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Changes in wheat starch grains using different cooking methods: Insights into ancient food processing techniques

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We investigate the morphological changes in starch grains from wheat (*Triticum aestivum*) using different cooking methods (boiling, steaming, frying, and baking). We compare the cooked starch grains with starch grains from ancient wheat flour cakes (Astana Cemetery, Turpan Basin, Xinjiang, China) to determine the cooking techniques used by people in Xinjiang 1200 years ago. Heat and water content affect starch grains when different cooking methods are used. Boiling and steaming results in the collapse of wheat starch grains accompanied by extreme swelling, curved granules, pasting, almost full gelatinization, a distinct extinction cross and vague granule outlines. Frying and baking cause less swelling, fewer curved granules, less pasting and only partial gelatinization of wheat starch grains, but the extinction lines are still distinct and the outlines of granules relatively clear. The pale brown substances on the starch grains make starch from baked-wheat products distinct from those cooked using other methods.

cooking experiments, food processing, starch grains analysis, Triticum aestivum

Cereals have been used by humans for more than 10000 years [1,2]. With the development of agriculture, cereals have been made into different kinds of food using various tools and methods: the use of stone tools, pottery and metal tableware; and the processes of grinding and cook-over a fire. Through using these methods, humans have acquired sufficient nutrition to maintain health and to reproduce [3,4]. Because food processing has played an important part in human evolution, the study of ancient food preparation helps us to understand and reconstruct ancient ways of life [5].

Fire revolutionized the human diet. Through using fire, different cooking methods, including steaming, boiling, baking and frying, were developed to produce food with various tastes and nutritional values. Certainly, with different regional environments and cultural backgrounds, people living in different places and at different times had varying traditional diets. The remains of processed cereal food have been uncovered from archaeological sites. Owing to some fairly well-preserved food products, the raw materials and cooking processes for staple foods have been studied through observing the morphological features of starch grains. Wollstonecroft et al. [6] observed the processing of plant foods in the Near Eastern Epipalaeolithic and proved that pulverizing and heating had been implemented to transform Bolboschoenus maritimus into edible food. Detailed work was also done by Samuel to investigate ancient Egyptian cereal food processing, including baking and brewing methods, using correlative microscopy on the remains of bread loaves and beer [7]. Similar work was done by Gong et al. [8] who studied ancient noodles and cakes from a 2300-year-old Subeixi site in western China to understand ancient food preparation technologies through cooking experiments. These studies on visible food residues from archaeological sites have provided important information concerning ingredients of food remains and ancient food preparation techniques.

In China, solid foods including pastries, cakes and noodles have been frequently recorded from early times. However, because of poor preservation conditions such as the acidic soil in the South, cereal food remains are rarely encountered in archaeological excavations. Fortunately, the Turpan Basin of Xinjiang in China has such a dry cli-

Citation: Dai J, Yang Y M, Wang B, et al. Changes in wheat starch grains using different cooking methods: Insights into ancient food processing techniques. Chin Sci Bull, 2013, 58(Suppl.I): 82–89, doi: 10.1360/tb-2013-suppl003 mate that many man-made products, plants and food remains, buried in the desert have been well preserved without decaying. Cakes of different shapes were excavated in the Askchar Cemetery of Hami District, dating from 3000 aBP [9]. Ancient cakes of different sizes and resembling modern "Naan" were found in the 1800-yearold Sampula Cemeteries [10]. Noodles and cakes, unearthed in the Subeixi Site (cal. 500-300 BC) of Turpan District, were investigated using starch grain analysis and cooking experiments, and found to have been baked [8]. These archaeological materials help us to better study the diet tradition and cooking culture in ancient Western China. However, there is little previous work to help explain the diet tradition of Xinjiang in the times after the opening of the Silk Road which would reveal more information about cultural communications between East and West.

Besides research on archaeological remains, experiments on modern samples of cereal food have also been carried out to study starch changes during processing. Food scientists have shown that different cooking methods affect starch grains in the shape, size and other features change under transmitted and polarized light. Some scholars have shown that starch grains will swell and gelatinize with increasing temperature and time when cooking in liquid, sometimes in association with changes of the extinction cross visible under polarized light [11-13]. Furthermore, different water contents including limited/unlimited water systems, temperature and other processing conditions lead to various morphological changes in starch granules [14]. For wheat, one of the most important cereals, the morphology of starch grains changes during different cooking methods. For example, starch grains from wheat products, cooked in boiling water, will swell, gelatinize and gradually lose the extinction cross when boiled for a long time. In contrast, starch grains from dried wheat products, cooked without water, do not swell but smaller grains attach to larger ones [14,15]. When baking wheat products, starch will gelatinize and form a continuous starch network. Amylose and amylopectin (starch polymers) separate, with amylose accumulating in some sections of the starch granule [16]. However, the results of these studies on changes in the starch from wheat grain during various cooking methods have

not been applied to archaeological food remains. In this present study we perform a series of experiments on modern wheat products to observe how various cooking techniques, such as boiling, baking, steaming and frying, affect starch grains. We also study ancient cakes, uncovered from the 1200-year-old Astana Cemetery in Xinjiang, China, to reveal how these solid foods were prepared by ancient indigenous people in Turpan.

1 Background

The Turpan Basin located in the northwest of China is an important cultural communication center between East and Central Asia. This region was occupied by the Gushi people before the kingdom was defeated by the Western Han Dynasty (202 BC-AD 9). After the domination by the Han Dynasty, people from different area, including the local ethnic minority and Han immigrants, lived together to develop and protect this area. From the middle of the 5th century to the middle of the 7th century, the Gaochang Kingdom was the political power until it was conquered by the Tang Dynasty (AD 618-907) in AD 640 [17]. The Astana Cemetery is a public graveyard of the ancient Gaochang people, with an area of 10 km² located in front of the Flaming Mountains (Huoyan Shan) of the Turpan District in the Xinjiang Uygur Autonomous Region. Between 1959 and 1975, more than 500 tombs were excavated, dating from the 3rd to the 9th century [17,18]. Owing to the extremely dry climate, funeral objects including textiles, ceramics and ancient documents were preserved without deterioration. Some cereals were packaged carefully or stored in earth pots and buried in the tombs for further use by the deceased, while some were filled with objects used daily, e.g. stalks of Triticum aestivum were used for filling pillows. Cakes of different shapes were excavated in Tomb 64TAM37. The cereals Seteria italica, T. aestivum, and Hordeum vulgare var. coeleste were found buried in the tombs [19].

2 Materials and methods

Three cakes, well preserved in shape and discovered in Tomb 64TAM37 (from AD 768), were used in the study (Figure 1, Table 1). A previous study on starch grains



Figure 1 Ancient cakes from the Astana Cemetery. Numbered as Cakes A to C. Scale bar = 2.5 cm.

Material	Sample no.	Description					
Cake A	64TAM37: 10	Original shape round with thick edges; thin in the middle; 4.5 cm in length; edge 1.8 cm thick and middle 1.2 cm thick; brown in color but with a lighter edge color					
Cake B	64TAM37: 7	Original shape square, side view showing layers; 3.1 cm in length; 2.4 cm thick; brown in color					
Cake C	64TAM37: 9	Original shape round, with thick edges; thin in the middle; 5.3 cm in length; edge 1.9 cm thick and middle 1.4 cm thick; brown in color but with a lighter edge color					

 Table 1
 Information about ancient cakes from Tomb 64TAM37

from cakes and epidermal cells of bran indicated that these cakes were made from the flour of *Triticum aestivum* [19]. Starch grains from the cakes were scraped from the interior of the cakes which were less affected by taphonomic factors.

To observe the changes in starch grains during cooking and to compare them with starch grains from ancient cakes, suitable cooking methods for the experiments were chosen. As a ceramic steamer "Zeng" and a water heating pot "Fu" dating from the Northern Dynasty (AD 386-581) were excavated in Turpan [20] and cakes were baked 2300 years ago in Turpan [8], four possible methodsboiling, steaming, baking and frying were used. Modern wheat flour was used as a reference to examine changes in starch grains during cooking: (1) The dough (flour mixed with water) was made into noodles and cooked in boiling water (98-99°C) for 5 min so that the noodles could cook thoroughly; (2) The dough was shaped into 8-cm thick buns and steamed in a steamer (temperature 100.5°C) for 30 min; (3) The dough was made into 1.5-cm diameter finger-shaped sticks and fried in hot oil (155°C) for 3 min; (4) Finally, to reproduce the traditional baking method, an iron stove was chosen for baking, instead of a modern electrical one, as ancient Turpan people probably baked food in an oven-like hearth [8]. The dough was made into 2-cm thick block-shaped cakes, while the stove was pre-heated. The cakes were then placed on an iron pan (surface temperature 220°C) and baked in the stove for 10 min to guarantee that they were baked thoroughly.

The six types of wheat products (flour, dough, noodles, steamed buns, fried food and baked cakes) were stored at

 Table 2
 Size of starch grains in modern and archaeological samples

room temperature for one day for observation. A small piece of sample material from each was put into a 50-mL tube with 7.5 mL deionized water and left for several hours. After shaking in an oscillator to disperse the solid sample, a drop was pipetted onto a microscope slide and a cover slip applied, fixed with 50:50 glycerin/water solution and the edges sealed with Canada balsam. Slides were then scanned in both transmitted light and polarized light at a magnification of \times 500 to identify and photograph the starch grains. Starch grains swell to varying degrees according to different heating temperatures and times [12,13]. Therefore, the length and width of 100 granules from each sample were measured to observe the degree of swelling.

3 Results

The terminology for the morphological description of starch grains was based on the International Code for Starch Nomenclature (ICSN) 2011. There were two types of starch grain in the wheat flour: one 15–37 μ m in length, 7–32 μ m in width (Table 2) and the other 1–2 μ m in diameter of oval shape. Smaller grains were spherical or with one facet, while larger ones were almost circular in the plane view and lenticular from the side view. Although lamellae were not completely obvious, one or two rings could be seen near the center of the grain. Larger grains had a rough surface, a distinct extinction cross and saddle extinction arms. Both the larger and smaller grains showed an extinction cross under polarized light. The cross is radially symmetrical with thick, straight and distinct cross lines (Figure 2A). Since smaller crosses are

	Samples	Mean length (µm)	Range of length (µm)	Mean width (µm)	Range of width (µm)	Count number
	Flour	24.30±4.49	15.34-37.06	19.49±4.74	7.29-32.43	100
	Dough	23.45±4.18	15.21-34.96	19.38±4.83	9.24-30.05	100
Modern	Boiling	39.06±9.00	22.67-66.98	31.26±8.88	14.25-59.31	100
samples	Baking	27.94±8.63	18.21-42.84	20.61±5.75	10.09-43.34	100
	Steaming	39.72±6.82	27.09-53.39	25.92±6.12	10.99-40.27	100
	Frying	30.22±7.82	12.68-55.54	23.09±6.54	10.71-41.37	100
	Cake A	27.07±5.87	15.88-43.50	19.70±5.34	9.61-33.61	100
Ancient cakes	Cake B	27.47±4.17	17.37-41.98	23.23±5.44	11.42-38.14	100
	Cake C	29.16±3.46	19.30-35.81	21.49±5.10	12.62-35.14	100



Figure 2 Starch grains from modern common wheat products. The upper row of photographs shows starch grains under transmitted light, while the lower row shows the same grains under polarized light. A, Starch grains from flour; B, starch grains from dough; C, starch grains after boiling; D, starch grains after steaming; E, starch grains after frying; F, starch grains after baking.

not easy to identify, only the larger ones with a length of more than 15 μ m were selected to count and observe. Starch grains from dough were not much different from those of flour granules, but their outlines were not very sharp and the grains more dispersed than is the case with flour starch (Figure 2B).

Various cooking methods were observed to lead to specific changes in the starch grains analyzed. Boiling led to a remarkable degree of swelling, collapse and gelatinization. Statistical data showed that the starch granules swelled 1.51–1.66 times during boiling (Table 3), with almost a complete loss of the extinction cross and the disappearance of lamellae. Most starch grains were pasting and had vague outlines, so can be supposed to have reached full gelatinization. Few starch grains became puckered, curved or irregularly shaped (Figure 2C). As with boiling, steaming led to a remarkable degree of swelling and gelatinization of the starch granules. Starch grains from the steamed buns swelled 1.62–1.66 times (Table 3), with pasting and an almost total loss of the extinction cross under polarized light. Meanwhile, the gelatinization obscured the granules' outlines (Figure 2D).

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	Cooking method	Degree of swelling (times)	Granule outlines	Extinction cross	Appearance
Modern samples	Boiling	1.51-1.66	Vague	Lost extinctions	Pasting and full gelatinization
	Steaming	1.62-1.66	Vague	Lost extinctions	Pasting and extensive gelatinization
	Baking	0.97-1.27	Mostly clear	Vague and confused extinction lines	Pasting and partial gelatinization
	Frying	1.13–1.32	Mostly clear	Distinct extinction lines but vague from fully gelatinized grains	Pasting but partial gelatinization
Ancient samples	Cake A	1.07-1.14	Some of them clear	Vague and confused extinction lines	Pasting and partially gelatinized
	Cake B	1.10-1.18	Some of them clear	Vague and confused extinction lines	Pasting and partially gelatinized
	Cake C	1.13-1.30	Mostly clear	Vague and confused extinction lines	Pasting and partially gelatinized

 Table 3
 Conditions of starch grains after different cooking methods

Frying is technically different from the above cooking methods because of the use of cooking oil. Most of the starch grains during the frying process were pasting but partially gelatinized. Generally, the granules were oval in shape and had distinct outlines, a different behavior compared with boiled or steamed starch grains (Figure 2E). There was also a considerable number of extinction crosses remaining with oil drops clearly visible under transmitted light (Figure 2E, arrow). In all the cooking methods used, baking caused the most varied modifications to starch grains. Some starch grains in baked food were pasting, had swollen 0.97-1.27 times and become gelatinized, with the extinction phenomenon still present, but showing vague and confused lines. Moreover, some pale brown substances around or on the granules had destroyed the original outlines of the grains, which was not observed in the other three cooking methods: this made the baked starch food different from the others (Figure 2F).

As for the ancient materials of different shapes, these three cakes would have been processed using the same cooking method, judging from the appearance of the starch granules. As can be seen from Figure 3, the starch grains in Cakes A, B and C presented the familiar pattern of starch grains pasting to form a large cluster, while sometimes the outlines of granules were difficult to recognize because of the covering of pale brown substances surrounding the granules. All starch grains had swollen and partially gelatinized (Table 3). Extinction phenomena still remained but had lost their original appearance of a Maltese cross to become darker and more irregular. As well as the clusters, there were also some single granules showing more serious swelling and gelatinization with an indistinct extinction cross. The appearance of these starch grains most closely resembled that of the baked grains: the pale brown substances which appeared in both the modern wheat products and the ancient cakes were almost exactly



Figure 3 Starch grains from ancient cakes. The upper row shows starch grains under transmitted light, while the lower row shows the same grains under polarized light. A–C starch grains from Cakes A, B, C respectively.

alike. Detailed information on the starch grains and the conditions of modern and ancient samples is summarized in Table 3. According to the swelling ratio and other features of starch grains, these three ancient cakes clearly resembled modern baked food.

The morphology of ancient starch grains do not significantly alter after burial [4,8,21,22]. In the Astana Cemetery, the extremely dry stony desert climate had dehydrated the cakes buried in the dry sand and protected them from damage by water and heat. As samples from the cake were scraped from the interior of the cakes, it is most likely that the observed morphology of the starch grains is the result of the cooking process.

The modern baked wheat products were stained by an iodine solution to determine if the pale brown substances were starch. After staining, the color of the starch grains from the baked cake turned purple as Figure 4A shows. Furthermore, the clusters, including swollen and gelatinized starch grains and brown substances, also turned purple, despite the brown substances sometimes maintaining their original color because of incomplete staining (Figure 4B). As a result, it was confirmed that the brown substances were starch.

4 Discussion and conclusions

Heating and water availability strongly affect morphological changes in starch grains. Cooking experiments on starch from *P. miliaceum* have proved that heating in water causes swelling and distortion of the starch grains with the loss of the extinction cross in a short time. However, baking for 20 min results in less damage to the starch grains but leads to disintegration of the grains and the appearance of visible shadows or hollows at the center, although fissuring is extremely rare [8]. Based on experimental results from wheat products, starches from both common millet and wheat appear the same after boiling and steaming and undergo swelling, gelatinization and the loss of the extinction cross. Nonetheless, starch grains from wheat are found to be structurally more vulnerable to boiling and steaming and change more radically than millet during these cooking processes. In contrast to baked *P. miliaceum*, starches of baked wheat did not show hollows at the center and revealed only slight swelling and clusters with pale brown substances.

Changes in starch grains depend on both temperature and the amount of water available [23]. In the study using traditional baking methods, the soil-brick stove was pre-heated then cakes were introduced for baking without an open fire until cooked. In contrast to boiling and steaming, this process involves water loss. Therefore, the appearance of starch resulting from baking is quite different from the other cooking methods and easy to recognize. Our results are consistent with previous studies: cooking with or without water leads to a different range of changes in starch; cooking with water (boiling and steaming) results in extreme swelling and gelatinization in starch grains, along with the loss of the extinction cross; cooking without water (baking) causes slight swelling in the starch but without the loss of the extinction cross; and with baking, brown substances cover the starch granules.

Because of climate, rainfall, geographical environment and natural resources and also religion, ancestor-worship and cultural traditions, the long-term continuity of various diet traditions including food preparation and consumption in different regions around the world have been investigated [24,25]. Recent studies have shown that roasting and grinding technology have been the main food processing methods in western Eurasia (the Near East and the Mediterranean), while boiling and steaming of food are the most common cooking methods in eastern Eurasia (China and the Far East), with overlapping food patterns in South Asia [26]. In North America and southwestern



Figure 4 Starch from a modern baked wheat product after staining with iodine solution. A, Individual starch grains stained purple; B, clusters which include swollen and gelatinized starches and brown substances also stained purple in color.

Europe, stone-boiling and other hot-rock cookery are thought to have been the most common cooking methods in Paleolithic times [27,28]. Based on archaeological evidence, Eastern China has proved to be part of the boiling/steaming food pattern, and this is supported by artifacts such as steamers and cooking vessels [26,29]. However, because of few archaeological artifacts, the food processing systems used in western China in early times, especially during the cultural exchange after the opening of the Silk Road in the Western Han Dynasty (202 BC–AD 9), still need to be explored.

In China, with the invention of the griddle, wheat bran and flour could be separated by sieving to obtain finer flour. This important invention and application was first recorded in an article named *Bingfu* written by Mr. Xi, who described different types of cooked wheaten food in the Western Jin Dynasty (AD 265–316) [30]. After that time, the ancient Chinese started to enjoy highly processed cereal food. In the Xinjiang region, solid food including pastries, cakes and noodles were frequently recorded in early times. The famous Dunhuang literature, which recorded many aspects of life between AD 406– 1002, listed 26 kinds of cake including "Naan", which has been a traditional Xinjiang food through the ages. "Naan" means "Bread" in Persian and was mentioned in the book of *Qi Min Yao Shu*, a comprehensive agriculture book written 1500 years ago. The appearance and processing of this baked wheaten food in Xinjiang was recorded in detail. It resembled a round hardtack biscuit of irregular size, made from the flour of *T. aestivum*, mixed with animal fat or other ingredients and baked in an oven-like hearth. This kind of food is thought to have come from West or Central Asia, was adopted by the indigenous people of Xinjiang and then spread to Central China after the opening of the Silk Road.

The present study on cakes from the Astana Cemetery proves that baking was used for cooking wheaten food 1300 years ago in the Turpan Basin. Baked foods such as "Naan" and cakes are still common and popular today in Xinjiang; this kind of food has a lower water content so can be preserved for a long time and is easy to carry in the desert. We conclude that baking was a traditional cooking method from ancient to modern times in Xinjiang, especially in the Turpan region.

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