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The effect of temperature and duration of cooking on plantain and banana fruit texture and cytoplasmic and cell wall components was investigated. The firmness of both banana and plantain pulp tissues decreased rapidly during the first 10 min of cooking in water above 70 °C, although plantain was much firmer than banana. Cooking resulted in pectin solubilization and middle lamella dissolution leading to cell wall separation (as observed by SEM). Dessert banana showed more advanced and extensive breakdown than plantain. Although dessert banana had a higher total pectin content than plantain, the former had smaller-sized carboxyethylenediaminetetraacetic acid (CDTA) soluble pectic polymers which are associated with plant tissues that have a propensity to soften. Plantain had higher levels of starch and amylose than banana but this was associated with a firmer fruit texture rather than a softening due to cell swelling during starch gelatinization. Different cooking treatments showed that cooking in 0.5% of CaCl₂ solution and temperatures below 70 °C had significant effects on maintenance of pulp firmness.

Keywords: *Texture; cooking; banana; plantain; SEM; starch; pectin*

INTRODUCTION

Plantain (*Musa* spp., AAB group) and banana (*Musa* spp., AAA group) are important starchy staple foods, reported as being the fourth most produced global food group after rice, wheat, and milk in terms of gross value (Anon, 1992). They are major crops of west and central Africa and are grown in some 120 countries throughout the developing world. The green mature fruits have a nutrient composition comparable to potatoes and are widely consumed as a cooked product (Marriott, 1980).

Texture is viewed by consumers as one of the most important attributes of the cooked product in determining a good banana or plantain. A short cooking time to reach acceptable softness is an advantage where fuel is very scarce, as is the case in many tropical countries (Almazan, 1990). Nevertheless, the hardness of the uncooked fruit is obviously an advantage in post-harvest management as it leads to less handling damage during transportation (Baldry and Dempster, 1976). The thermal softening of fruits and vegetables, in particular potatoes, has been studied by many researchers. The rate of softening of plant tissue during heating generally follows first-order kinetics (Loh and Breene, 1981; Harada et al., 1985a,b; Huang and Bourne, 1983; Rao and Lund, 1986; Harada and Paulus, 1987). Loh and Breene (1981) and Harada et al. (1985a) have demonstrated a logarithmic relationship between objective textural parameters and heating time at a constant temperature. However, some studies have suggested that cooking kinetics are more complex (Huang and Bourne, 1983).

Despite their importance in the human diet, there is very little information available on the cooking behavior of banana and plantain and the impact of cooking on the fruit tissues. The aim of the experiments reported in this paper is to study textural and biochemical changes in two distinct *Musa* types, plantain and dessert banana, during cooking. Textural changes were measured by a penetrometer during heating. This was accompanied by measurement of various cytoplasmic components such as starch and amylose, as well as changes in the cell wall component, pectin, which may be responsible for differences in thermal softening. Scanning electron microscopy (SEM) of raw and cooked banana and plantain pulp tissues was undertaken to observe changes at the cellular level during cooking. In addition, the effects of temperature of cooking and different cooking media (salt solutions) on texture were investigated.

MATERIALS AND METHODS

Plant Materials. Green Cavendish dessert banana (*Musa*, AAA group) and Big Ebanga plantain (*Musa*, AAB group) were obtained from commercial sources in the UK. All were at their green mature stage. The middle region of each fruit was sliced into 10-mm thick sections and peeled. At least six sections or disks from six different fruits were used for each treatment and chemical analysis detailed below.

Cooking Duration. Fruit sections were immersed in preheated distilled water in 250-mL beakers, using a ratio of sample:water of 1:3 (by weight). The beakers were placed in a bath of boiling water and heated for treatment periods varying from 1 to 30 min. At the end of each treatment, the cooking solution was poured out and the sections were allowed to cool to room temperature. Firmness was then estimated with a penetrometer and the sections were then freeze-dried for chemical analysis.

Temperature and Salt Solution Treatments. Dessert banana pulp sections in distilled water were subjected to different temperature treatments during cooking (60, 70, 80,

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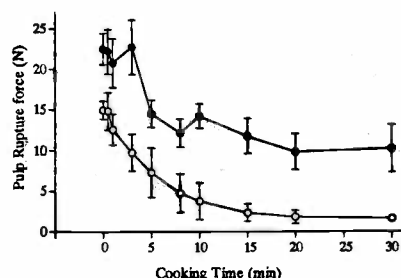


Figure 1. Dessert banana and plantain (Big Ebanga type) pulp rupture force changes during cooking at 100 °C. Error bars show standard deviation on mean (mean \pm SD, $n = 12$). N = newton; (○) dessert banana, (●) plantain (Big Ebanga type).

90, and 100 °C, each for 10 min). In addition, dessert banana and plantain pulp sections were cooked at 100 °C for 15 min in either 0.5% (w/v) CaCl₂, 0.5% (w/v) NaCl, or 0.5% (w/v) ethylenediaminetetraacetic acid (EDTA) using the same sample-to-weight ratio as above.

Texture Measurements. The firmness (rupture force) of each fruit section was measured with a penetrometer fitted with a rounded 6-mm diameter probe. The probe was fitted to a benchtop pressure tester with a Salter 0–10 kg electronic force gauge. The value recorded for the rupture force was the average force for the probe to penetrate the pulp sections to a depth of 5 mm. Two or three measurements were taken from each of six sections.

Alcohol Insoluble Solids (AIS) Preparation. Freeze-dried banana and plantain fruit tissues were ground to a fine powder before passing through a 250- μ m sieve. A sample (ca. 2 g) of the sieved powder was weighed into a cellulose extraction thimble and refluxed with 80% alcohol for 3 h in a Soxhlet extractor. The resultant alcohol insoluble solids (AIS) were dried in a warm oven (60 °C) to constant weight. The AIS were stored in a desiccator at -20 °C for subsequent determination of their chemical constituents.

Estimation of Uronic Acid. Total polyuronide content of AIS was estimated by stirring 40 mg of the AIS at 100 °C with 1 M HCl for 2 h and then neutralizing with NaOH solution (Jarvis, 1984). An aliquot of the resulting solubilized material was then assayed for uronic acid content colorimetrically by the *m*-phenylphenol method (Blumenkrantz and Asboe-Hansen, 1973). Galacturonic acid was used as a standard.

Extraction of the Carboxyethylenediaminetetraacetic acid (CDTA) Soluble Pectin and Its Molecular Weight Determination by Gel Filtration Chromatography. These were carried out by the methods described by Qi et al. (1995).

Starch and Amylose Determination. The starch content of the AIS was determined using the ferricyanide colorimetric method (Rickard, 1992). Amylose was extracted from AIS and determined spectrophotometrically according to McCready et al. (1950) using amylose (type III from potato, amylopectin free) as a standard.

Scanning Electron Microscopy (SEM). The parenchyma tissue of raw and cooked dessert banana and plantain were cut into approximately 3 \times 5 \times 5 mm pieces and frozen in liquid nitrogen before being fractured with a sharp blade (Huang et al., 1990). Fractured samples were then freeze-dried for 24 h. The temperature of the condensing plate was maintained at -80 to -60 °C. The dried samples were mounted on aluminum dishes and sputter coated with gold for 3–5 min. The fractured surfaces of samples were examined with Joel T330 SEM and Joel 6310 SEM microscopes operating at 10–15 kV.

RESULTS AND DISCUSSION

Effect of Different Cooking Times on the Texture of *Musa*. Raw Big Ebanga plantain pulp was 33% harder than raw dessert banana (Figure 1). The firmness of dessert banana pulp decreased sharply during

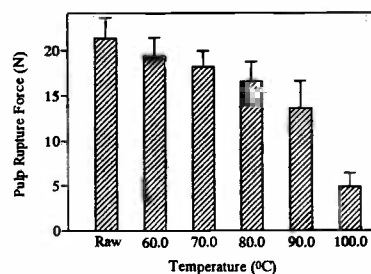


Figure 2. Firmness of dessert banana pulp after cooking in distilled water at different temperatures for 10 min. Error bars show standard deviation on mean (mean \pm SD, $n = 15$). N = newton.

the first 10 min of cooking, losing 75% of its original firmness compared to a loss of 37% of the original firmness for plantain. Little change in firmness took place in either type of fruit after a further 10 min of cooking. Thus plantain pulp softened at a slower rate than banana and remained firmer throughout cooking.

There was an inverse negative linear relationship between the force needed to penetrate into the pulp tissues (firmness) of the cooked *Musa* and cooking time in the first 10 min of cooking at 100 °C. Correlation coefficients between cooking time and pulp rupture force in the first 10 min of cooking were -0.98 ($r^2 = 0.95$) and -0.88 ($r^2 = 0.78$) for dessert banana and Big Ebanga plantain, respectively. Less of a correlation was found after 10 min of cooking. The results indicate that there is significant difference between the different *Musa* genotypes in their textural changes before and during cooking. Cooking time has a big influence on the cooked *Musa* texture; however, the cooking kinetics were different before and after 10 min of cooking. A similar finding was also reported with cooked potatoes (Harada et al., 1985a). These workers were able to use a first order equation to describe the change in shear force during short cooking times, but over prolonged periods, a second order equation provided a better fit to the data. Huang and Bourne (1983) postulated that there are two simultaneous first order kinetic mechanisms involved in vegetable softening during early and prolonged cooking. Mechanism 1 is probably due to pectic changes in the middle lamella layer and responsible for approximately 95–97% of the firmness of the raw commodity, and the remaining firmness is contributed by mechanism 2 in which the biochemical nature is unknown.

Effect of Different Cooking Temperature on Texture of Banana. Heating dessert banana at 60–70 °C for 10 min had little effect on pulp firmness compared to heating at 80–100 °C (Figure 2). The pulp rupture force of dessert banana decreased significantly, by 29%, only when the temperature reached at least 80 °C. Cooking at 90 °C caused 36% loss of firmness. Cooking at 100 °C in water resulted in the softest pulp texture, the firmness decreasing by 77% by the end of the cooking treatment. This phenomenon was also observed by Loh and Breene (1981) with potatoes, and it has been suggested that this might be due to the retention of pectin methylesterase (PME) activity at cooking temperatures below 70 °C (Hoff, 1972). PME has the ability to de-esterify the methylated pectin into free carboxyl groups, which are resistant to heat degradation. The results obtained in this study indicate that the temperature of cooking influences the final texture of the cooked *Musa* fruit tissue.

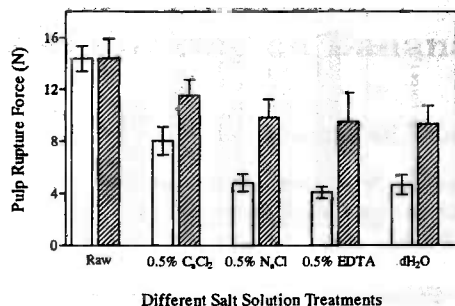


Figure 3. Effect of cooking dessert banana (empty bars) and Big Ebanga plantain (striped bars) at 100 °C in different salt solutions on pulp rupture force. The cooking time for all the treatments is 15 min. Error bars show standard deviation on mean (mean \pm SD, $n = 15$).

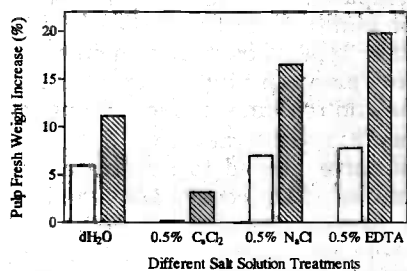


Figure 4. Effect of different salt solutions on water uptake by the pulp tissues of cooking dessert banana (empty bars) and Big Ebanga plantain (striped bars) during cooking. The cooking time for all the treatments is 15 min. Each bar shows the mean of five measurements.

Effect of Different Salt Solution Treatments on Texture. When 0.5% CaCl₂ was present in the cooking medium, the tissue retained significantly more firmness compared to cooking in distilled water, 0.5% NaCl or 0.5% EDTA solution (Figure 3). In dessert banana, cooking in CaCl₂ solution caused only 44% loss of the original firmness compared to 67.5% in distilled water, 66.4% in NaCl, and 71.4% in EDTA solution. A similar tendency was also found in plantain, although firmness declined less significantly. The dominant role of Ca²⁺ in promoting firmness can be attributed to the ability of Ca²⁺ to promote aggregation between pectin chains through formation of ionic Ca²⁺ bridges (Morris et al., 1982). The newly formed Ca²⁺-pectic gels lead to the firming of tissue which may be through either decreasing pectin solubilization and an improved cementing function of pectin (van Buren, 1986) and/or a reduction of water uptake which prevents the cell wall components from hydrating, thus increasing the cohesiveness of the cell wall matrix (Warren and Woodman, 1974). Both of these mechanisms could delay the cell wall softening and cell wall separation. It should be noted that cooking in 0.5% CaCl₂ solution resulted in reduced water uptake in both *Musa* types, particularly banana (Figure 4).

Conversely, sodium ions are considered to induce softening by displacement and competition with Ca²⁺ (van Buren, 1984; van Buren et al., 1988). EDTA, a strong Ca²⁺ chelator and pectin extractant, could remove Ca²⁺ from pectin effectively, resulting in pectin solubilization. Cooking in EDTA solution results in a very soft texture of snap beans (van Buren and Pitifer, 1992). However, both NaCl and EDTA solutions had little effect on the texture of the cooked banana and plantain, implying that the calcium-linked pectin may only represent a small proportion of the total pectin content, perhaps due to low levels of calcium in the pulp

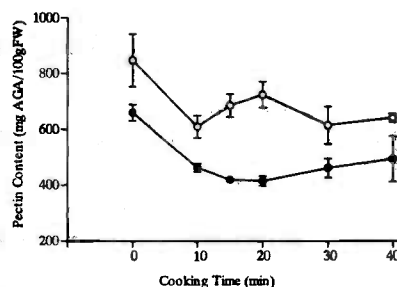


Figure 5. Effect of cooking duration on the levels of total polyuronides remaining in the cooked tissues of dessert banana (○) and Big Ebanga plantain (●). Error bars show standard deviation on mean (mean \pm SD, $n = 4$).

tissue. Thus the natural level of calcium in *Musa* may contribute very little to the texture and this effect is easily overcome during cooking. Therefore, mature fruits, which normally contain little calcium, would undergo a significant firming after calcium treatment (Jarvis, 1984), whereas Na⁺ and EDTA only had minimal softening effects on the tissues.

Pectin Solubilization during Heating. The total pectin content of raw dessert banana pulp was much higher than that of plantain with 848 mg of AGA/100 g of FW and 660 mg of AGA/100 g of FW, respectively (Figure 5). The pectin content decreased sharply in the first 10 min of cooking in both banana (28%) and plantain (30%). Little change in pectin content was found during further cooking, the total pectin content remaining higher in banana than plantain throughout cooking. Therefore, a major proportion of the "total" pectin remained in the cooked dessert banana and plantain pulp tissue disks. Although banana contains higher amounts of pectin than plantain, it is considerably softer after cooking. This may be due to a predominance of "protopectin", which is not involved in middle lamella structure (Hughes et al., 1975a).

It seems that the initial solubilization of relatively small amounts of a particular type of pectic material may considerably weaken the intercellular cement, with a loss of cell adhesion and firmness. The pectic material released later during cooking may have been of different origin to that released earlier and may only be partially concerned with cell wall strength, as suggested by Hughes et al. (1975b) from their studies with potatoes.

The molecular weight distribution of CDTA-soluble pectic polymers was different for the dessert banana and plantain. Isolates from the raw dessert banana cell wall contained much smaller sized materials which eluted between fraction numbers 50–70, similar to the blue dextran (MW = 2,000,000), whereas that of plantain eluted between fraction numbers 30–65, which represented higher molecular materials (Figure 6). Carrots with chelator-soluble pectin of relatively lower molecular weights tended to soften more extensively during heating (Greve et al., 1994). This suggests that the propensity for dessert banana to soften more readily than plantain is associated with smaller-sized pectin polymers. The viscosity of a pectin solution increases as the polymer length increases. In addition, in the cell wall, increased pectin size might increase the possibility of an assortment of inter-polymer associations. This in turn could increase tissue firmness.

Starch and Amylose during Cooking. Plantain pulp tissue contained much higher starch, amylose, and dry matter than dessert banana (Table 1). During

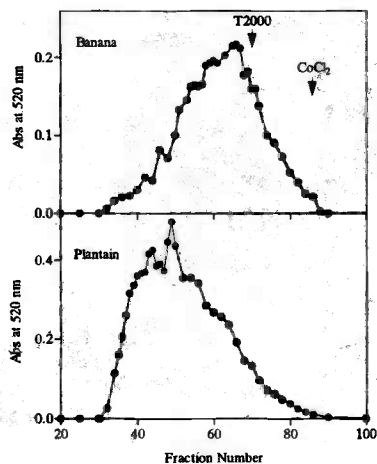


Figure 6. Gel filtration profiles of CDTA-soluble pectic polymers isolated from the cell wall materials of raw dessert banana and Big Ebanga plantain. T2000 (blue dextran), MW = 2 000 000; CoCl_2 = cobalt chloride. CDTA = carboxyethyl-enediaminetetraacetic acid.

Table 1. Chemical Composition of Dessert Banana and Big Ebanga Plantain^a

	dessert banana	plantain (Big Ebanga)
dry matter, % FW	26.31 ± 0.37	37.62 ± 0.45
starch, % FW	19.39 ± 0.69	30.02 ± 0.63
amylose, (% total starch)	27.35 ± 0.93	33.37 ± 0.86
polyuronide, AGA ^a % FW	0.85 ± 0.04	0.66 ± 0.03

^a Values are means (±SD) of four measurements. AGA^a = anhydrous galacturonic acid; FW = fresh weight.

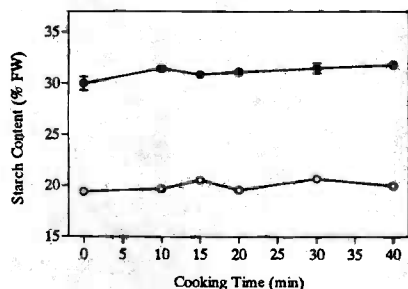


Figure 7. Effect of cooking duration on the levels of starch remaining in the cooked tissues of dessert banana (○) and Big Ebanga plantain (●). Error bars show standard deviation on mean (mean ± SD, $n = 4$).

cooking, the starch content of both dessert banana and plantain (Big Ebanga type) pulp remained constant (Figure 7). The higher starch content of plantain would be expected to produce more starch swelling pressure than banana during cooking, which in turn would lead to a softer texture. Although this relationship between the starch content and firmness was found with potato by Jarvis et al. (1992), other work on potato has shown that more starch (and amylose) is associated with firmer tissues (Sharma et al., 1959; Linehan and Hughes, 1969a,b; McComber et al., 1994).

Linehan and Hughes (1969c) suggested that amylose chains might act as a cement between potato tuber cells by formation of hydrogen bonds with polysaccharides of the cell walls. However, Keijbets et al. (1976) found no other interactions between purified potato starch and pectic galacturonan other than the transfer of Ca^{2+} ions to galacturonan, by which they are much more strongly

complexed resulting in a firmer texture. During heating of the banana and plantain fruit, the starch content remained the same throughout. This implies that changes in starch content per se are not responsible for changes in the texture of the cooked banana and plantain pulp tissue, although starch accounts for about 20% and 30% of fresh weight (Table 1). This is similar to the result found with potatoes (Harada et al., 1985b; Harada and Paulas, 1987; Loh et al., 1982).

SEM Observations of Pulp Tissue during Cooking. In the raw sample of both banana and plantain, the cell walls were smooth, and starch granules were also smooth and not fused (Figure 8a,e). The shape of the plantain starch grain appeared to be more rounded and elongated than the starch grains of banana which were more platelike. As the banana, tissue was heated, starch grains lost their distinct definition and merged into a uniform reticulated structure, and intercellular space expansion became evident (Figure 8b). However, in plantain, only gelatinization took place after the same period of heating (Figure 8f). After 3 min of cooking, the starch in both banana and plantain had developed a reticulated appearance with intercellular space expansion; however, intercellular material accumulation was observable only in banana (arrow in Figure 8c). There was very little difference between banana and plantain in the appearance of their microstructures after 20 min of cooking (Figure 8d,h). Van Marle et al. (1992) suggested that intercellular space expansion in cooked potato tissue indicated dissolution of the middle lamella and cell wall separation. The reticulated materials present in the intercellular space may indicate cell wall damage hence leakage of the wall due to heating. Therefore, the results obtained here suggest that the thermal softening of banana and plantain pulp tissues in the early stages of cooking is related to middle lamella dissolution causing cell wall separation. Further softening of the tissue during the later stages of cooking may be caused by starch "swelling pressure", along with thermal expansion of the cells, aiding further cell separation.

In conclusion, there were two phases of firmness loss of the banana and plantain pulp tissues during cooking. The first phase, which was also the fastest, occurred within the first 10 min and more than half of the original firmness was lost within this period. The second, much slower phase of firmness loss continued for a further 10–15 min. Plantains were much firmer after the same periods of cooking than dessert banana.

Starch and amylose content was much higher in hard Big Ebanga plantain than in soft dessert banana. However, dessert banana contained 30% more pectin than Big Ebanga plantain. However, the molecular weight of the CDTA-soluble pectin isolated from the dessert banana cell wall materials was lower than that from plantain. SEM observations revealed that the middle lamella dissolution and cell wall separations corresponded to the firmness loss during the early stages of cooking. Starch swelling and gelatinization contributed to further firmness loss. Both cell wall separation and starch swelling resulted in a very soft edible texture in banana and plantain. A temperature below 70 °C had only little effect on thermal firmness loss in dessert banana. Cooking in 0.5% CaCl_2 solution resulted in a much firmer texture and less water uptake

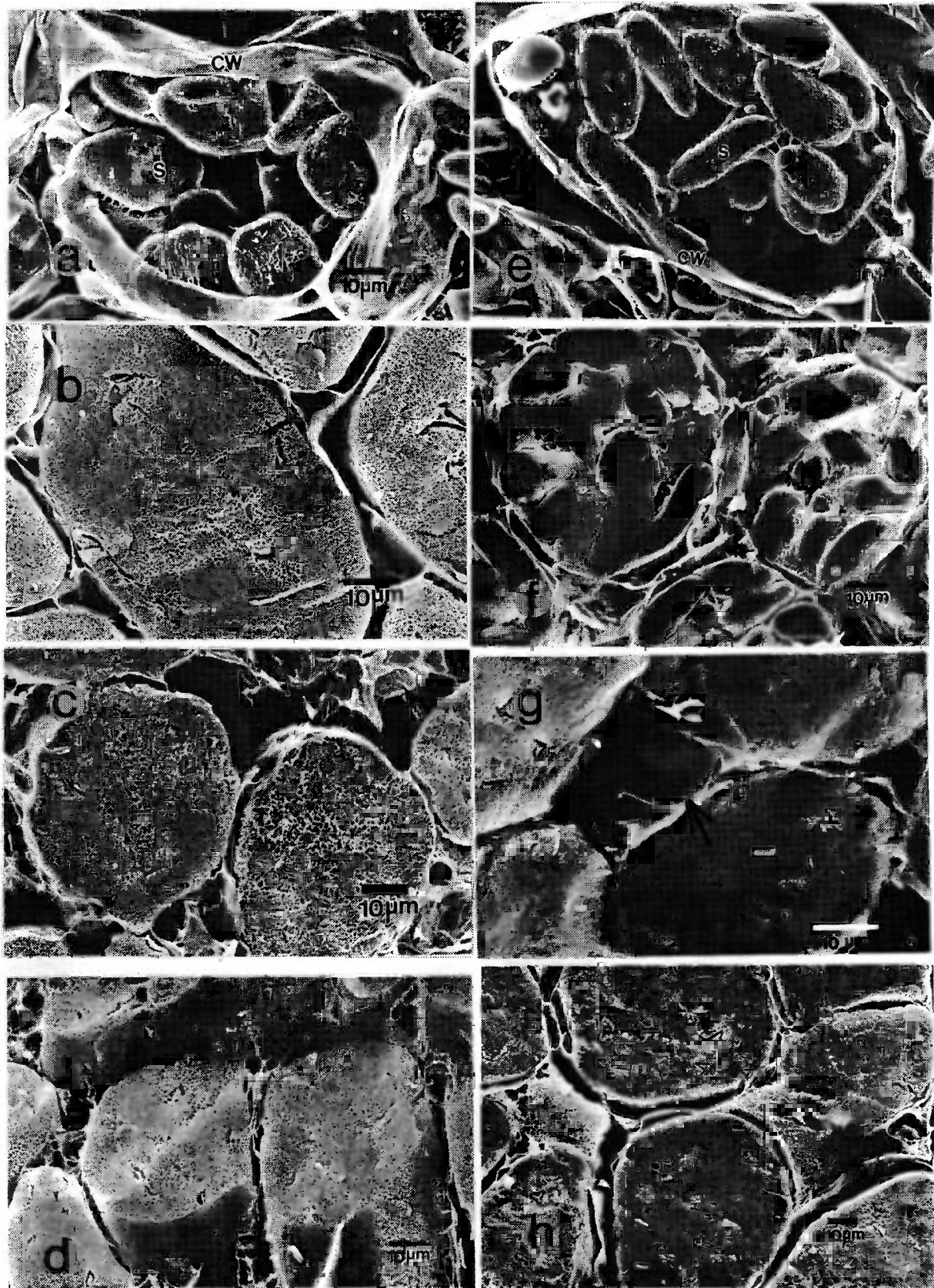


Figure 8. SEM micrographs of dessert banana (a–d) and Big Ebanga plantain (e–h) pulp parenchyma tissues during cooking. (a) Raw banana; (b) 2 min cooked banana; (c) 3 min cooked banana; (d) 8 min cooked banana; (e) raw plantain; (f) 2 min cooked plantain; (g) 3 min cooked plantain; (h) 8 min cooked plantain. Arrows in (b) and (g) indicate intercellular space expansion, and the arrow in (c) indicates intercellular materials. CW = cell wall; S = starch; G = starch gel; CWS = cell wall separation.

in both dessert banana and Big Ebanga plantain than by cooking in pure water, 0.5% EDTA, and NaCl

solutions. This was particularly obvious with dessert banana compared to plantain.

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This paper is dedicated to the memory of Dr. Keith Moore.

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