3 RESEARCH

The research was conducted in three phases. Preliminary work, which is reported in section 3.1, was done to select two cowpea varieties from a collection of varieties obtained from Bunda College of Agriculture in Malawi and Agricol in South Africa. Once the two cowpea varieties were identified, the second phase investigating the effect of micronisation which comprised of tempering the cowpea seeds and infrared heating, on cooking characteristics of the selected cowpea varieties was done and this is reported in section 3.2. The third phase concentrated on the underlying structural and physicochemical changes that contributed to the change in cooking characteristics of the cowpea seeds and functionality of the resultant flours. The work from the third phase is reported in sections 3.3 and 3.4.

3.1 Physicochemical and cooking characterisation of nine cowpea (*Vigna unguiculata* L. Walp) varieties

Abstract

Nine cowpea (*Vigna unguiculata* L.Walp) varieties were characterised in order to identify two varieties with divergent cooking characteristics. The cowpeas were significantly ($P \leq 0.05$) different in size ranging from 11.4 g to 14.1 g per 100 seeds of Bechuana white and Var. D, respectively. Bechuana white and Agribleu had significantly ($P \leq 0.05$) lower rate of water uptake during soaking although the amount of water absorbed during cooking followed a similar trend for all the varieties. Var. 462 had a significantly ($P \leq 0.05$) harder texture than all the other cowpea varieties after 75 min of cooking, while Bechuana white had significantly ($P \leq 0.05$) higher incidence of splits during cooking than the other cowpeas. The greatest variation in cooked texture and splitting was observed between Var. 462 and Bechuana white, and these were selected for the main study.

Key words: cowpeas, physicochemical, cooking time, texture, splits, water absorption

3.1.1 Introduction

Cowpeas (*Vigna unguiculata* L. Walp) are widely produced and consumed in most developing countries of sub Saharan Africa where they are a good source of affordable protein and vitamins to the mainly carbohydrate-based diet of sub Saharan Africa (Phillips *et al*., 2003). The optimum utilisation of cowpeas however faces challenges such as long cooking time that is required for the cowpeas to attain soft texture and be palatable for consumption (Taiwo, 1998). Long cooking time of legumes such as cowpeas leads to increased energy use particularly in rural and peri urban areas where fuel wood is the main source of household energy (Brouwer *et al*., 1996). In addition, long cooking time means that women have to spend more time in meal preparation. The cooking time of cowpeas is mainly dependent on variety due to differences in physicochemical properties such as protein, calcium and phytic acid (Akinyele *et al*., 1986). Storage conditions of the seeds (Abu, Arogba & Ugwu, 1999) and ionic composition of the water used for cooking (Onigbinde & Ojeabulu, 1999) also have an effect on cooking time.

Several methods have been proposed and are used to reduce the cooking time of cowpeas. Soaking in water or dilute organic acids or sodium salt solutions (Onigbinde & Ojeabulu, 1999), have been used to reduce the cooking time of cowpeas. Micronisation has been used to process and significantly reduce the cooking time of legumes such as lentils (Arntfield *et al*., 1997). Micronisation refers to infrared heating, and has been applied in legumes such as split peas, lentils and black beans (Cenkowski & Sosulski, 1997; Cenkowski & Sosulski, 1998; Bellido *et al*., 2006). The application of micronisation as a precooking process for dried whole cowpeas will depend on the cooking characteristics of both the raw material and the processed product. The success of micronisation of whole cowpea products will depend on the quality characteristics of the moisture-conditioned and micronised products. Cooking quality in legumes encompasses several characteristics such as cooking time, splitting during cooking, texture and other sensory attributes.

The objective of this study was to characterise the cooking qualities of nine cowpea varieties from the region in order to identify the varieties with most divergent physicochemical characteristics (protein and moisture contents, water uptake during soaking and cooking, splitting of cooked cowpeas and cooked texture) in order to

select the two most divergent varieties, which could be used to determine the structural and physical chemical changes caused by micronisation of moisture-conditioned seeds.

3.1.2 Materials and methods

Seven cowpea varieties were obtained from Bunda College of Agriculture in Malawi and two from Agricol in Potchefstroom, South Africa. Cowpea samples were cleaned to remove chaff, shrivelled and broken seeds. The cleaned seeds were packed in polypropylene bags and stored at 4 °C until the time of use.

3.1.2.1 Moisture determination

Moisture content of the cowpea seeds was determined according to the method of Ajibola, Aviara and Ajetumobi (2003). Thirty grams (M0) of cowpea seeds were weighed into pre dried (1 h, 103 ºC) moisture tins that had been cooled in a dessicator. The samples were then dried for 72 h in a hot air oven at 103 ºC. The dried samples were then cooled in a dessicator and weighed (M1). Moisture content of the cowpea seeds expressed as g of water kg^{-1} cowpea was calculated as follows:

Moisture content = {(M0-M1)/M0} * 1000

3.1.2.2 Crude protein determination

Crude protein content of the cowpeas was determined using the Dumas method. A factor of 6.25 was used to calculate the crude protein from the nitrogen content determined using a Leco Nitrogen Analyser FP 528 (Leco Africa Pty, Kempton Park, South Africa).

3.1.2.3 Seed size determination

The size of cowpeas was expressed as the weight of 100 seeds weighed using a Precisa (0.01g) top loading balance.

3.1.2.4 Determination of water absorption during soaking

Water absorption during soaking was determined according to a modified method of Agbo, Hosfield, Uebersax, and Kimparens, (1987). Approximately 10 g of cowpea seeds were placed in 100 ml Erlenmeyer flasks containing 50 ml deionised water. The Erlenmeyer flasks were placed in an incubator at 22 °C for 1, 2, 3, 4, 5 and 6 h. After

soaking, the excess water was drained using a metal sieve (2.5 mm) and the cowpeas were blotted dry with absorbent paper to remove excess water and weighed. The gain in weight was expressed as g of water kg^{-1} cowpea.

3.1.2.5 Determination of water absorption during cooking

The amount of water absorbed during cooking was determined according to a modified method of Cenkowski and Sosulski (1997). For each cowpea variety approximately 10 g of cowpea seeds were placed in 100 ml Erlenmeyer flasks containing 50 ml deionised water. The Erlenmeyer flasks were placed in a heavy aluminium pan containing 1500 ml of deionised water. The pan was tightly covered and brought to boil, allowing 5 min for heating up. The cowpeas were cooked up to 90 min. Every 15 min, two sample flasks per cowpea variety were removed and excess water was drained using a metal sieve (2.5 mm). Cowpeas were cooled to room temperature (22 ± 2 °C) for 1 h, blotted dry with absorbent paper to remove excess water and weighed. The gain in weight (g) was expressed as g water kg^{-1} cowpea. The boiled cowpeas were then used to determine splitting and texture.

3.1.2.6 Determination of splitting during cooking of cowpea seeds

The tendency of seeds to split during cooking was determined according to the method of van Buren, Bourne, Downing, Quele, Chise, and Comstock (1996). The cowpeas with split seed coats and cotyledon were counted as splits. The degree of split was calculated as follows:

$$\frac{\text{Number of split seeds}}{\text{Number of whole seeds}} \times 100$$

3.1.2.7 Determination of seed texture during cooking of cowpea seeds

Texture was measured as work (area under the curve, Nmm) done to cut individual cowpea seeds through a distance of 5 mm at a speed of 4 mm/s based on the method of Sefa-Dedeh *et al*. (1978). A texture analyser (TA-XT2, Stable Micro Systems, Surrey, England) with A/CKB craft knife adapter mounted with Hilite® heavy-duty blades (Hilite Hardware, Hatfield, Pretoria, South Africa) was used to measure texture. A single cowpea seed was positioned on its side and cut below the hilum.

The blade was replaced after 5 determinations. Four seeds were measured per sample of cowpeas cooked for 15, 30, 45, 60, 75 and 90 min.

3.1.2.8 Statistical analysis

The experimental work was conducted on duplicate samples to generate data that was analysed using Statistica statistical software version 6.0. Analysis of variance (ANOVA) was used to evaluate the data based on a 5 % level of significance. When the F-test was significant, differences between means were determined using the Least Significant Difference (LSD) test.

3.1.3 Results and discussion

Nine cowpea varieties were sourced and described (Table 3.1.1). All the cowpeas used in the study had smooth seed coats. The moisture content of the cowpeas ranged from 89 to 121 g of water kg^{-1} of Bechuana white and Var. D, respectively. The crude protein content of the cowpeas ranged from 240 to 283 g of protein kg^{-1} and was within the range reported in literature. Akinyele *et al*. (1986) alluded to a possible effect of protein content on cooking time. A positive correlation between cooking time and protein content of cowpeas was reported (Akinyele *et al*., 1986).

Bechuana white and Var. 462 were relatively smaller in size when compared with the other varieties (Table 3.1.1). Demooy & Demooy (1990) reported that small seeded cowpeas have been reported to have longer cooking time as compared to the larger seeded varieties. However this is in contrast to results found by Olapade *et al*. (2002) where small seeded cowpeas had cooking times which were comparable to large seeded cowpeas. Var. 418 and Agribleu were relatively large seeded and would be preferable to consumers (Langyintuo *et al*., 2004). Olapade *et al*. (2002) reported the seed size of cowpeas to range from 1.92 to 24.4 g per 100 seeds. Hence the cowpeas used in this study would be medium sized. The small to medium sized cowpeas seeds would be suitable for micronisation in order to attain uniform heat transfer (Fasina *et al*., 2001). Cenkowski and Sosulski (1998) alluded to the difficulty of obtaining uniform heating through the depth of large seeds as compared to smaller seeds.

Table 3.1.1 Source and selected physicochemical characteristics of nine cowpea varieties

Variety	Source	Colour	Moisture ($g\ kg^{-1}$)	Protein ($g\ kg^{-1}$)	Seed size (g/100 seeds)	Texture (work) after 75 min of cooking (N mm)
Var. 223/1	Bunda College	Pinkish	113^{b} (6.9)	283^{e} (4.4)	13.9^{cd} (0.40)	4.10^{ab} (0.94)
Var. 418	Bunda College	Maroon	107^{b} (6.2)	260^{bc} (5.0)	15.0^{e} (0.48)	5.99^{bc} (0.64)
Bechuana white	Agricol- South Africa	Cream	89^{a} (3.8)	240^{a} (1.6)	11.4^{a} (0.14)	3.31^{a} (0.75)
Agribleu	Agricol- South Africa	Purple	109^{b} (8.2)	267^{c} (3.5)	14.7^{de} (0.45)	3.71^{ab} (0.52)
Var. 462	Bunda College	Maroon	11.7^{bc} (8.0)	257^{b} (2.4)	11.2^{a} (0.24)	7.34^{c} (3.74)
Var. A	Bunda College	Beige to brown	113^{b} (6.9)	280^{e} (4.2)	12.6^{b} (0.55)	4.56^{ab} (1.29)
Var. B	Bunda College	Beige to brown	107^{b}(10)	279^{e} (9.8)	13.1^{bc} (1.11)	5.58^{abc} (1.31)
Var. C	Bunda College	Beige to brown	120^{c} (1.4)	272^{d} (6.8)	14.1^{d} (0.95)	4.36^{ab} (0.46)
Var. D	Bunda College	Beige to brown	121^{c} (3.6)	266^{cd} (4.2)	13.4^{c} (0.52)	4.35^{ab} (0.96)

Means followed by the same superscript in a column are not significantly different at $P \leq 0.05$; Standard deviations of the means are in parenthesis

3.1.3.1 Water uptake during soaking

During traditional boiling of legumes such as cowpeas, soaking is used to enhance rehydration of the seed contributing to shorter cooking time. In all the cowpea varieties the amount of water absorbed per unit weight of the seeds increased with increasing soaking time (Figure 3.1.1), a pattern that has been reported in previous cowpea work (Taiwo *et al*., 1998). Var. 223/1 exhibited significantly ($P \leq 0.05$) higher initial (3 h) water absorption while Bechuana white had the lowest. High rate of water absorption during soaking has been related to amorphous and thin seed coats (Sefa-Dedeh & Stanley, 1979a). Bechuana white and Agribleu absorbed significantly ($P \leq 0.05$) lower amount of water per unit weight of cowpeas after 6 h of soaking than the other cowpea varieties.

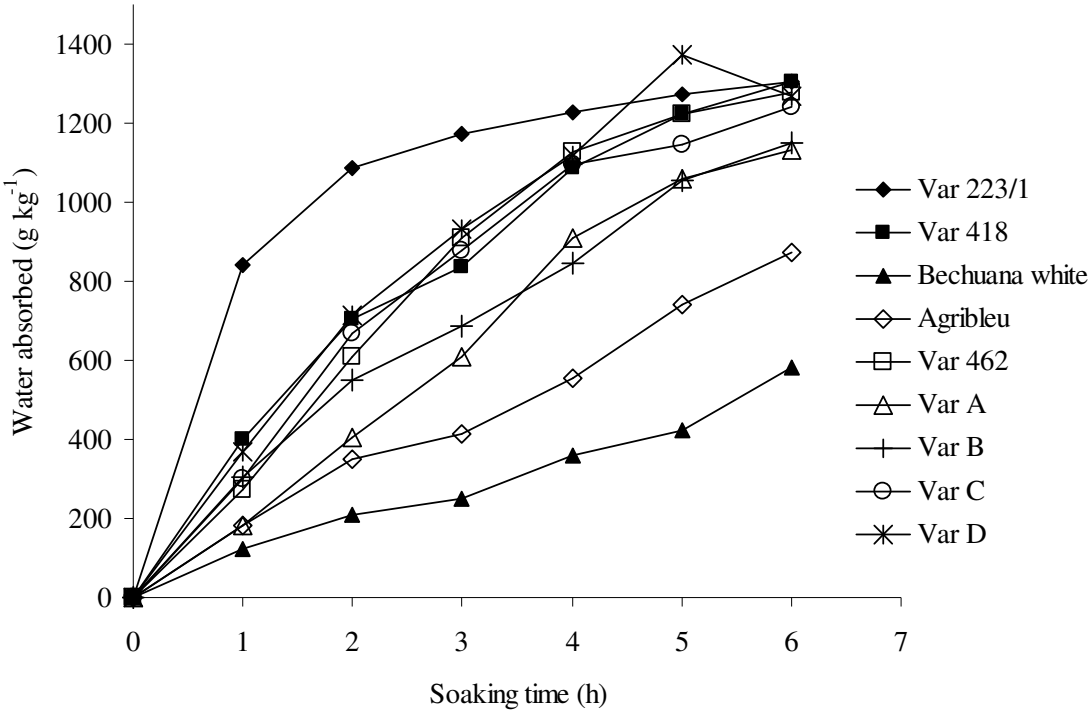

Figure 3.1.1 Water absorption patterns for 9 cowpea varieties during 6 h of soaking

The hydration properties of the cowpeas are important in determining the parameters considered during tempering of cowpeas prior to micronisation. Dry cowpeas can be

rehydrated either by steeping the seeds in water for a specific period of time or adding a predetermined amount of water to the sample in order to adjust the moisture content to targeted moisture content (Phadi, 2004). Tempering of cowpeas is an important step required to maximise the effect of micronisation for legumes such as cowpeas (Arntfield *et al*., 1997). Adequate rehydration is necessary for the gelatinisation of starch during the micronisation of pulses (Arntfield *et al*., 1997) such as cowpeas.

3.1.3.2 Water absorption during cooking

The amount of water absorbed by all the cowpea varieties increased with increase in cooking time (Figure 3.1.2). The increase in the amount of water absorbed by the cowpeas is possibly due to starch gelatinisation and protein gelation.

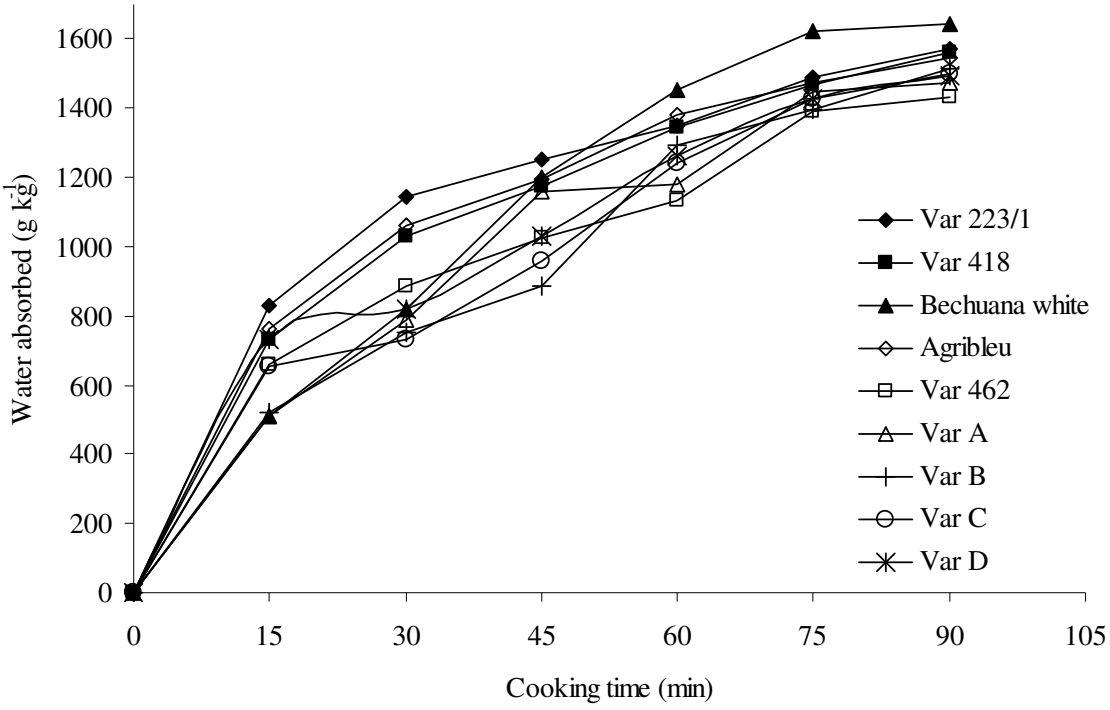

Figure 3.1.2 Water absorption pattern for 9 varieties of cowpeas during 90 min of cooking

Cowpeas contain approximately 48 % starch (Kerr *et al*., 2001), which undergoes the process of gelatinisation during cooking. During the first 15 min of cooking,

Bechuana white, Var. 462, Var. A, Var. B, and Var. C, absorbed significantly less amount of water as compared to Var. 223/1, Agribleu, Var.418 and Var. D cowpeas. There was no significant increase in the amount of water absorbed by all the cowpeas after 75 min of cooking, possibly due to the full hydration of the gelatinised starch. There were no significant differences in the amount of water absorbed by the cowpeas at 90 min of cooking.

3.1.3.3 Splitting of cowpea seeds during cooking

Overall, Bechuana white had significantly higher number of splits as compared to the rest of the varieties (Figure 3.1.3).

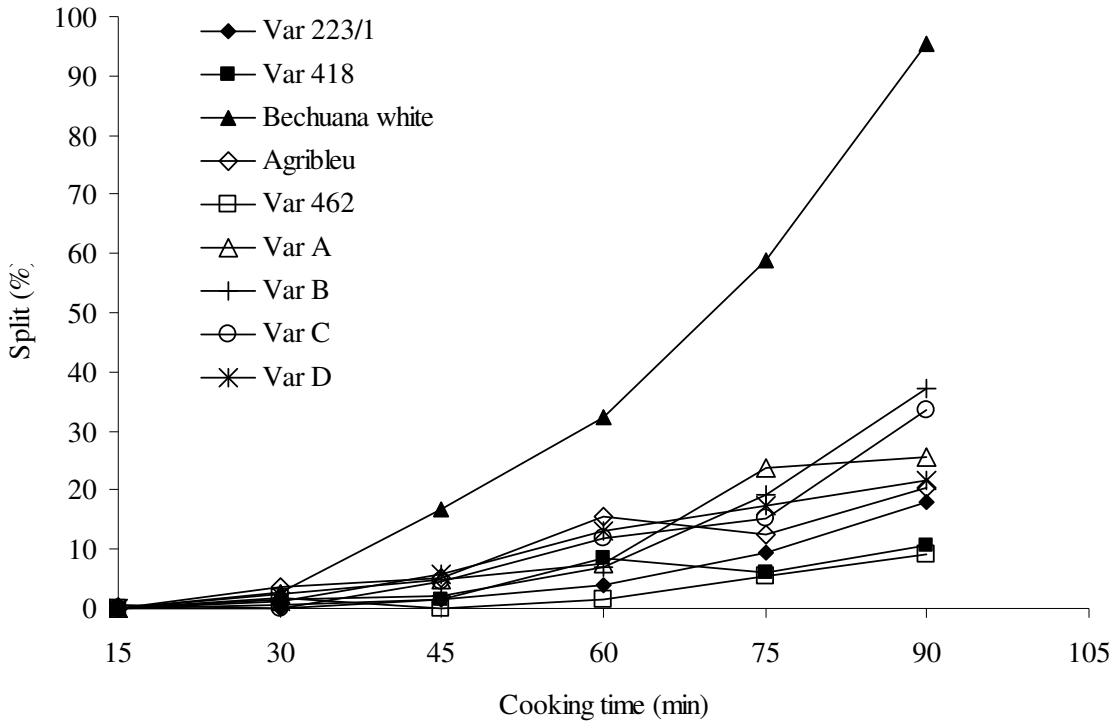

Figure 3.1.3 Splitting of cowpea seeds during 90 min of cooking

Extensive splitting of cooked whole cowpeas is an undesirable characteristic (Afoakwa *et al*., 2006). Splitting during cooking of cowpeas has been positively related to drained weight of cooked seeds (Taiwo *et al*., 1998). Cowpeas that have high water absorption properties during cooking tend to have a higher incidence of

splits. Splitting during cooking is an important quality characteristic for cowpeas that would be exposed to micronisation process.

3.1.3.4 Texture of cooked cowpea seeds

Texture is an important quality characteristic for cooked cowpeas (Sefa-Dedeh *et al*., 1978), and is usually used to measure the cooking time of cowpeas. Texture has been defined as the sensory and functional manifestation of structural, mechanical and surface properties of foods that is detected through the senses of vision, hearing, touch and kinesthetics (Szczesniak, 2002). Dry cowpeas are boiled until they attain a texture that is palatable for consumption. Table 3.1.1 shows that Var. 462 had a significantly harder texture as compared to the other cowpea varieties after 75 min of cooking. This may mean that Var. 462 may require longer cooking time to attain a softer texture that is similar to the other cowpea varieties. Since Var. 462 cowpeas did not have a hard shell, as indicated by the rapid hydration properties, the longer cooking time for Var. 462 could possibly be due to variations in compositional factors such as phytic acid, calcium and pectic substances.

3.1.4 Conclusions

Significant variation exists in the pattern of water uptake during soaking, cooked texture and splitting of the cooked cowpea varieties. These characteristics are most divergent between Bechuana white and Var. 462 cowpeas. Therefore these two varieties were selected for use in the subsequent study on the effect(s) of hydrothermal treatment (tempering and micronisation), on the structure of cowpeas and the physicochemical properties of carbohydrates and proteins as they relate to cooking quality characteristics.

3.2 Hydrothermal treatments of two cowpea (*Vigna unguiculata* L. Walp) varieties: effect of micronisation on physicochemical and structural characteristics[1]

Abstract

The effects of a hydrothermal treatment consisting of tempering (to 41 % moisture) and infrared heating to 153 °C (micronisation) on the structural and physicochemical characteristics of two cowpea varieties were studied. The untreated varieties had similar cooking times, although cooked Bechuana white was significantly ($P \leq 0.05$) softer and had a higher incidence of splitting than Var. 462 cowpeas. This may be due in part to differences in cotyledon structure affecting water uptake during cooking. The hydrothermal treatment changed the physical structure and chemical properties of the cowpea seeds. This led to significant ($P \leq 0.05$) reductions in cooking time of micronised (41 % moisture, 153 °C) Bechuana white and Var. 462 cowpeas, by 44 and 36 %, respectively, as compared with control samples. Micronisation (41 % moisture, 153 °C) caused physical fissuring of the seed coat and cotyledon and significantly ($P \leq 0.05$) reduced the bulk density of treated seeds. These changes in the physical structure significantly ($P \leq 0.05$) improved the initial water uptake during soaking and cooking, increased the enzyme-susceptible starch and reduced the protein solubility and hydration capacity of the cowpea seeds. Cooked (60 min) micronised (41 % moisture, 153 °C) cowpeas also had significantly ($P \leq 0.05$) more splits and a significantly ($P \leq 0.05$) softer texture than control samples.

Key words: cowpea seeds, micronisation, cellular structure, cooking time, texture, splits, water absorption

[1] Published in part in the *Journal of the Science of Food and Agriculture* (2006), 86, 35-45.

3.2.1 Introduction

In sub-Saharan Africa the problem of protein-energy malnutrition still exists despite the availability of legumes, such as cowpeas which are a substantial source of affordable protein, B vitamins and minerals (Phillips *et al*., 2003). The utilisation of dried cowpeas is limited in part owing to long cooking times (up to 160 min, CT_{50}[2]), which translates into increased demands on energy and time required for meal preparation (Akinyele *et al*., 1986). These problems are prevalent in southern Africa where dry cowpeas are usually boiled without soaking (Demooy & Demooy, 1990). The cooking time of legumes has been related in general to starch gelatinisation, protein denaturation and degradation of the middle lamella between parenchyma cells of the cotyledon (Sefa-Dedeh & Stanley, 1979a). Gelatinisation of cowpea starch in the cotyledon during cooking is considered to be one of the major physicochemical and structural changes that must occur prior to softening of cowpeas (Liu *et al*., 1993a). Heat-induced denaturation and coagulation of proteins have to occur after starch gelatinisation otherwise it may result in a physical barrier that could restrict water uptake and swelling of the starch granules (Liu *et al*., 1993a). Another major physicochemical and structural change that must occur prior to softening of cowpeas is the disintegration of the middle lamella during cooking of cowpeas. This is evidenced by the separation of cells along the cell wall observed using scanning electron microscopy (Sefa-Dedeh *et al*., 1978; Sefa-Dedeh & Stanley, 1979a).

Cooking of dry cowpeas is a process that involves both rehydration and heating. These two processes may take place simultaneously as in the case of cooking cowpeas without pre-soaking, or rehydration may be done prior to heating through soaking. Therefore, in order to reduce the cooking time of legumes, methods have been proposed that are based on facilitating the gelatinisation of starch by supplying water to the starch granules early in the cooking process, e.g. by soaking in water at 25 °C for different time intervals (Sefa-Dedeh *et al*., 1978; Jackson & Varriano-Marston, 1981) or at elevated temperatures between 45 and 75 °C for 1 h (Taiwo *et al*., 1997b). However, Demooy and Demooy (1990) reported that 12 h of soaking at 15 °C did not significantly reduce the cooking time of cowpeas. Furthermore, legumes such as cowpeas have also been soaked in dilute organic acid or sodium salt solutions in order

[2] CT_{50} . Cooking time determined using a Mattson Bean Cooker using the 50 % cooked stage

to displace calcium ions (Onigbinde & Ojeabulu, 1999). These solutions reduce the formation of calcium pectates in the middle lamella during cooking (Rockland & Jones, 1974). The formation of calcium pectates would limit the desirable cell separation and increase the time required to attain a soft texture.

Another method that has potential of reducing cooking time of legumes is micronisation. Micronisation is an infrared (IR) heat treatment, which when used on moisture-conditioned grains and legumes, has been reported to reduce cooking times by 50 % for Laird lentils (Cenkowski & Sosulski, 1997; Arntfield *et al*., 2001) and 30 % for split peas (Cenkowski & Sosulski, 1998). Reports show that micronisation of preconditioned seeds pregelatinises starch and denature proteins in treated split peas (Cenkowski & Sosulski, 1998) and lentils (Arntfield *et al*., 2001). Physically, micronisation has been shown to increase the rate of rehydration during soaking of IR-treated Pinto beans (*Phaseolus vulgaris*) at 22 °C (Abdul-Kadir *et al*., 1990) and cooking of micronised split peas (Cenkowski & Sosulski, 1998). Although micronisation (17 % moisture, 99 and 107 °C) improved the hydration rate of IR-heated Pinto beans, it also increased the cooking time (Abdul-Kadir *et al*., 1990). Increased cooking time, a hardening of seed texture, and reduced water absorption capacity have also been reported in micronised (17 % moisture, 69, 88 and 90 °C) chickpeas (Sarantinos & Black, 1996). Preliminary trials involving micronisation of moisture-conditioned cowpeas indicated a strong effect of genotype and that the hydrothermal process effectively shortened cooking time. There is a possibility that cowpeas could be processed into a quicker cooking legume, thus reducing energy and time requirements and leading to increased utilisation and consumption.

In order to understand the mechanisms whereby micronisation of moisture-conditioned seeds induces changes in cooking characteristics of legumes, this study examined the effect of micronisation on the structural and physicochemical characteristics of moisture-conditioned cowpeas and the resulting changes in cooking characteristics of two cowpea varieties with different physicochemical characteristics.

3.2.2 Materials and methods

3.2.2.1 Raw materials

During a preliminary study as reported in section 3.1, nine cowpea varieties (from South Africa and Malawi) were screened in terms of their chemical composition, textural properties during cooking, and water absorption during soaking and cooking. Two varieties differing in these physicochemical characteristics were chosen for the study. Cowpea varieties with smooth seed coats; Var. 462 (maroon colour) and Bechuana white (cream colour) were obtained (within 1 month of harvest) from Bunda College of Agriculture in Malawi and Agricol in Potchefstroom, South Africa, respectively. Cowpea samples were cleaned to remove chaff and shrivelled and broken seeds. The cleaned seeds were packed in polypropylene bags and stored at 4 °C until the time of use.

3.2.2.2 The hydrothermal process

The micronisation parameters (moisture content and microniser settings) were selected in order to obtain relatively stable products without burning (Phadi, 2004) as illustrated in Figure 3.2.1. Cowpeas were tempered to approximately 41 % moisture content by steeping in deionised water (1:5 w/v) at 22 °C for 2 h for Var. 462 and 6 h for Bechuana white. The cowpeas were removed from the water, blotted dry on absorbent paper and held for a further 12 h at 22 °C to equilibrate the moisture throughout the seed. The cowpeas were micronised in 160 g batches using a tabletop microniser with three 2 kW Phillips IR lamps (Technilamp Pty, Johannesburg, South Africa) operating at 66.7 % output. The microniser was preheated for 20 min before micronising the cowpeas in a single layer (21 cm from energy source) for 6 min to a final surface temperature of 153 °C. Temperature during micronisation was monitored using thermocouples attached to a Grant Squirrel 800 data logging system (Monitoring and Control Lab, Johannesburg, South Africa). After micronisation the cowpeas were spread on a tabletop and cooled to room temperature for 1 h before being packed in zipper bags (Plastilon Packaging, Pretoria, South Africa) and kept at 22 °C. All samples were analysed within 2 days.

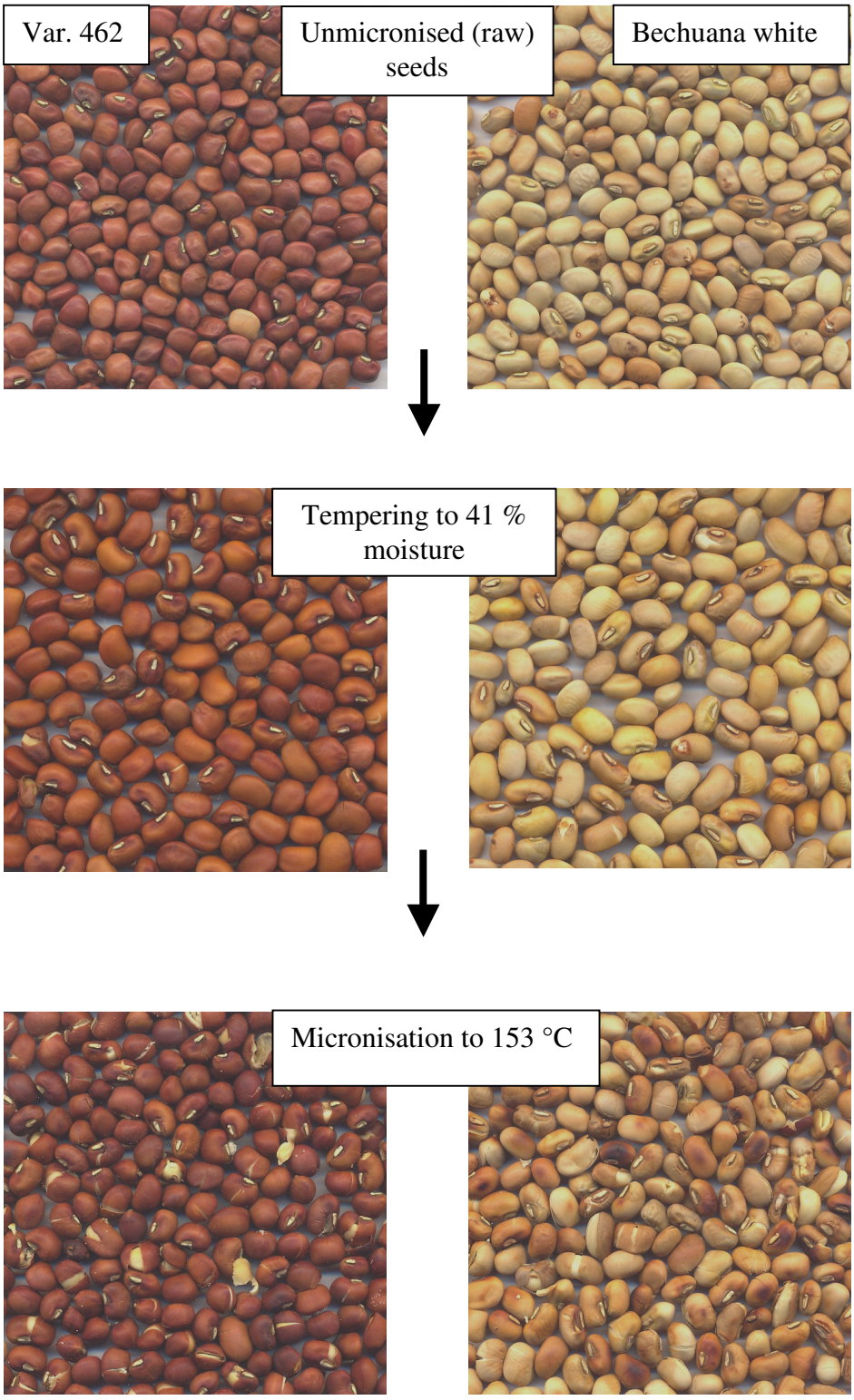

Figure 3.2.1 Flow diagram for the hydrothermal process used in micronising (41 % moisture, 153 °C) cowpea samples

3.2.2.3 Determination of seed moisture content

The moisture content in raw, tempered and micronised (41 % moisture, 153 °C) cowpea seeds was determined according to the method of Ajibola *et al*. (2003) as reported in section 3.1.2.1.

3.2.2.4 Determination of crude protein content

Crude protein content in the cowpeas was determined using the Dumas method as reported in section 3.1.2.2.

3.2.2.5 Determination of protein solubility

Reduction in protein solubility has been associated with denaturation, therefore protein solubility of the samples was determined according to the method of Arntfield *et al*. (1997) with minor modifications. A sample dispersion of 5 % (w/v) in 0.5 M NaCl at pH 7 was centrifuged at 3500 *x g* for 10 min. The nitrogen content in the supernatant was determined using a Leco FP 528 nitrogen analyser (Leco Africa Pty, Kempton Park, South Africa).

3.2.2.6 Determination of total and enzyme-susceptible starch

The total starch content in unmicronised and micronised (41 % moisture, 153 °C) cowpeas was determined according to the method of McCleary, Gibson and Mugford (1997) using the Megazyme total starch assay kit (Megazyme International, Wicklow, Ireland). The method was slightly modified to measure the percentage of enzyme susceptible starch in the uncooked micronised (41 % moisture, 153 °C) and unmicronised cowpeas, which is a measure of starch gelatinisation (Hoover & Manuel, 1996b). Enzyme-susceptible starch was determined by digesting the samples with thermo stable α-amylase and incubating at 37 °C.

3.2.2.7 Determination of seed bulk density

Cowpea seed bulk density was determined according to the method described by Fasina *et al*. (1999). The cowpea seeds were placed in a metal funnel and allowed to flow from 15.5 cm height into a 500 ml metal cup. The grains were levelled without pressing with a metal scraper. The ratio of the weight of sample in the metal cup to the volume of the cup was expressed as kg m^{-3} and recorded as bulk density.

3.2.2.8 Determination of water absorption during soaking and hydration capacity

Water absorption during soaking was determined according to a modified method of Agbo *et al*. (1987) as reported in section 3.1.2.4. The amount of water (g) absorbed by 10 g of cowpeas after 18 h of soaking reflected the hydration capacity (g water kg^{-1} cowpeas) as reported by Wang, Daun and Malcolmson (2003).

3.2.2.9 Determination of water absorption during cooking

The amount of water absorbed during cooking was determined according to a modified method of Cenkowski and Sosulski (1997) as reported in section 3.1.2.5. The boiled cowpea samples were then used to determine splitting and texture.

3.2.2.10 Determination of splitting during cooking

The tendency of seeds to split during cooking was determined according to the method of van Buren *et al*. (1986) as reported in section 3.1.2.6.

3.2.2.11 Determination of seed texture during cooking

Texture was measured as the work (area under the curve, N mm) done to cut individual cowpea seeds through a distance of 5 mm at a speed of 4 mm s^{-1} based on the method of Sefa-Dedeh *et al*. (1978). A TA-XT2 texture analyser (Stable Micro Systems, Godalming, UK) with A/CKB craft knife adapter mounted with Hilite® heavy-duty blades (Hilite Hardware, Pretoria, South Africa) was used to measure texture. A single cowpea seed was positioned on its side and cut below the hilium along the cross-section. The blade was replaced after 5 determinations. For each sample of unmicronised and micronised (41 % moisture, 153 °C) cowpeas cooked for 15, 30, 45, 60, 75 and 90 min, 10 seeds were measured.

3.2.2.12 Determination of cooking time

A custom made Mattson bean cooker (Pretoria, South Africa) as described by Wang *et al*. (2003) was used to determine the cooking time of micronised (41 % moisture, 153 °C) and unmicronised cowpea samples. For each test sample, 25 cowpea seeds were positioned in the perforations of the cooker and placed in an aluminium pan with 1500 ml of deionised water and cooked. The cooking time of the cowpeas was recorded as the moment when 80 % of the pins had fallen through the softened seeds.

3.2.2.13 Scanning electron microscopy (SEM)

Scanning electron microscopy (SEM) of cowpea samples (unmicronised, micronised (41 % moisture, 153 °C), unmicronised samples cooked for 30 and 60 min, micronised (41 % moisture, 153 °C) samples cooked for 15 and 30 min) was conducted according to the method of Sefa-Dedeh and Stanley (1979a) with modifications. These cooking times represent half-cooked and fully cooked stages of unmicronised and micronised (41 % moisture, 153 °C) samples, respectively. Cowpea samples (3 seeds) were fixed in 2.5 % glutaraldehyde in 0.075 mol L^{-1} phosphate buffer, pH 7.4, for 24 h at 4 °C. The samples were then rinsed three times using the same buffer at 15 min intervals. Dehydration of the samples was accomplished by 20 min sequential changes in 50, 70, 90 % ethanol followed by three 20 min changes in 100 % ethanol. The samples were dried using the critical point drying technique and mounted on aluminium stubs with the aid of double-sided carbon tape, followed by coating with gold. The coated samples were viewed and photographed using a JSM-840 scanning electron microscope (JEOL, Tokyo, Japan) at an accelerating voltage of 5.0 kV.

3.2.2.14 Enzyme digestion and environmental scanning electron microscopy (ESEM)

In order to elucidate the presence of protein and pectic substances outside the parenchyma cells, the control cowpea seeds were cooked for 30 min and digested with pectinase or protease. The cooked cowpea seeds were cut in half across the hilum. A sample was digested for 1 h in 2 ml of pectinase (Pectinase from Rhizopus Sp, CAS No. 9032-75-1, Sigma Inc, St Louis Missouri) at room temperature while another sample was digested in 10 ml of protease (1g ml^{-1}, Sigma EC 232-752-2, in pH 7.5 phosphate buffer) for 1 h at 37 °C. The cooked seeds were mounted onto 13 mm diameter aluminium stubs using double adhesive tape. Samples were viewed and photographed using an environmental scanning electron microscope (ESEM, Electroscan model E-3, Wilmington, MA) at an accelerating voltage of 15.0 kV following the method reported by McDonough and Rooney, 1999.

3.2.2.15 Statistical analysis

The experimental work was conducted on duplicate samples and repeated three times to generate data that were analysed using Statistica version 6.0 (StatSoft Inc, Tulsa,

USA). Analysis of variance (ANOVA) of the (2 x 2)-factor experiment was used to evaluate the data based on a 5 % level of significance. When the F-test was significant, differences between means were determined using the least significant difference (LSD) test. Two-dimensional regression was used to determine correlations between texture, splitting and water absorbed at 15 min intervals, from 15 min to 90 min of cooking. The regression was tested for significance at 5 %.

3.2.3 Results and discussion

3.2.3.1 Soaking and hydration characteristics

Var. 462 cowpeas had a significantly ($P \leq 0.01$) higher uptake of water than Bechuana white cowpeas (Figure 3.2.2) during 6 h of soaking. After 6 h of soaking, unmicronised Var. 462 cowpeas absorbed 1130 g water kg^{-1}, which was significantly ($P \leq 0.05$) higher than 532 g water kg^{-1} absorbed by Bechuana white cowpeas.

The hydration capacity of Var. 462 cowpeas was also significantly ($P \leq 0.05$) higher than that of Bechuana white cowpeas (Table 3.2.1). Water imbibition during soaking of legumes such as cowpeas and beans is a process that is related to physical characteristics of the seed and its component macromolecules, specifically proteins (Sefa-Dedeh & Stanley, 1979b). Var. 462 cowpeas had significantly ($P \leq 0.05$) higher crude protein content than Bechuana white cowpeas, although the percentage of soluble protein was similar (Table 3.2.1). Protein is one of the major macromolecules in cowpeas. Proteins are considered to play a major role in water absorption during soaking (Sefa Dedeh & Stanley, 1979b) hence Var. 462 showed higher water absorption than Bechuana white cowpeas (Figure 3.2.2).

In addition to variations in protein content, Var. 462 cowpeas had a significantly lower bulk density than Bechuana white cowpeas (Table 3.2.1). The lower bulk density implied that there were more air spaces in Var. 462 than in Bechuana white cowpeas. The SEM micrographs of the cotyledon structure of unmicronised Var. 462 cowpeas (Figure 3.2.3 (a)) showed loosely packed cells with larger intercellular spaces as compared to the compact cotyledon structure of Bechuana white cowpeas (Figure 3.2.3 (b)).

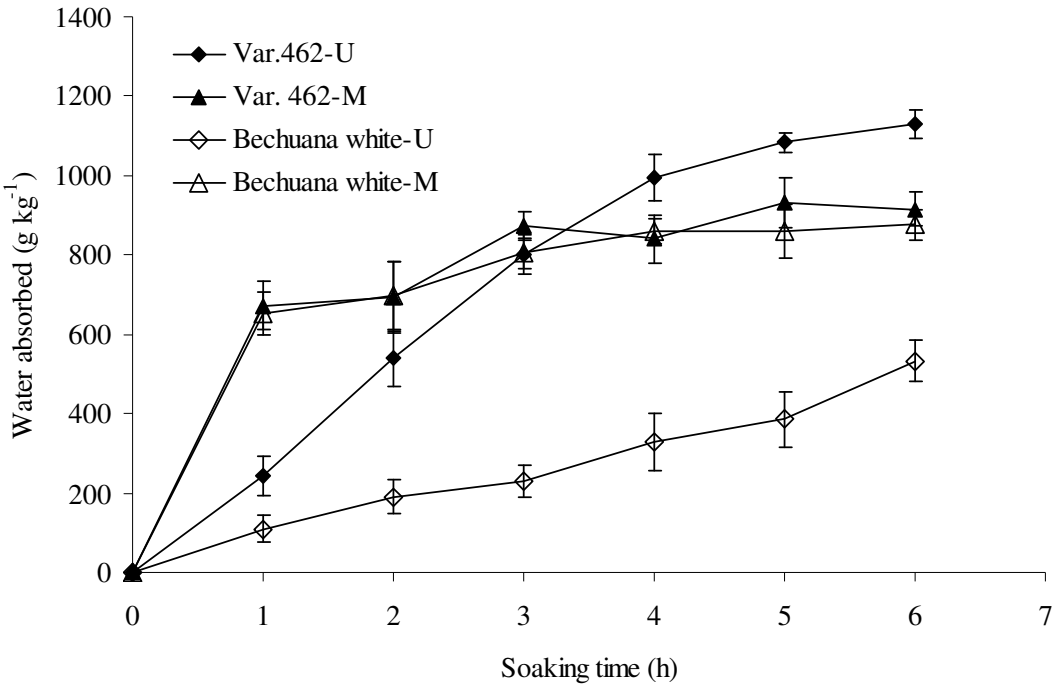

Figure 3.2.2 Effect of micronisation (41 % moisture, 153 °C) on water absorption during the soaking of Var.462 and Bechuana white cowpeas at 22 °C (vertical bars indicate standard deviations of the means, and U = Unmicronised (raw), M = Micronised (41 % moisture, 153 °C))

This difference in cotyledon structure could be responsible for the difference in water uptake patterns of the two cowpea samples when soaked at 22 °C (Sefa Dedeh and Stanley, 1979b). The initial rapid water uptake during soaking at room temperature has been reported to be due to the filling up of free capillary and intercellular spaces (Phlak *et al*., 1989), hence Var. 462 with more capillary and intercellular spaces showed a higher water uptake during the 6 h of soaking than Bechuana white cowpeas.

Table 3.2.1 Effect of variety and micronisation (41 % moisture, 153 °C) on physicochemical properties of cowpea seeds

Physicochemical characteristics	Var. 462		Bechuana white	
	[y]Unmicronised	[z]Micronised	[y]Unmicronised	[z]Micronised
Moisture ($g\ kg^{-1}$)	117^{b} (0.8)	157^{a} (25.6)	89^{c} (3.8)	123^{b} (21.5)
*Crude protein ($g\ kg^{-1}$ db)	257^{b} (2.4)	277^{a} (8.6)	240^{c} (1.8)	262^{b} (6.5)
Protein solubility (%)	85^{a} (8.9)	33^{b} (6.5)	88^{a} (7.0)	34^{b} (10)
*Starch ($g\ kg^{-1}$ db)	439^{b} (17)	489^{a} (30)	445^{b} (23)	459^{b} (22)
ESS (%)	14^{d} (1)	86^{a} (3.1)	21^{c} (6.8)	68^{b} (2.8)
Bulk density ($kg\ m^{-3}$ db)	801^{b} (2.6)	638^{d} (11.7)	870^{a} (4.4)	658^{c} (9.2)
Cooking time (min)	59^{a} (0.2)	38^{b} (2.4)	57^{a} (1.9)	32^{c} (6.9)
Hydration capacity ($g\ kg^{-1}$ cowpeas db)	1341^{a} (30)	975^{c} (26)	1179^{b} (55)	928^{c} (50)

ESS= Enzyme-susceptible starch; [y]Unmicronised (raw), [z]Micronised (41 % moisture, 153 °C); means followed by the same letter within a row are not significantly different at level $P \leq 0.05$; standard deviation of the means are in parenthesis; * = The increase in these values does not reflect the effect of micronisation

3.2.3.2 Cooking characteristics

Cooking time of the unmicronised cowpeas was not significantly different between the two varieties, as determined by the Mattson bean cooker (Table 3.2.1). These cooking time values are within the ranges (36 to 56 min) reported by Demooy and Demooy (1990) for 7 unsoaked cowpea varieties. Cooking time refers to the time required for the cowpeas to attain a level of softness, a textural parameter.

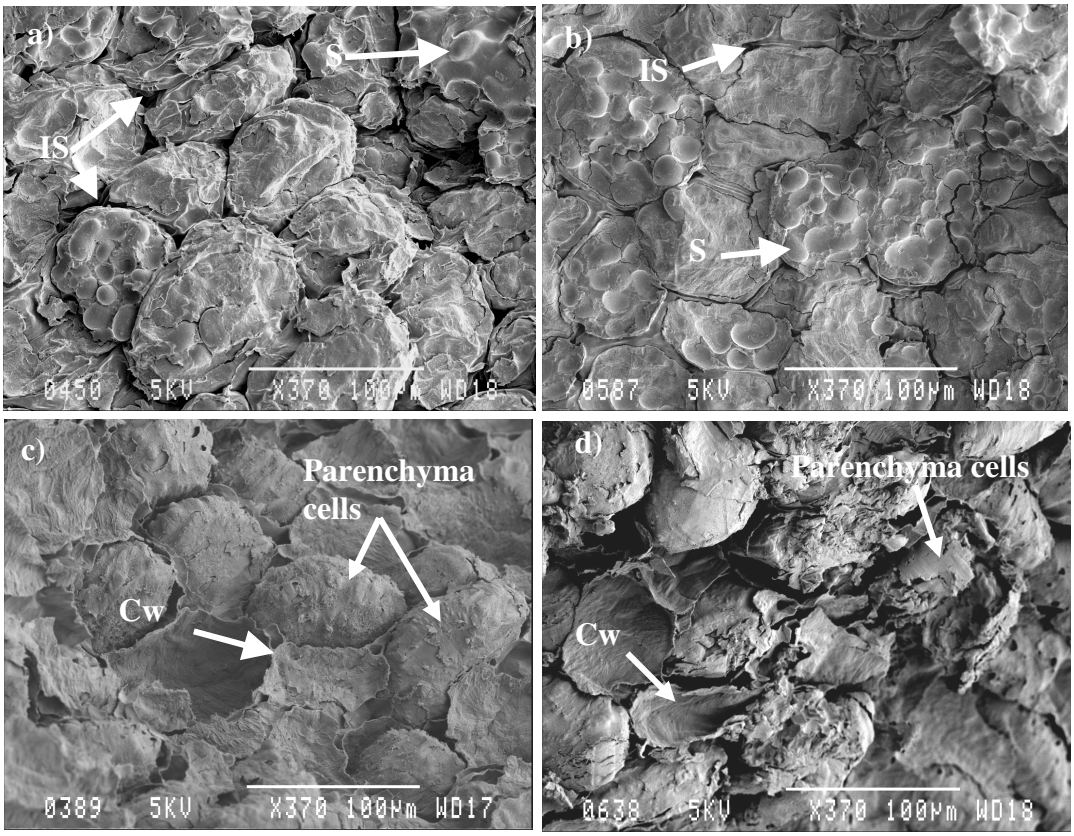

Figure 3.2.3 Varietal differences and micronisation (41 % moisture, 153 °C) effect on the cotyledon structure of two cowpea varieties: cotyledon cross-section of raw Var. 462 (a); raw Bechuana white (b); micronised Var. 462 (c); micronised Bechuana white (d); Cw = Cell wall, IS = Inter- cellular space, S = Starch granule

The texture (work required to cut through a seed) of the two cowpeas varieties became increasingly softer with increasing cooking time (Figure 3.2.4). This is not surprising since there was a significant ($P \leq 0.0001$) negative correlation between cooking time and texture (Var. 462 cowpeas, $r = -0.90$; Bechuana white cowpeas, $r = -0.88$). The decrease in work required to cut through the seed may be related to the separation of cotyledon parenchyma cells.

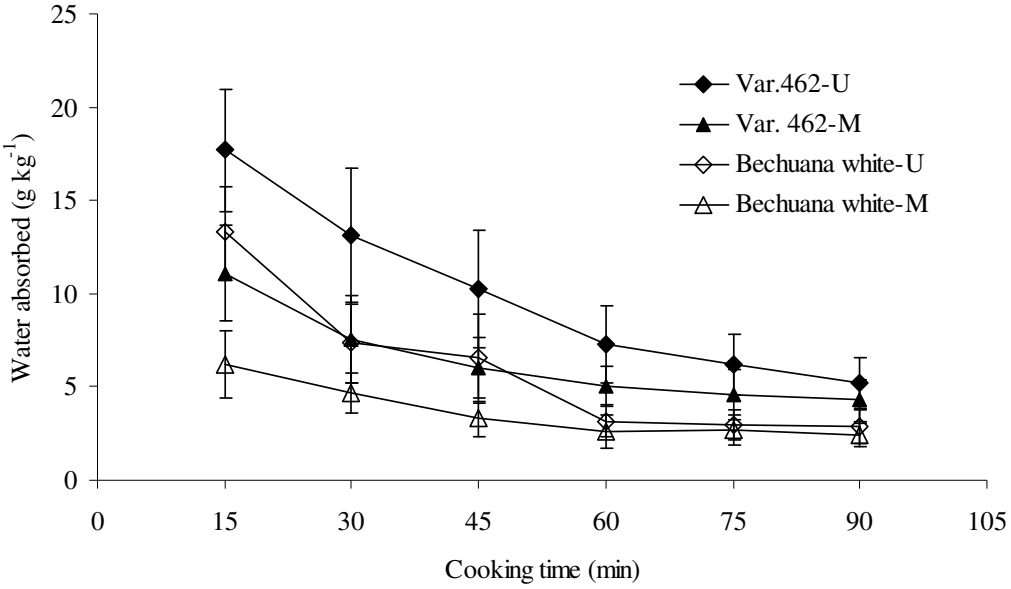

Figure 3.2.4 Effect of micronisation (41 % moisture, 153 °C) on the texture (work in Nmm) of Var. 462 and Bechuana white cowpeas during 90 min of cooking (vertical bars indicate standard deviations of the means and U= Unmicronised (raw) and M = Micronised (41 % moisture, 153 °C))

The disintegration of the middle lamella of the cells that were cemented together is shown in Figures 3.2.5(a), 3.2.5(b), 3.2.5(e) and 3.2.5(f). Earlier researchers have also observed that the disintegration of the middle lamella corresponds to the softening of cowpeas during cooking (Sefa Dedeh & Stanley 1979a). The disintegration of the middle lamella in cowpea cotyledon cells probably allows the cells to separate readily during mechanical fracturing, resulting in a softer texture.

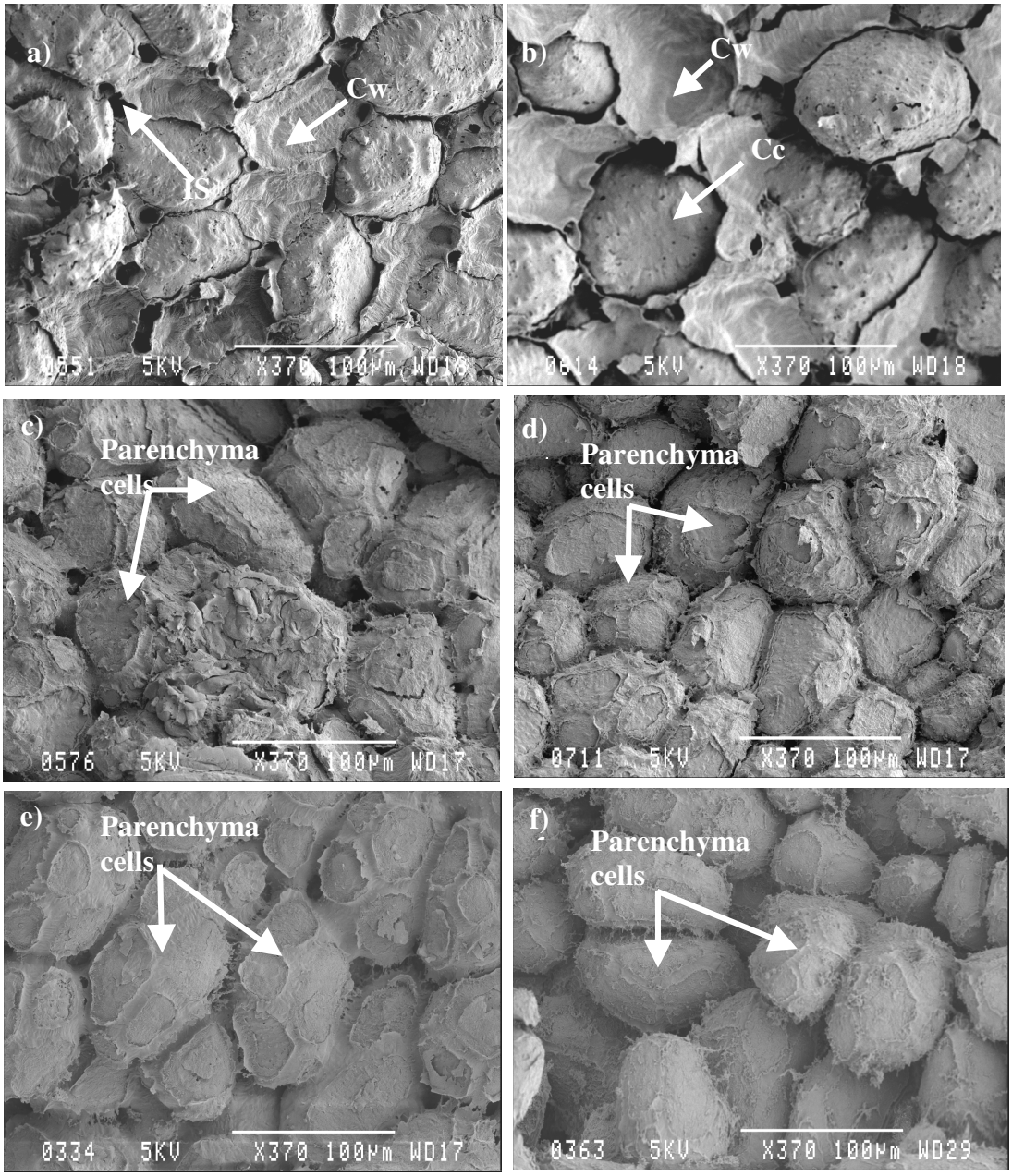

Figure 3.2.5 **Cotyledon cross sections of unmicronised (raw) and micronised (41 % moisture, 153 °C) cowpeas at half cooked and fully cooked stages: 30 min cooked unmicronised (a) Var. 462 and (b) Bechuana white; 15 min cooked micronised (c) Var. 462 and (d) Bechuana white; 60 min cooked micronised (e) Var. 462 and (f) Bechuana white; 30 min cooked micronised (g) Var. 462 and (h) Bechuana white; Cw = Cell wall; Cc = Cellular contents; and IS = intercellular spaces**

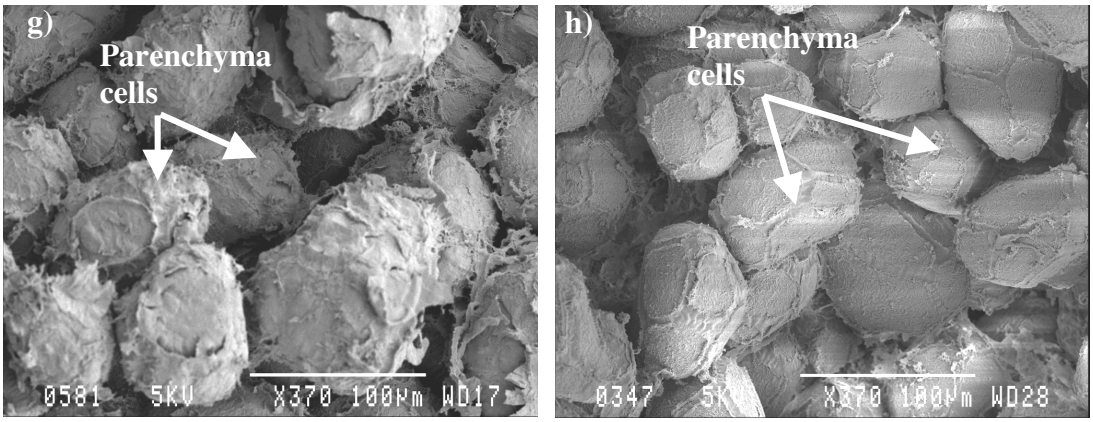

Figure 3.2.5 Continued

In addition to the solubilisation of the middle lamella during cooking, it appears that protein gelation outside the cell also provides some form of adhesive between the cells after cooking. Through the use of ESEM in combination with enzyme digestion it was evident that protein material was present outside the cells (Figure 3.2.6 (a), 3.2.6 (b) & 3.2.6 (c)) and was digested by proteinase.

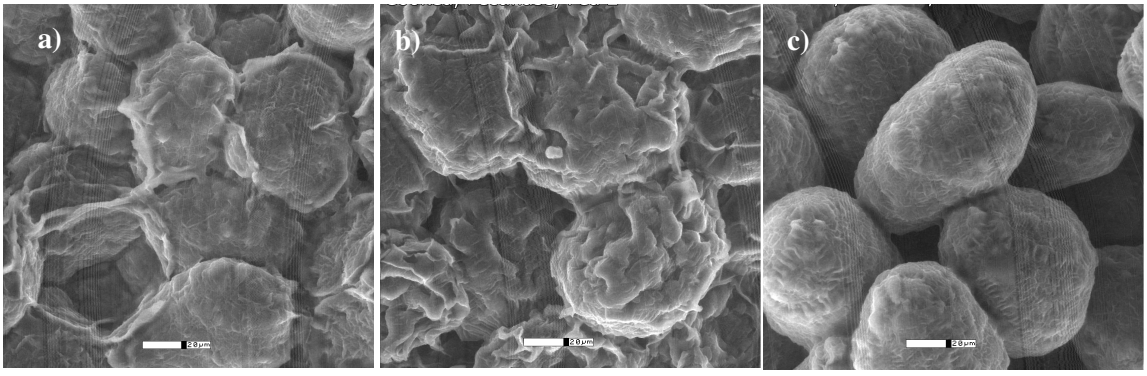

Figure 3.2.6 Environmental scanning micrographs (ESEM) of unmicronised (raw) cowpea seed cotyledon cooked for 30 min showing the effect of enzyme digestion: (a) no enzyme treatment, (b) pectinase, (c) proteinase; bar =20 µm

Unmicronised Bechuana white cowpeas had a significantly softer texture than unmicronised Var. 462 cowpeas after 60 min of cooking, which is close to the cooking times determined using the Mattson bean cooker which were 59 and 57 min, respectively (Tables 3.2.1 & 3.2.2). Differences in the cooked texture of cowpeas were also reported by Demooy and Demooy (1990), where some cowpea varieties had a smooth mushy texture with a softened seed coat when cooked. This was observed with Bechuana white cowpeas. Other cowpeas are reported to have a tough seed coat even after the cotyledon has become soft and mushy (Demooy & Demooy, 1990). This pattern was observed with cooked Var. 462 cowpeas.

Table 3.2.2 Effect of variety and micronisation (41 % moisture, 153 °C) on cooking characteristics of cowpeas after 60 min of cooking

Variety	Micronisation	Water uptake (g H_2O kg^{-1} seed)	Texture (N mm)	Splits (%)
Var. 462	[y]Unmicronised	1140^{c} (62)	7.3^{a} (2.0)	2.2^{d} (1.2)
	[z]Micronised	1248^{b} (92)	5.0^{bc} (1.1)	34.4^{c} (4.9)
Bechuana	[y]Unmicronised	1390^{a} (22	3.2^{c} (0.9)	45.3^{b} (9.2)
white	[z]Micronised	1292^{b} (89)	2.6^{d} (0.9)	61.9^{a} (7.6)

[y]Unmicronised = raw; [z] = Micronised (41 % moisture, 153 °C); means followed by the same letter within a column are not significantly different at level $P \leq 0.05$; standard deviations of the means are in parenthesis

The difference in the texture of cooked unmicronised Var. 462 and Bechuana white cowpeas could also possibly be due to the significantly higher amounts of water absorbed during cooking by Bechuana white cowpeas (Figure 3.2.7). During the initial 15 min of cooking, there was no difference in amount of water absorbed between the two varieties. Thereafter, unmicronised Bechuana white cowpeas absorbed more water than unmicronised Var. 462 cowpeas. Availability of water in the cotyledon facilitates heat transfer and is necessary for starch gelatinisation during cooking (Arntfield *et al*., 1997).

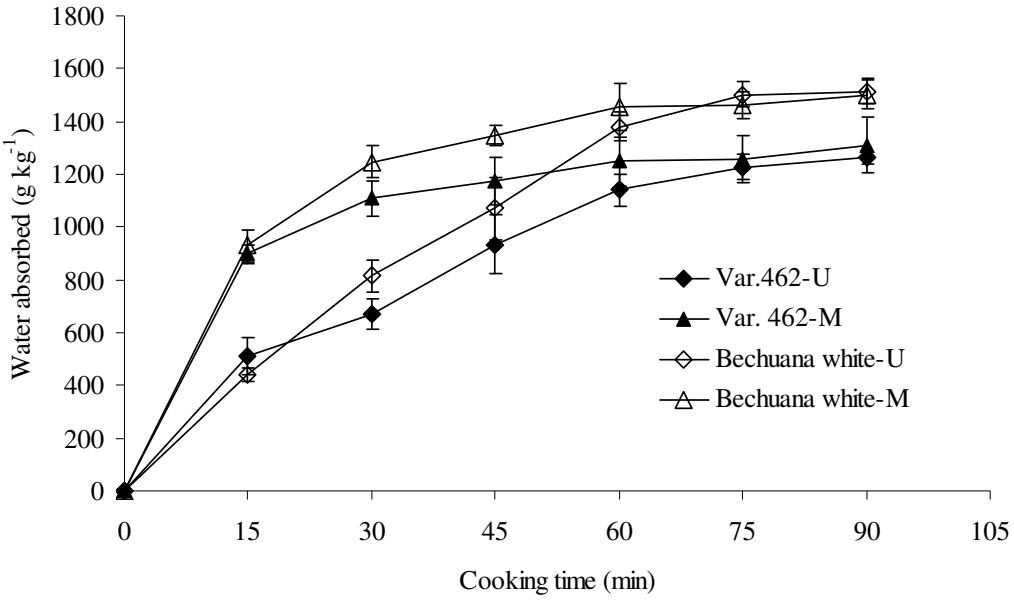

Figure 3.2.7 Effect of micronisation (41 % moisture, 153 °C) on water absorption during 90 min of cooking Var. 462 and Bechuana white cowpeas (vertical bars indicate standard deviations of the means, U = Unmicronised (raw), M= Micronised (41 % moisture, 153 °C))

Although unmicronised Var. 462 cowpeas absorbed more water during soaking at 22 °C (Figure 3.2.2), Bechuana white cowpeas absorbed more water during cooking (Figure 3.2.7). Bechuana white cowpeas had higher ($P \leq 0.05$) enzyme-susceptible starch content than Var. 462 cowpeas (Table 3.2.1), and the greater amount of damaged starch may have contributed to increased water absorption.

High water absorption by cowpeas during cooking has also been associated with increased incidence of splits (Taiwo *et al*., 1998). After 15 min of cooking, unmicronised Bechuana white cowpeas had significantly ($P \leq 0.05$) more splits than Var. 462 cowpeas (Figure 3.2.8). The percentage of split cowpeas for both varieties correlated ($r= 0.73$; $P \leq 0.05$) with water absorption during cooking.

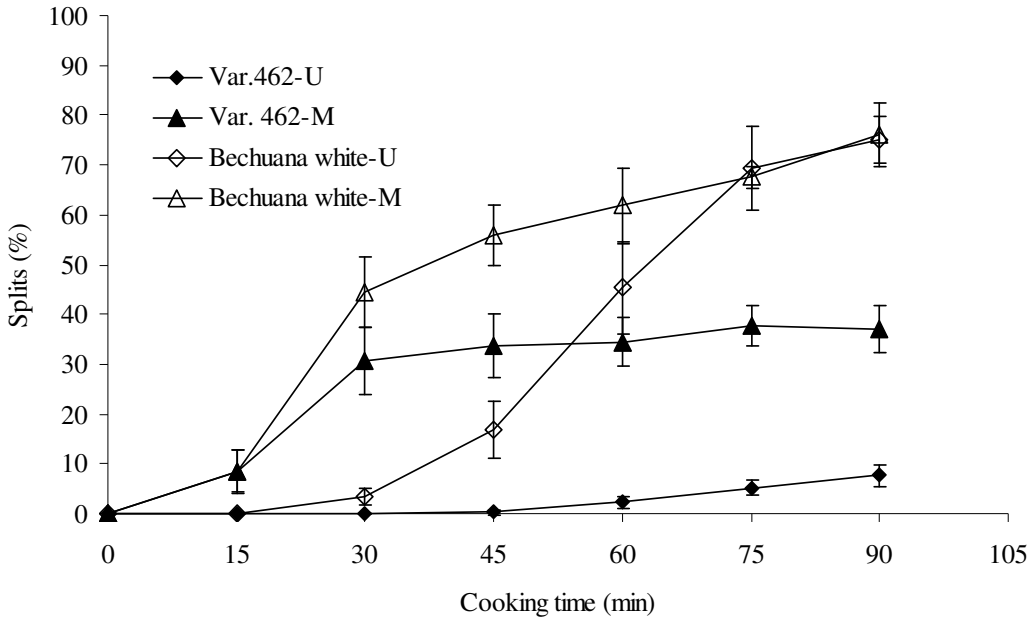

Figure 3.2.8 Effect of micronisation (41 % moisture, 153 °C) on splitting of Var. 462 and Bechuana white cowpeas during 90 min of cooking (vertical bars indicate standard deviations of the means; U = Unmicronised (raw); M = Micronised (41 % moisture, 153 °C))

The pattern of splitting in unmicronised cowpeas seemed to start with cracking of the seed coat through to the cotyledon transversely below the hilum (Figure 3.2.9) or along the edges resulting in the separation of the two cotyledons.

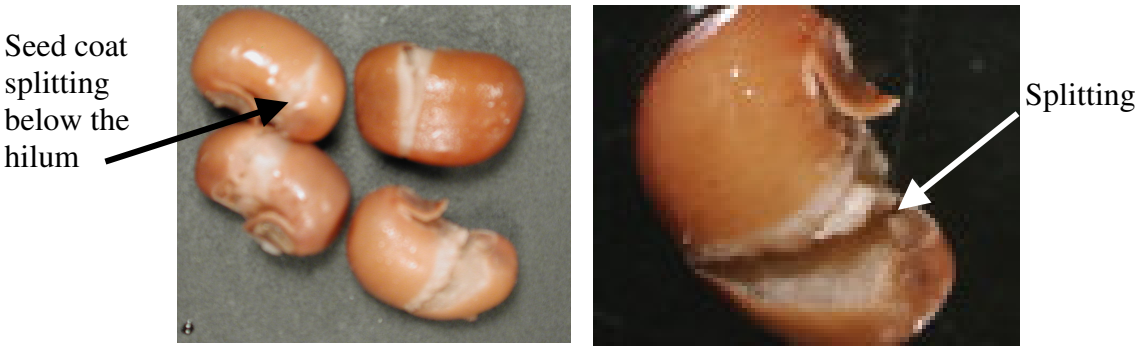

Figure 3.2.9 Cooked Bechuana white (unmicronised) seeds showing the pattern of splitting during cooking

Taiwo *et al*. (1997b) reported a similar pattern of splitting in cowpeas. Moreover, Taiwo *et al*. (1998) reported that % splits in cowpeas increased with softening texture and increasing drained weight of cooked cowpeas. The % splits in unmicronised Bechuana white cowpeas was negatively correlated with texture ($r= -0.81$; $P \leq 0.001$) and positively correlated with water uptake during cooking ($r= 0.92$; $P \leq 0.001$). Water uptake during cooking results in increased volume as the cotyledon cells absorb more water and expand. The expanding cells require more space and the continuity of the testa and/or cotyledon is compromised or broken. Bechuana white cowpeas had higher bulk density initially and higher water uptake during cooking; therefore the dense seeds expanded and transversal splitting of cotyledons occurred during cooking (Table 3.2.2). Conversely, Var. 462 cowpeas were less dense, had lower water uptake during cooking and showed less disruption in the integrity of the cotyledon and testa during cooking (Table 3.2.2). Similarly, Heil, McCarthy and Özilgen (1992) observed that the splitting tendency in beans (*Phaseolus vulgaris*) increased with increasing seed density.

It was observed that the split Bechuana white cowpeas tended to form lumps during extended cooking, a phenomenon that was previously reported in cowpeas (Taiwo *et al*., 1997b). The lumps consisted of several split and non-split cowpeas. The functionality of the major components of cowpeas changes during cooking, i.e. starch is being gelatinised and proteins are being denatured becoming less extractable. It is postulated that starch dispersion and retrogradation could result in aggregation of the split and non split cowpeas.

3.2.3.3 Effect of micronisation (41 % moisture, 153 °C) on soaking and hydration characteristics of cowpeas

The hydrothermal treatment increased the amount of water absorbed at 22 °C during the first hour of soaking in both varieties (Figure 3.2.2). The distinctive rapid increase in water uptake during the first hour of soaking is due to fissures in the seed coat integuments (compare Figures 3.2.10(a), to 3.2.10(l)) and the significant ($P \leq 0.05$) reduction in bulk density of micronised (41 % moisture, 153 °C) seeds (Table 3.2.1). In unmicronised cowpeas the seed coat is the first barrier to water transfer into the cotyledon (Sefa-Dedeh & Stanley, 1979b; Fasina *et al*., 1999).

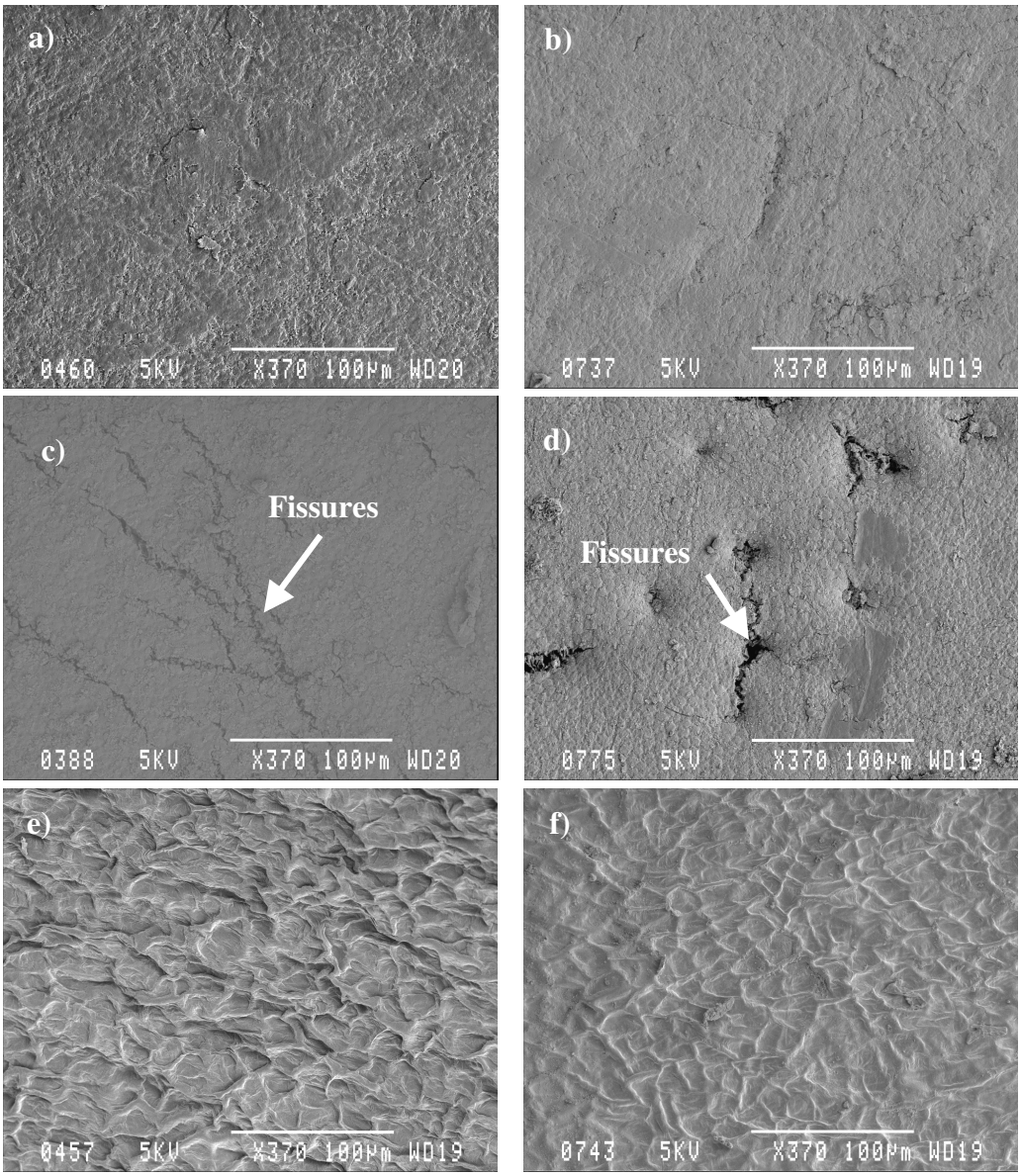

Figure 3.2.10 Effect of micronisation (41 % moisture, 153 °C) on structure of cowpea seed coat layers: outer surface of unmicronised (a) Var. 462 and (b) Bechuana white; outer surface of micronised (c) Var. 462 and (d) Bechuana white; inner surface of outer integument of unmicronised (e) Var. 462 and (f) Bechuana white, inner surface of outer integument of micronised (g) Var. 462 and (h) Bechuana white; outer surface of inner integument of unmicronised (i) Var. 462 and (j) Bechuana white; outer surface of the inner integument of micronised (k) Var. 462 and (l) Bechuana white; Unmicronised = raw; Micronised = 41 % moisture, 153 °C

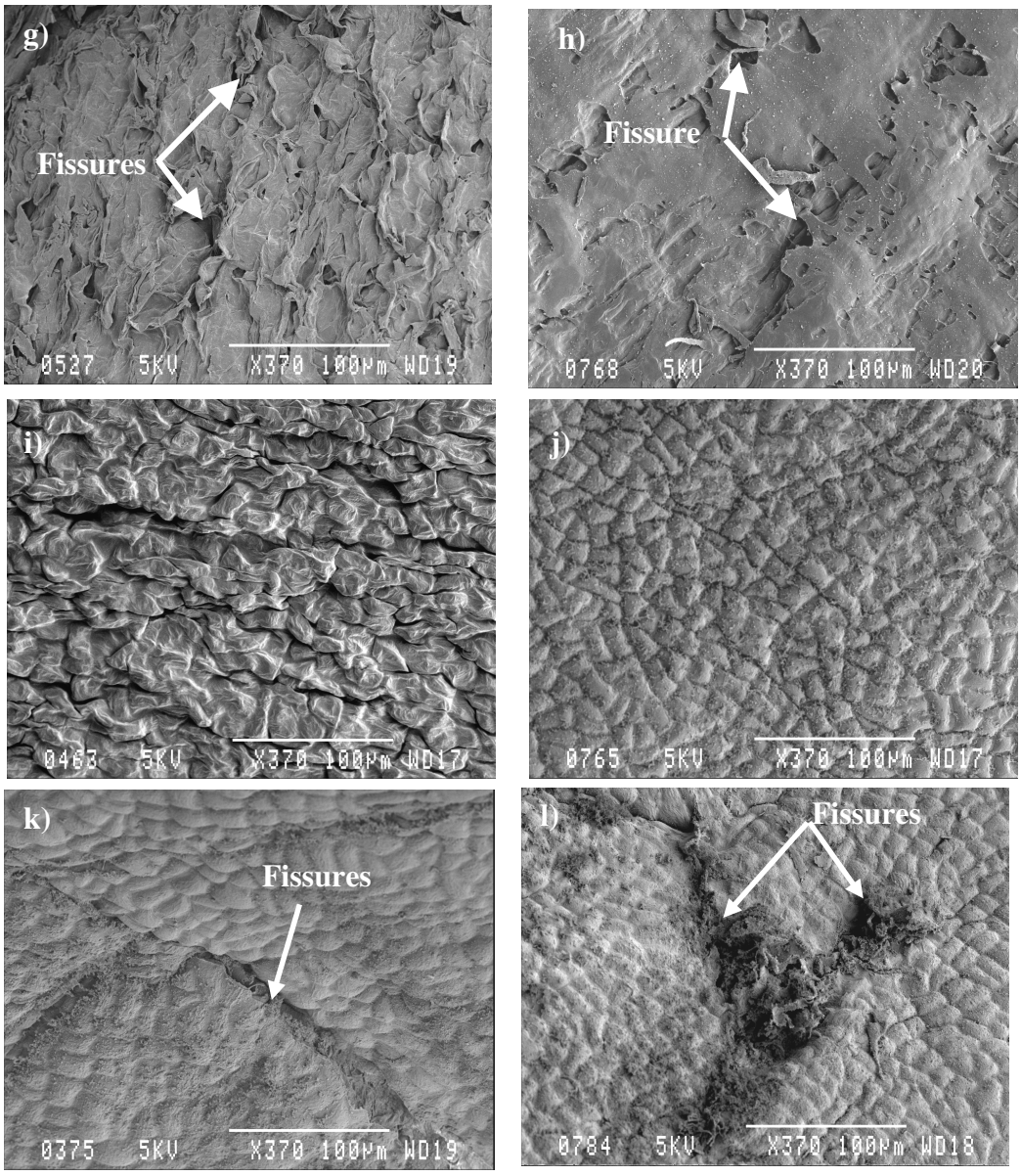

Figure 3.2.10 Continued

However, the seed coat is no longer intact in micronised (41 % moisture, 153 °C) cowpeas (Figures 3.2.10(c), 3.2.10(d), 3.2.10(g), 3.2.10(h), 3.2.10(k) and 3.2.10 (l)). Water has increased access into the cotyledon, which is fissured and has cavities (Figure 3.2.11). The presence of cavities and channels in the cotyledon was suggested by the decreased bulk density of micronised (41 % moisture, 153 °C) cowpeas (Table 3.2.1). Also, the contents of cotyledon cells are clumped together and detached from the cell wall, revealing spaces in most cells not filled with solids. Abdul-Kadir *et al.*

(1990) also reported significant increases in water absorption during 8 h of soaking (22 °C) of micronised (17 % moisture, 99, 107 °C) Pinto beans.

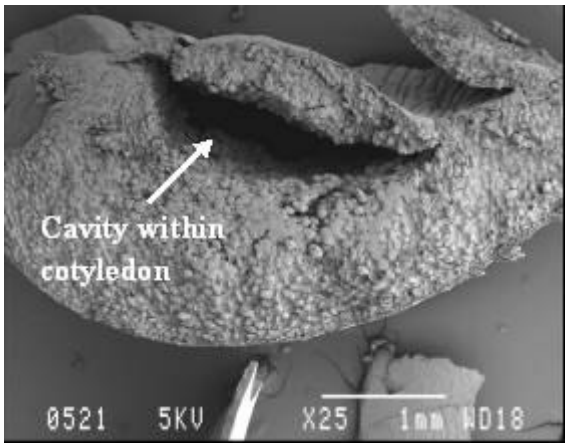

Figure 3.2.11 Formation of a cavity in the cotyledon of micronised (41 % moisture, 153 °C) cowpea seed

The hydration capacity of hydrothermally treated cowpeas was reduced by 20-25 % compared to unmicronised cowpeas (Table 3.2.1). Micronisation has been shown to reduce the hydrophilicity of legume proteins owing to unfolding of protein molecules thereby exposing hydrophobic sites (Zheng *et al*., 1998). Significant reductions in protein solubility for micronised (41 % moisture, 153 °C) cowpea seeds were observed in this study (Table 3.2.1). Cowpea protein from untreated seeds is highly hydrophilic (Mwasaru *et al*., 1999a) and contributes to water imbibition during soaking of cowpeas (Sefa Dedeh & Stanley, 1979b). The reduction in hydration capacity was possibly not due to shrinkage of stomata-like cells as was suggested by Fasina *et al*. (1999) for soaked, micronised barley.

3.2.3.4 Effect of hydrothermal treatment on cooking characteristics

Micronisation (41 % moisture, 153 °C) significantly ($P \leq 0.05$) reduced cooking time of the two cowpea varieties (Table 3.2.1). Cooking time was reduced by 44 % for Bechuana white cowpeas and 36 % for Var. 462 cowpeas. The reduction in cooking time concurs with the results on texture (work to cut through a seed) of the cooked cowpeas. For example, micronised (41 % moisture, 153 °C) Bechuana white cowpeas

required 4.7 N mm to cut through the seeds after approximately 30 min of cooking. Unmicronised Bechuana white cowpeas required 3.2 N mm to cut through the seeds after 60 min cooking. Cooked Bechuana white cowpeas were softer (required less work to cut) than cooked Var. 462 cowpeas. This means that the Var. 462 cowpeas yielded a harder texture (structure) after cooking with or without micronisation (41 % moisture, 153 °C), even though the seeds had lower density (Table 3.2.1).

Overall, the micronised (41 % moisture, 153 °C) cowpeas had a significantly softer texture than unmicronised cowpeas when cooked for the same length of time (Figure 3.2.4). Arntfield *et al*. (2001) indicated that micronised (33 % moisture, 138 and 170 °C) lentils required shorter time to reach acceptable hardness values for cooked lentils. The significant increase in enzyme-susceptible starch in micronised (41 % moisture, 153 °C) cowpeas (Table 3.2.1) probably contributed to the reduced cooking time. The microstructure of micronised (41 % moisture, 153 °C) cowpeas cooked for 15 min (half cooked stage) was similar to that of untreated cowpeas cooked for 30 min (half cooked stage) (Figure 3.2.5). Similarly, micronised (41 % moisture, 153 °C) samples attained a fully cooked microstructure after 30 min of cooking as compared with the 60 min required for untreated samples.

Since texture is an expression of structural, mechanical and surface properties of foods (Szczesniak, 2002), the loose and porous structure formed in some parts of the cotyledon during micronisation (41 % moisture, 153 °C) of cowpeas is weaker than the compact structure that is observed in unmicronised seeds (Figures 3.2.3(a); 3.2.3(b) & Figure 3.2.12), resulting in an overall softer texture in micronised (41 % moisture, 153 °C) seeds. This increased porosity of the cotyledon probably led to the higher rate of water absorption during both soaking and cooking of micronised (41 % moisture, 153 °C) cowpeas (Figures 3.2.2 & 3.2.7).

Comparison of SEM micrographs of moisture-conditioned Var. 462 and Bechuana white cowpeas micronised to 153 °C and soaked in water for 3 h (Figures 3.2.13(a) & 3.2.13(b)) shows marked cell separation along the middle lamella and the presence of cell wall remnants, which is similar to patterns reported in the cotyledon of lentils micronised to 138 °C (Arntfield *et al*., 2001) and in cooked cowpea cotyledon (Rockland & Jones, 1974; Sefa Dedeh *et al*., 1978).

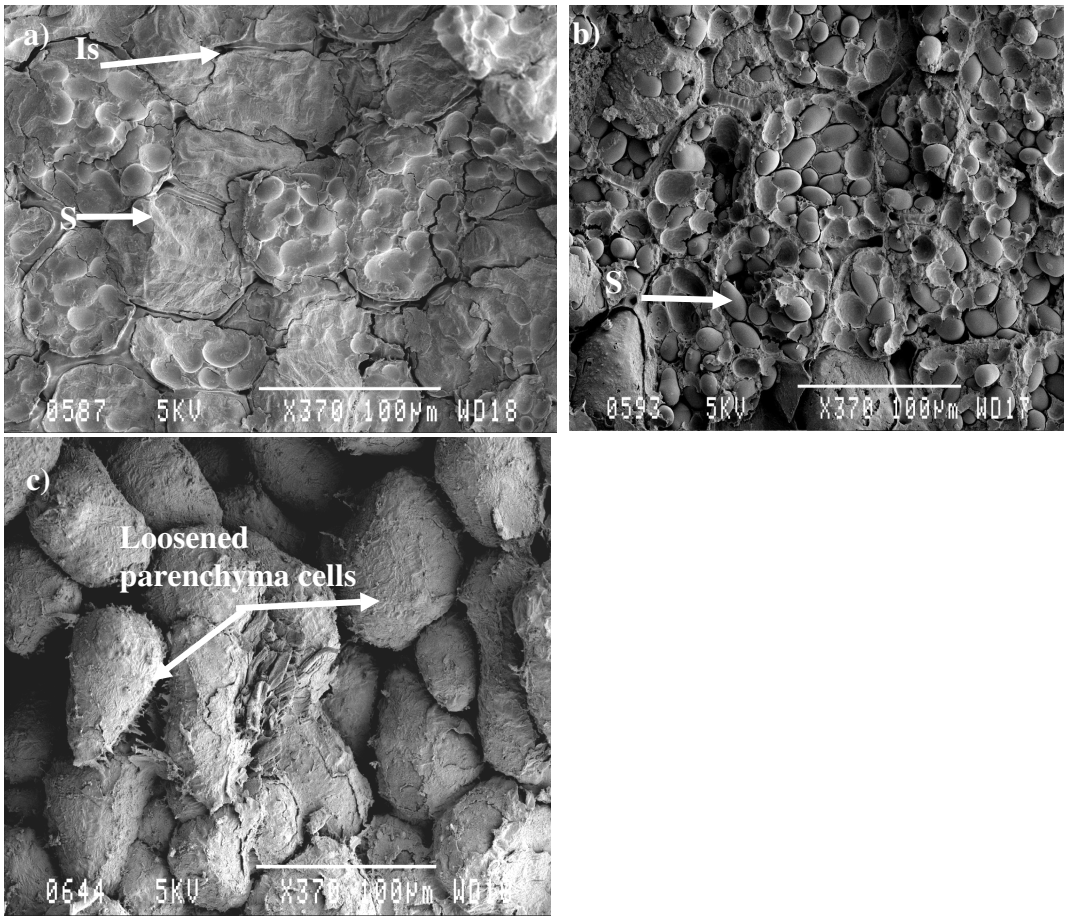

Figure 3.2.12 Cotyledon cross section of Bechuna white cowpea showing separation of parenchyma cells following micronisation; (a) unmicronised, (b) moisture-conditioned and (c) micronised (41 % moisture, 153 °C)

Cell separation could be an indication of solubilisation of pectic substances leading to the disintegration of the middle lamella (Rockland & Jones, 1974). These results might imply that micronisation to 153 °C solubilises or breaks down the pectic substances of the middle lamella into water-soluble fractions and contributes to shorter cooking times. This postulation was not supported by Arntfield *et al*. (2001) where a non-significant increase in soluble pectins was observed in lentils micronised to 138 and 170 °C.

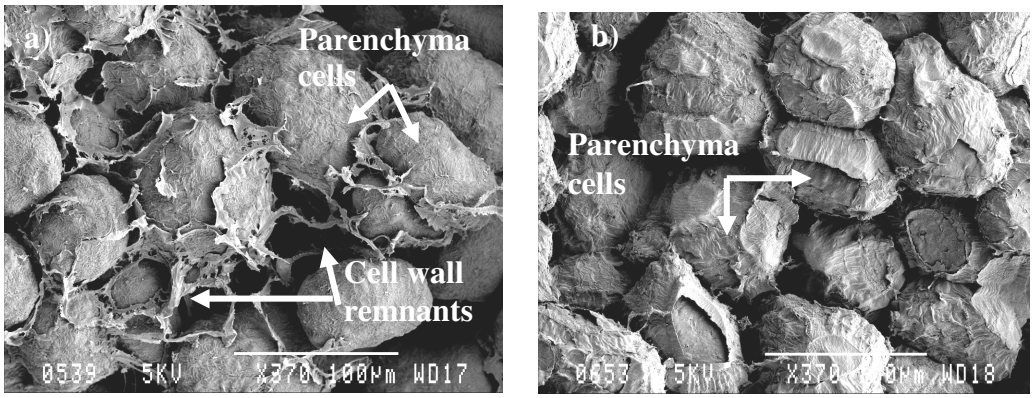

Figure 3.2.13 Varietal differences and micronisation (41 % moisture, 153 °C) effect on the cotyledon structure of two cowpea varieties: cotyledon cross section of micronised (41 % moisture, 153 °C) and soaked Var. 462 (a) and Bechuana white (b)

In addition, fissures that developed in the seed coat and cotyledon (Figures 3.2.9(c), 3.2.9(d), 3.2.9(g), 3.2.9(h), 3.2.9(k) 3.2.9(l) & 3.2.10) were instrumental in facilitating higher water uptake during cooking. Water uptake had a significant ($P \leq 0.001$) negative correlation (Var. 462, r = -0.82; Bechuana white, r = -0.92) with the texture of the cowpeas. Improved rates of water uptake during cooking of moisture-conditioned and micronised lentils (Cenkowski & Sosulski, 1997; Arntfield *et al.*, 2001) and split peas (Cenkowski & Sosulski, 1998) have also been reported.

3.2.3.5 Effect of micronisation (41 % moisture and 153 ºC) on splitting of cooked seeds

Micronisation (41 % moisture, 153 °C) significantly increased the tendency of both varieties to split during cooking, with the increase in splitting being more evident in Var. 462 cowpeas (Figure 3.2.8). This increase in splitting in micronised (41 % moisture, 153 °C) samples was probably due to the development of cracks in the testa and cotyledon during micronisation (Figure 3.2.9 and 3.2.10). The rapid temperature increase probably causes liquid water to turn into steam (gas). If the seed is able to hold the expanding gas, then pressure builds up and the cotyledon collapses under the pressure or explodes to release the pressure, resulting in modified cotyledon cells (Figures 3.2.3(c) & 3.2.3(d)).

3.2.4 Conclusions

The two cowpea varieties have similar cooking times, although Bechuana white has a softer cooked texture, absorbs more water during cooking and has a higher degree of splitting than Var. 462 cowpeas. This may be as a result of differences in cotyledon structure. The hydrothermal treatment significantly reduces the cooking time of both cowpeas, although differences in texture and splitting are still evident. Micronisation (41 % moisture, 153 °C) produces fissures in the cowpea seed coat and cotyledon, which leads to improvement in water uptake, a softer texture and increased splitting during cooking. The treatment also pregelatinises starch and denatures the protein. Cowpeas that are susceptible to splitting during cooking would not be appropriate for micronisation processing if whole cowpeas are desired after cooking.