CHAPTER 10

MODIFIED STARCH

Delwen Samuel

Modified starch derived from ancient remains has an unusual capacity to provide detailed insights about the processing of starchy resources, but to date this potential has only been realised in a few key cases. Modified starch is produced when the morphological or physico-chemical structure of native starch is disrupted in some way, such as during food preparation (cf. Chapters 4, 5). Since it is more susceptible to organic decay than native starch granules, ancient modified starch is only likely to be preserved in particular conditions, such as in arid or otherwise unusually protected situations.

Since processing methods affect native starch morphology in specific and predictable ways (e.g., Boxes 4.2, 4.4), these morphological changes provide a link between exploited starchy resources, artifacts and installations involved in food preparation, and the ways in which both ingredients and tools were used. As a consequence, studies of ancient modified starch can contribute to an understanding of ancient food technology and of variations in cuisine among different social groups.

Analysis of modified starch may also be relevant to ancient nutrition. As discussed in Chapter 5, processed starch may be classified according to how easily it is digested by humans (i.e., rapidly digestible, slowly digestible, or resistant). Currently, a high intake of rapidly digestible starch is considered detrimental to health (Roberts 2000). In ancient times, with less efficient processing technologies and much more active lifestyles, increasing starch digestibility may have been an advantage.

Starch food staples can be bland and their monotony may depress appetite before sufficient calories have been consumed. The taste of traditional foods may be improved by various accompaniments (Mintz 1985; Christensen 2002) or by using different methods to process the raw starch staple. Analyses of ancient modified starch could indicate how the problem of palatability was resolved in the past.

Just as evidence for native starch granules on artifacts can indicate past usages (Chapter 9), the detection and analysis of modified starch can improve our understanding of the function of food-processing equipment. The application of heat is one of the most common ways to modify starch. Fire installations such as cooking pits, hearths, and ovens may have come into contact with heated starchy material and may therefore retain traces of modified starch. The containers, tools, and installations used to make prepared starchy foodstuffs, such as pottery, troughs, and baskets, may also bear starch residues from various stages of food preparation, as depicted in the general starch pathways model in Chapter 4 (Figure 4.1).

Most research on the physical and chemical changes observed when starch is modified has been done on cereals, especially wheat and barley, but other grains such as maize, sorghum, and rice have also been studied. Far less data is available on the behaviour of starch from underground storage organs (although see review in Hoover 2001), but the general principles of starch alteration derived from cereals should apply more widely to all types of starch.

PRESERVED FORMS OF MODIFIED STARCH

The processes that make native starch more digestible for humans render modified starch highly vulnerable to the type of microbial breakdown discussed in Chapter 5. It is thus unlikely that ancient modified starch will survive if it is not protected from degradation by charring or by desiccation. It is therefore important to consider the archaeological contexts in which modified starch might be recovered.
Discrete Desiccated Macroremains
Among the most recognisable ancient starchy prepared foodstuffs are discrete desiccated macroremains. These are coherent foods that are not attached to another object. When complete or nearly whole, such as ancient bread loaves, they are quite recognisable. If fragmented, they may be recognised as food residues but a more precise identity may be unclear. They may incorporate whole or fragmented plant material such as seeds, grains, and root fragments which can help to identify the residues as processed foods. Discrete macroremains may be the intended final foodstuff, such as bread loaves found in ancient Egyptian tombs and temple foundation deposits, or they may be intermediate products of the food processing sequence, such as starch-rich, chaffy lumps produced during ancient Egyptian brewing.

Attached Desiccated Residues
Cooks and those who wash up are familiar with traces of foodstuffs that cling to the surface of utensils. For example, when discrete starch foods such as rice or potatoes are boiled, fine particulate matter including modified starch collects at the surface of the water and adheres in a ring to the inner surface of the cooking vessel. If the cooking water boils over, the particulate matter may be distributed in a thin irregular deposit over the lid and outer surface of the cooking vessel or on a supporting structure. Overcooking, especially of thick, starchy, porridge-like foods, may lead to a dense mass encrusted on the interior base of the pot. This crust can be difficult to clean off even with prolonged soaking. If the container was not cleaned or was discarded shortly after food preparation, the residues may be preserved in arid conditions. Utensils used to stir or transfer cooked starchy foods may also end up in the archaeological record with residue still adhering to them. Another source of attached desiccated residue may be sediment remaining after evaporation of a liquid in an abandoned or deliberately deposited container. Uncooked starchy mixtures can also form persistent encrustations.

Identification of attached desiccated residues may be affected by the quantity of surviving residue, its appearance (colour, texture), and also awareness by excavators that such residues may be recovered. Thick encrustations with obvious plant tissues embedded in them are the most likely to be recognised (Figure 10.1). Thin smears, such as that illustrated in Figure 10.2, are often covered in a coating of sediment and may well be overlooked, mistaken for dirt, and consequently inadvertently scrubbed off as part of routine finds processing. Some residues will only be microscopic (Box 9.5). The use of Congo Red dye may be helpful for identifying small samples of processed starch still adhering to artifacts (Lamb and Loy 2005).
Charred Residues

Another route by which modified starch can be preserved is through charring. For example, Hather (1993) has shown that native starch can survive in a chemically or microscopically recognisable form within a charred matrix. Charring occurs through exposure to heat or by direct or close contact with fire. The precise temperatures required depend on the time of exposure and the nature of the material, but in general, temperatures above about 180°C can char organic material over a period of time (Boardman and Jones 1990; Hather 1993). Although charred starchy residues may be considerably more difficult to recognise and identify than desiccated materials, they could potentially survive in a wide range of taphonomic conditions, just as charred seeds do (Pearsall 2000: 240).

Accidental severe overcooking can produce large quantities of scorched or charred material. The burnt food may remain adhered to the cooking container or may have been scraped out and then preserved as scattered discrete fragments. Charred foodstuffs can also result from intentional discard of unwanted or excess food scraps into the fire. These may have been leftovers from a meal but may have been considered unpalatable for some reason and so may not be representative of the regular diet. Catastrophic charring accidents can result in the preservation of complete foods. For example, the volcanic eruption at Pompeii preserved whole bread loaves in the baker’s precinct (Mayeske 1979).
Additional Sites of Preservation

Modified starch granules, such as those described by Babot (Box 4.4) may persist on ground stone tools. The identification of starch on this class of artifacts has concentrated on native starch (e.g., Atchison and Fullagar 1998; Pearsall et al. 2004; Piperno 1998: 1875; Piperno et al. 2000; Box 9.4) but modified granules have also been observed (Dolores Piperno personal communication, 2002).

A final suggestion for site of preserved modified starch is on heavily used porous preparation or cooking surfaces. For example, I have found a few isolated non-birefringent but iodide-staining starch granules (see Chapter 3, Box 7.2) on the clay lining of a bread-baking tannour from New Kingdom Egypt (Samuel, unpublished data). Further investigation is needed to find out whether modified starch has survived in circumstances apart from those subjected to desiccation or charring.

RETRIEVAL, INITIAL ANALYSIS, AND SAMPLING

The choice of appropriate retrieval methods for particular archaeological contexts depends on the nature of the residue. If residues have been found or are expected on potsherds or other artifacts, it is important that such objects are not washed and are handled with extra care to avoid damage to residues. When desiccated or charred discrete residues are recognised during excavation, they should be carefully placed in plastic bags labelled with their provenience. Fragmented charred starchy remains may be retrieved if water flotation has been used to recover plant remains (Pearsall 2000: 153).

Visible residues have been found in museum collections, but the quality of accompanying information is variable. For example, there are several hundred ancient Egyptian bread loaves in museum collections worldwide, but many are derived from excavations characterised by rapid clearance and very basic record-keeping. Others were purchases derived from illicit activities in the nineteenth and early twentieth centuries and have no provenience data. Such museum accessions may have been damaged by careless handling, by inappropriate packing such as with sawdust, straw, and cotton wool, and even by 'conservation' with paraffin wax and other materials.

As for any archaeological find, data that should be recorded for excavated samples include context identifier (such as unit number or lot/locus number), type of context (for example, pit, hearth, floor), and status of context (e.g., disturbed, mixed, undisturbed). Records for museum material should include the accession number and storage or display location. Specific details may be relevant to particular excavations or museum collections and liaison with other specialists may be required.

As with the case of the residues described in Chapter 9, first observations are best made with the naked eye or with the help of a hand lens. A low power stereomicroscope can be very helpful at this stage, but is not always available when working in the field or at a museum. As analysis proceeds, higher levels of magnification become desirable. Detailed description, accompanied by a sketch (scale included) should include overall appearance and shape, the texture of the residue, and any visible inclusions or surface features such as tissue shreds or seed fragments. Sometimes desiccated residues have a discernable scent, which should be recorded if detected. Surface markings can be important. For example, impressions made by the ancient baker with fingers and thumbs on some Egyptian bread crusts can be used to reconstruct how the loaves had been formed.

One or more small samples must be removed from visible residues to investigate the starch content (Box 10.1). There is a problem, however, because no matter how carefully the residue is examined and even when several samples are taken from the same accession, the material obtained may still not be entirely representative of the whole foodstuff. For example, if the original preparation was made with a range of ingredients that were not thoroughly mixed, some components of the residue may be overlooked. It is impossible to be certain whether this is likely to be the case, although it can be judged to some extent by examining the heterogeneity (colour, texture, identifiable ingredients) of the residue. A conservative approach to initial sampling is recommended, since additional samples may be required as analysis proceeds.
Samples should be treated with a view to long-term conservation and storage, just as with the original material. The sample may be altered or destroyed during analysis, but any remaining material and all accompanying data records should be conserved with care.

Sample location should be chosen carefully with the aid of a magnifying glass or low power dissecting microscope if possible. If the residue appears homogeneous, only one sample need be taken. If there are variations or inclusions in the residue, it is desirable to take extra samples of each type of texture, inclusion, or other variable if possible. Differences between each sample should be recorded.

The best place to take a sample of discrete desiccated or charred residue is from a freshly broken surface since it is less likely to be contaminated by materials such as dust unrelated to its original preparation. Sometimes large pores are present on the surfaces of larger residues, into which a dissecting needle or small scalpel blade can be inserted. In this case a sample can be scraped from the interior of the residue even if the exact location and appearance of the area cannot be recorded. This is useful, for example, when dealing with a whole, undamaged bread loaf. Detailed notes should be taken about sampling locations.

It is more difficult to avoid dust and other post-depositional contaminants when sampling thin coatings of residue on potsherds or other substrates. Prior to sampling, the residue can be dusted by gently blowing air over the surface, for example with a pipette bulb attached to a length of rubber laboratory hose. This will remove much of the loose dust and sediment that may be adhering to the residue. If the residue is not too thin, gentle scraping might be used to remove the top layer so that the freshly exposed surface can be sampled for further analytical work. In general, however, it is not always possible to sample thin coats of adhering residue without also collecting dust, sediment, and other possible contaminants.

**Sampling**

Since many have been charred, ancient desiccated starchy foodstuffs are often highly friable. Sampling starchy residues can be done with a scalpel or dissecting tool. These should be thoroughly cleaned and dried with 50 percent alcohol and disposable wipes between each sample to prevent cross-contamination. Samples may come away in one piece, but often they crumble. If a whole sample fragment can be obtained, it can be placed directly into a storage container. If the residue is friable and comes away as small crumbs and dust, this material can be saved for possible future analysis of starch or other constituents of interest. A fresh paper funnel should be used for each accession to prevent cross-contamination of samples. Plastic weigh boats, glass Petri dishes, and similar containers are not appropriate for catching residue crumbs, because they easily build up static and a considerable amount of residue may adhere to their surfaces. I have never observed contamination by paper fibres.

In general, the sample size should be kept to the minimum necessary to obtain useful information while leaving enough to repeat procedures. Depending on the size and density of the original ancient residue, a sample quantity of between 50 to 150 mg should be adequate. Weigh all the samples. Having done this, estimation can be made of appropriate subsample quantities for subsequent analyses.

The most convenient way to store small samples is in clear gelatin capsules. These are best stored in small glass vials with plastic push tops or some other type of container that can be stored upright in racks made from expanded polystyrene or wood, for example. Essential provenience information on a paper label inside the vial as well as written on the glass vial itself should accompany the gelatin capsule.
HIGH POWER LIGHT MICROSCOPY

Two methods using high power light microscopy can be applied to desiccated remains: free suspensions (Box 10.2) and thin sections (Box 10.3). Since each yields different data about modified starch and poses particular problems, ideally both techniques would be applied to each sample.

Identifying modified starch is less straightforward than for native granules because starch morphology changes when it is processed. The properties of birefringence and the polarisation cross may be partially or completely absent. Starch granules may be considerably altered in shape or completely dispersed. Identification of modified starch may only be possible by staining with iodine-potassium-iodide (Box 7.2). Free suspensions are the easiest way to apply staining (see Box 10.2). This technique also allows detection of starch-derived soluble dextrins (cf. Table 7.2).

The drawbacks of free suspensions are that the arrangement of the modified starch within the residue structure is lost and the arrangement of the suspension on the slide cannot be controlled. The preparation of thin sections may be preferred.

Box 10.2. Preparing Free Suspensions Of Desiccated Residues

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Free suspensions are destructive of samples so comprehensive record keeping, including photography of the slide preparations, is essential.

Method

1. Rigorously clean and air-dry all equipment between each sample to prevent contamination. Use new slides and coverslips for each sample and clean them thoroughly before use with 50 percent alcohol and disposable wipes.
2. Select a representative subsample of material using a low power light microscope. If the sample is heterogeneous, take separate subsamples of each type of material. The ideal quantity for each slide is approximately 2 to 5 mg. The minimum amount of sample is about 1 mg. Although a smaller sample can be used, it is difficult to manipulate and can be easily lost from the mount.
3. Place the subsample on a cleaned glass slide. Carefully and thoroughly crush the ancient material with a cleaned small metal spatula. Scrape the powder into the centre of the slide.
4. Add one drop of distilled water to the crushed powder with a Pasteur pipette.
5. Carefully cover the water suspension with a cleaned glass coverslip.
6. Examine each slide with direct transmitted light. Magnifications of between x200 and x400 are usually appropriate. Starch granules will be easily visible if present. Other constituents such as fragments of plant tissue and phytoliths may also be present.
7. Observe using polarizing transmitted light to locate birefringent and partially birefringent starch granules. Modified starch granules may look morphologically indistinguishable from native starch granules but may have partially or completely lost their birefringence. It is therefore useful to photograph the same granules with direct light and again with polarizing transmitted light.
8. Add a drop or two of iodine-potassium-iodide (IKI). Use protocol described in Box 7.2. Record the stained mount with photomicrography fairly promptly. Modified starch, particularly well-gelatinised and pasted starch, may be permanently affected by this procedure and will not retain valid information about its structure for long after the IKI is added.
Although various embedding media are available for thin sections destined for light microscopy, one of the most flexible is London Resin White (L.R. White, http://www.emsdiasum.com/microscopy/technical/datasheet/14380lm.aspx) available from Electron Microscopy Services (EMS, http://www.emsdiasum.com/microscopy/default.aspx). L.R. White allows very thin (10 microns and less) sections to be made, which can be observed with light microscopy and with electron microscopy if required. Sectioning starch granules can be challenging (although ancient granules are not as difficult as modern granules), but this resin holds the granules well. This box provides a general outline of the procedure, together with comments that apply specifically to ancient residues. For further details and practical assistance, it is advisable to seek help from an experienced microscopist.

Sampling
About 20 to 50 milligrams of each sample are needed for embedding. It is a good idea to fix and embed two or three fragments from each residue sample.

General Method

Day One: Embedding in Agar and Fixation
Because ancient samples are often highly friable and the biomolecular structure often highly soluble, an agar-embedding step prior to the normal fixation and resin-embedding procedure is advisable. Experimentation with the most suitable method for specific ancient samples might be necessary. One procedure is suggested.

- Prepare 2 percent agar solution. Heat to melting point as necessary.
- Cool agar to about 50° C.
- Place items to be embedded on clean glass slide.

- Carefully place a drop of agar over each item.
- Immediately place in fixation solution. Do not allow agar to soak into items.

Choose an appropriate fixation medium (refer to EMS data sheet). During fixation, modern samples are often placed on a rotator or given similar gentle agitation, but this is not ideal for fragile material. If constant mechanical agitation is not used, gentle agitation by hand from time to time may be helpful.

Day Two: Dehydration
A graded ethanol series is recommended for L.R. White. Acetone must be rigorously excluded.

Day Three: Resin Embedding
Embed samples with resin according to method used.

Sectioning and Staining
When the acrylic resin has hardened sufficiently, the specimens are best sectioned with a glass knife. The appropriate thickness of the thin sections may vary according to the sample but 4 to 10 microns are probably best. Overly thin sections will not take up stain as well as modern material. The sections can be floated onto a distilled water drop on untreated, thoroughly cleaned glass slides and dried on a hot plate. The starch will not be affected by the heat because it is fixed within the acrylic resin. It is important to dry the sections quickly so that they adhere evenly, without wrinkles. When dry, the sections will continue to adhere to the slides even when liquid stain is applied. Wherever possible, use serial sections to allow comparison of structures within the food matrix.
because this technique shows the forms of nondispersed modified starch and allows detection of dispersed starch, while preserving the arrangement of the modified starch within the residue matrix. The relationship of starch to other components can provide valuable information about the original processing methods of the starchy ingredients. Unlike free suspensions, thin sections can be stored indefinitely after preparation. Both free suspensions and thin sections allow the detection of nonstarch microcomponents in the ancient residues, such as shreds of plant vascular tissue or seed and fruit pericarp fragments.

The disadvantages of thin-sectioning ancient residues over free suspensions are that it is more time consuming, demands much more skill, and requires specialised equipment. Collaboration with an experienced microscopist is therefore beneficial. Unlike the preparation of modern material described by Field (Box 6.6), thin sections of ancient residue require more precise preparation due to the small volume of material and the need to stabilise highly friable samples. To target structural relationships, ancient residues must be sectioned more thinly than modern reference material. Even modern native starch granules may lose their birefringence when sliced so thinly. The technique is destructive, but, like free suspensions, only tiny quantities are required. Among the repertoire of analytical methods, this method is probably best left until last.

Charred starchy residues require special treatment for high power light microscopy work. The black, opaque structure of the charred material means that, unlike desiccated material, starch cannot be observed directly. The charred sample must first be disaggregated and any surviving starch isolated. During the starch isolation procedure, any dispersed and soluble starch within the charred residue will be lost, but a proportion of native or slightly distorted granules may be recovered. Box 10.4 outlines a suggested preparation technique.

**SCANNING ELECTRON MICROSCOPY**

The scanning electron microscope has been usefully applied to the analysis of charred residues (Hather 1993; Paz 2001; Willcox 2001), but is most informative for desiccated residues (Samuel 1996a, 2000). For ancient starch analysis, magnification up to 2,000 times is generally sufficient. The intensity of the electron beam at high magnifications may destroy the starch, depending on the machine and settings used. Techniques to prepare modern organic material for scanning electron microscopy are often lengthy, but because they are already desiccated, ancient remains need no special preparation. Box 10.5 presents a suggested procedure for preparing visible residues for the SEM.

**CASE STUDIES**

Arid areas are most likely to provide evidence for ancient modified starch, although few studies have been made to date. Two case studies focused on ancient Egyptian bread and beer have demonstrated the potential of this approach. Bread and beer were the key staple foods of ancient Egyptian society.
throughout all periods. The ancient recipes for both have usually been assumed to be straightforward and uncomplicated. In contrast, an analysis of modified starch has shown that these technologies were considerably more complex than previously thought (Samuel 1996a, 1996b, 2000).

**Bread**

The ancient Egyptians distinguished many different types of breads and cakes. Over 40 types have been recorded (Gardiner 1947: 1196), although there is no documentary evidence describing their various attributes. Most scholarly accounts of ancient Egyptian baking describe how coarse flour was pounded or ground and then formed into dough and baked. While some attempts have been made to document bread types using artistic representations, these typologies rely entirely on form and decoration, with no information about possible variations in ingredients or preparation methods (Währen 1961). A notable study of an actual ancient bread loaf was made by Borchardt (1932).

Microscopic analysis of over 35 different loaves now in museum collections throughout the world has established that there were several ways in which ancient Egyptians made bread. In addition to the identification of previously unattested occasional ingredients, e.g., coriander, dates, and figs (Samuel 1994: 191), patterns of starch modification show there were variations in grain preparation. The simplest procedure was to mill grain either coarsely or finely and to form the flour into dough for baking. The presence of pitted and channeled starch granules in several loaves has shown that the ancient Egyptians sometimes made bread from sprouted grain (malt) (Plate 60). The enzymatic breakdown of the starch may have rendered it more digestible. Malted grain would have imparted a sweet flavour to the bread.

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**Box 10.4. Preparation Of Charred Material For High Power Microscopy**

*Linda Scott Cummings*

Dissolve the charred material in a fume hood with a Schulze solution of concentrated nitric acid and potassium chlorate. Despite this harsh acid treatment, some starch does survive. To make a Schulze solution, add a small quantity, approximately 7 or 8 ml, of potassium chlorate powder catalyst to about 50 ml of concentrated nitric acid and stir to dissolve the powder. Crush some of the charred sample and place it in a centrifuge tube and then add a small quantity of Schulze solution. Place the centrifuge tube in a container of hot sand to accelerate the oxidation reaction. If the sample is particularly stubborn, add hydrogen peroxide (30 percent) *one drop at a time*. Add one drop, mix, observe the reaction. Add another drop *only* if the reaction is very slight or when the reaction ceases. If numerous bubbles are formed, this is enough catalyst to continue the reaction. Adding hydrogen peroxide can cause a very violent reaction, so this step must be performed under a fume hood and the chemical must be added very slowly. This should dissolve the charred material, freeing any starches. When the reaction is finished and most or all of the charred material is dissolved, add distilled water and centrifuge. Remove the supernatant and rinse again with distilled water. Very little sample may remain in the bottom of the centrifuge tube, so use a conical tube that allows concentration of the remains. Rinse the sample until it is neutral (generally 4 or 5 complete rinses). If, after the first rinse, you observe a lot of charcoal remaining in the sample, repeat the above steps to treat with Shultzze solution. After rinsing until neutral, take an aliquot of the remaining suspension in the tube, place on a microscope slide, and examine with high power transmitted and polarising light microscopy.
The presence of large fragments of grain in ancient Egyptian bread has led some scholars to believe that milling was crude, implying a finer grade of flour was not possible using the available grinding technology. Microscopy of these large grain fragments shows they are mostly composed of well-gelatinised starch. This evidence indicates that ancient Egyptians deliberately added damp boiled grain to their dough prior to baking, because starch in raw, coarsely broken grain would hardly

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**Box 10.5. Preparing Samples For The Scanning Electron Microscope**

*Delwen Samuel*

The material to be examined by SEM should be scrutinised with a low power light microscope and a subsample selected on the basis of representative colour, texture, and inclusions. Only one representative fragment need be selected for an apparently homogeneous sample, but heterogeneous residues should be subsampled for a fragment of each type of material observed, unusual inclusions, or other variations.

Once the subsample is selected, mount it on an SEM stub with precut double-sided sticky tape or discs. Double-sided carbon discs are not recommended because they are insufficiently adhesive for bumpy samples. Then gently dust the surface of each fragment by blowing air over the sample to remove dust or loose particles which might cause a build-up of electron charge or which might obscure the real surface of interest. Attaching a pipette bulb to one end of a length of rubber laboratory sink hose and a plastic pipette tip to the other end can make a suitable duster. The pipette tip can be directed with precision and the bulb gently squeezed to blow air over the mounted specimens. (A computer keyboard compressed air canister is *not* recommended!)

When the specimens are mounted, draw a sketch of the stub, take a photomicrograph (optional), and make brief notes about the structure and appearance of each fragment and why it was selected for examination. These measures will help in later interpretations of the sample such as determining the location of the SEM images.

Apply a dab of silver dag paint so that it firmly links the side of each fragment to the surface of the tape. (This paint is toxic so avoid breathing the fumes and skin contact.) This procedure prevents charge build-up, a common problem with highly friable and discontinuous ancient starchy residues. Great care must be taken at this stage because the silver dag can easily be drawn into the highly desiccated specimen by capillary action, thus ruining its surface features. The best method is to trim the end of a wooden toothpick at an angle, put a thick dab of silver dag paint at the trimmed end, and cautiously push the silver dag over the tape towards the specimen. Only a tiny amount need touch the ancient material, but it must make contact. Dry the stubs in a 30°C drying oven for at least 3 hours to drive off the solvent, or leave to air-dry overnight. Sputter-coat the stubs to a depth of about 250 to 300 nm. They are now ready for scanning.

The complexity of the structure of ancient starchy residues often means each specimen needs very thorough examination and many records should be made of the surface features observed. Current technology favours digital image capture. It is important to bear in mind that the technology of digital image retrieval and reproduction may change in the future. The micrographs are the raw data of SEM. Since these are unique and unrepeatable, the digital data therefore needs to be conserved and kept accessible.
gelatinise within the matrix of the baking bread. The boiled grain could not have been dried before mixing into the dough either, because this would have produced gritty cooked grain fragments scattered through the bread. We can therefore conclude that the boiled coarse grain fragments were intentional and would probably have imparted a nutty flavour and a pleasant chewy texture to the loaves. These would have made a welcome addition to the ancient Egyptian baking repertoire.

Other variations in preparation and baking techniques undoubtedly developed over time. With a greater sample size of ancient Egyptian loaves, we could discern the most common methods of grain preparation, determine whether different groups in society had certain preparation methods, and monitor how bread making evolved.

**Brewing**

For many years brewing was considered by Egyptologists to have been a relatively simple process, closely resembling modern traditional Coptic and Nubian beer making (e.g., Morcos et al. 1973: 1170). This method involves heavily yeasted dough that is lightly baked into beer loaves, crumbled into a sieve, and rinsed through with water. The yeast from the lightly baked bread then ferments in the starchy suspension, producing beer. Dates are often thought to have been an essential ingredient of the ancient recipe, adding sugar necessary for the fermentation process. Analysis of modified starch granules recovered from the beer residues, however, does not bear out this interpretation.

A number of thin starchy residues have been found adhering to shallow ceramic drinking bowls (Figure 10.2). These residues contain fine shreds of chaff, showing they were derived from cereals. Other, more chaffy samples have been isolated from jars or retrieved as isolated finds (Figure 10.1). The main component of all these residues is heavily modified starch. Yeast cells have also been detected, some of which were actively growing just prior to being dried out. The pattern of starch modification from all types of cereal-derived residues included native starch, gelatinised and pasted starch, and pitted granules indicative of enzyme attack. Together, this evidence indicates that ancient Egyptian brewing involved a two-part process (Figure 10.3; Samuel 2000). First, cereal grain was divided into two batches. One batch may have been sprouted (malted) and once crushed, was very well cooked in plenty of water, perhaps to the consistency of porridge. This process gelatinised the starch. The other batch was sprouted to produce malt and then crushed and mixed with water, but was not exposed to heat. The sprouting process produced enzymes that attacked the starch granules, causing pits and channels (Plate 60). The two batches were then mixed together to create a warm, opaque liquid. Within the mixture, the unheated malted component provided enzymes that attacked the gelatinised starch from the cooked portion. This process yielded the sugars required for yeast (and possibly lactic acid bacteria) fermentation.

The ancient Egyptians may not have understood the complex biochemical processes which took place during beer making, but they would have had an excellent empirical knowledge of how to manipulate different conditions, such as time, quantities of ingredients, and degree of heating to achieve consistent and desirable results. The ancient Egyptian process is very similar to that used for a number of modern traditional sub-Saharan African beers, the most sophisticated of which is probably Sudanese *merissa*.

Far from the coarse, rather crude foods often described, the cereal staples of ancient Egyptian diet were clearly sophisticated. These results fit much better with our understanding of other aspects of this culture and they provide new data relevant to ancient economy and social interactions. For example, the use of grain sprouting for malt production as a key cereal processing technique demonstrates considerable time and resources must have been devoted to this task. (Dirar 1993: 840)
FUTURE RESEARCH

A high priority for ancient modified starch research is the location and identification of additional data. Ancient grain cooking and malting has been identified through starch analysis by Juan-Tresserras (1998) from Bronze and Iron Age sites on the Iberian Peninsula, and other modified starches have been recovered from Egyptian food remains and papyri, from the unique find of the Austrian iceman Ötzi (Box 9.1), and from Lapita pottery in the Pacific region (Crowther 2005; Horrocks and Bedford 2005). However, there are a number of places throughout the world where modified starch can be expected to survive in reasonable quantities. These include all areas where organic material might have been rapidly desiccated and protected from decay, and where foodstuffs were provided with burials.

Although charred remains are far more widespread than desiccated material, the problems of extracting, identifying, and interpreting modified starch from them are greater. More extensive analysis may show that native and near-native starch is most commonly preserved in charred material. Despite these limitations, charred residues are likely to contain valuable records of starch exploitation, especially for those taxa that do not survive well in the archaeological record.

The primary aim of much ancient human starch exploitation was the production of modified starch (cf. Chapter 4), but ironically modified starch will always remain rare in the archaeological record. With knowledge of the conditions required for its persistence over time, it should be possible for archaeologists to target specific circumstances where it may be found. Once located, modified starch can provide unique insights into ancient life.