research is focused on personal choice and identity as these preferences are individual and tie into a desire for a Roman identity through a shared pallet, much like how modern French cuisine, Chinese food, or American fair, are linked to a cultural identity through flavor. In other
words, food has the power to connect individuals and communities. Phytoliths, with the proper resources, can expand our ability to study ancient food ways like never before due to their unique characteristics. In terms of the study of human and plant relations, phytolith analysis is the future of the study of the past.
Figure 1. *Piper nigrum* plant on tree support, Goa, India. Note the plants display of unripen green drupes. By J.M.Garg - Own work, CC BY 3.0, https://commons.wikimedia.org/w/index.php?curid=8356482
Figure 2. Unripened drupes of a *Piper nigrum* plant which form the spices of white pepper and black pepper. Taken in Thiruvananthapuram, Kerala, India. By K Hari Krishnan - Own work, CC BY-SA 3.0, [https://commons.wikimedia.org/w/index.php?curid=24927667](https://commons.wikimedia.org/w/index.php?curid=24927667)
**Figure 3.** Full color drawing of the *Piper longum* plant including the unripe aggregate drupelets which form the spice of long pepper. By Francisco Manuel Blanco (O.S.A.) - Flora de Filipinas [...] Gran edicion [...] [Atlas II].[1], Public Domain, [https://commons.wikimedia.org/w/index.php?curid=1274030](https://commons.wikimedia.org/w/index.php?curid=1274030)
Figure 4. Peppercorns of black pepper (left) and white pepper (right). Notice the wrinkled pericarp on the specimens of black pepper. By en:User:Bunchofgrapes - en:Image:Dried Peppercorns.jpg, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=1570672
Figure 5. Catkins of long pepper. CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=182313
Figure 6. Empress Head Pepper Pot (*piperatorium*) from the British Museum. This *piperatorium* was found as part of the Hoxne Hoard. https://commons.wikimedia.org/wiki/File:British_Museum_Hoxne_Hoard_Empress_Pepper_Pot.jpg
Figure 7. Three samples of black pepper (right) and one sample of long pepper (left) in conical microcentrifuge tubes filled with hydrochloric acid during phytolith processing. Note the darker coloration associated with the black pepper samples (97). By Evan McDuff.
Figure 8. Cluster of light polyhedral irregular phytoliths from a sample of black pepper taken at 40x objective. Note the lumpy irregular texture and interlocking serrations between phytoliths. By Evan McDuff.
Figure 9. Cluster of light polyhedral irregulate phytoliths (left) and a cluster of dark polyhedral irregulate phytoliths (right) in a sample of black pepper taken at 20x objective. By Evan McDuff.
Figure 10. Small grouping of light polyhedral irregular phytoliths taken at 40x objective. Note the dendritic, almost serrated appearance of the phytolith’s edges. By Evan McDuff.
**Figure 11.** Cluster of oblong psilate phytoliths from a sample of long pepper taken at 40x objective. By Evan McDuff.
Figure 12. Small grouping of oblong psilate phytoliths from a sample of long pepper taken at 40x objective. Note the unknown dark inclusions found at the tips of some of the oblong psilate phytoliths. By Evan McDuff.
Figure 13. Example of a single “torpedo shaped” oblong psilate phytolith with dark inclusion at its tip from a sample of long pepper taken at 40x objective. By Evan McDuff.
Figure 14. Setting up the taphonomic experiment. By Evan McDuff.
Figure 15. Samples from the taphonomic experiment prior to the experimental run. Black pepper (top), white pepper (middle), long pepper (bottom). By Evan McDuff.
Figure 16. Set up of the taphonomic experiment in the Boston University greenhouse. By Evan McDuff.
Figure 17. Samples from the taphonomic experiment. After the experimental run. Ground preparations on the left, whole preparations on the right. White pepper (bottom), black pepper (middle), long pepper (top). By Evan McDuff.
Figure 18. Cluster of tracheid phytoliths (center left) with abutting oblong psilate type phytolith (below) from a sample of long pepper taken at 40x objective. Notice the laminations in the tracheid phytoliths. Tracheid morphologies are common across the plant kingdom and have little taxonomic value. Tracheid phytoliths appear in both samples of long and black pepper. By Evan McDuff.
Appendix A: Pepper in Ancient Texts

Aelian, *Characteristics of Animals*, Book IX
Antiphanes, quoted by Athenaeus
*Apicius*
Apuleius, *Florida*
Apuleius, *Metamorphoses*
Athenaeus, *The Learned Banqueters*
Ausonius, *Epigrams on Various Matters*, XIX
Ausonius, *Technopaegnion*, IX
Celsus, *On Medicine*
Columella, *On Agriculture*, Book XII
Diodorus Siculus, *The Library of History*, Book XIX
Diphius of Siphnus, quoted by Athenaeus
Eusebius of Caesarea, *Reply to Hierocles*, 18.1
Galen, *Hygine*
Galen, *A Method of Medicine to Glaucon*
Hippocrates of Cos, *Diseases 3*
Hippocrates of Cos, *Epidemics 2*
Hippocrates of Cos, *Nature of Women*
Hippocrates of Cos, *Regimen in Acute Diseases*
*Historia Augusta* 17. *Elagabalus*, XXI
*Historia Augusta* 18. *Severus Alexander*, XXXVIII
Horace, *Epistles*, Book I
Horace, *Satires*, Book II
Jerome, *Letters*, LII, 12
Juvenal, *Satire*, 14
Macrobius, *Saturnalia*, Book VI, 26
Martial, *Epigrams*
Ovid, *Ars Amatoria*, Book II
Persius, *Satires*
Petronius, *Satyricon*
Philostratus of Athens, *The Life of Apollonius of Tyana*
Pliny the Elder, *Natural History*
Plutarch, *Moralia, Table-talk*, VII
Sextus Empiricus, *Outlines of Pyrrhonism*, Book I
Sidonius, *Poems, Panegyric of Antheminus*
Statius, *Silvae*, Book IV, 9
Strabo, *Geography*, Book XVII, 4
Theophrastus, *Enquiry into Plants*, Book IX, xx
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