Physicochemical, Nutritional, and Microstructural Characteristics of Chickpeas (*Cicer arietinum* L.) and Common Beans (*Phaseolus vulgaris* L.) Following Microwave Cooking

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Microwave cooking of legumes such as chickpeas and common beans was evaluated by assessing the cooking quality (cooking time, firmness, cooking losses, and water uptake) and the physicochemical, nutritional, and microstructural modifications in starch and nonstarch polysaccharides. Compared to conventional cooking, microwave cooking with sealed vessels enabled a drastic reduction in cooking time, from 110 to 11 min for chickpeas and from 55 to 9 min for common beans. The solid losses, released in the cooking water, were significantly less after microwave cooking than after conventional cooking (6.5 vs 10.6 g/100 g of dry seed in chickpeas and 4.5 vs 7.5 g/100 g of dry seed in common beans). Both cooking procedures produced a redistribution of the insoluble nonstarch polysaccharides to soluble fraction, although the total nonstarch polysaccharides were not affected. Increases in in vitro starch digestibility were similar after both cooking processes, since the level of resistant starch decreased from 27.2 and 32.5% of total starch in raw chickpeas and beans, respectively, to about 10% in cooked samples and the level of rapidly digestible starch increased from 35.6 and 27.5% to about 80%. SEM studies showed that the cotyledons mantained a regular structure although most of the cell wall was broken down and shattered by both cooking procedures. In addition, the ultrastructural modifications in the cotyledon's parenchima and cells are consistent with the chemical modifications in NSP and the increase in starch digestibility after cooking.

Keywords: *Microwave cooking; chickpea and common bean; cooking quality; nonstarch polysaccharides; in vitro starch digestibility*

INTRODUCTION

One of the major problems associated with the consumption of dried legumes is their prolonged preparation and cooking. Recently, microwaves have been employed for a great variety of foods to significantly reduce their preparation time (cooking, thawing, blanching, drying, pasteurization, sterilization, dehydration, reheating, etc.) but rarely for legume processing (rehydration, cooking, and canning). Microwave energy under pressurized conditions has been used in blanching of vegetables and in pasteurization and sterilization of milk and dairy products (Decareau, 1985).

In addition, microwave heating with closed vessels has been successfully used in the analytical field for the rapid acid hydrolysis of proteins (Marconi et al., 1995, 1997), starch (Khan et al., 1980), dietary fiber polysaccharides (Li, 1998), and cell wall peptidoglycan (Marconi et al., 2000).

Microwave energy is, in fact, nonionizing radiation that leads to instantaneous heat generation within the product due to molecular motion (the migration of ions and the rotation of dipoles) but does not cause changes in molecular structure (Mudgett, 1985).

Some studies have shown that microwave heating affects the nutrient compounds in food (proteins, vitamins, etc.) less than conventional cooking, because preparation time is shorter and less water is used (Sanchez et al., 1981; Chen and Chen, 1993; Finot and Merabet, 1993; Lassen and Ovesen, 1995). The effects of microwave cooking on in vitro starch digestibility and on dietary fiber in dried legumes have not been fully investigated since the few studies carried out regard the use of microwaves for reheating conventionally pretreated samples (blanched/frozen or boiled) (Nyman et al., 1994; Svanberg et al., 1997, 1999; Velasco et al., 1997; Zyren et al., 1983). In addition, heating processes, affecting the physicochemical and structural characteristics of polysaccharides (Vidal-Valverde and Frias, 1991; Bravo et al., 1998; Lintas et al., 1995; Nyman et al., 1994; Periago et al., 1996; Tovar et al., 1992; Skrabanja et al., 1999), can influence some of the physiological and metabolic properties of legumes, such as their low glycaemic response (Jenkins et al., 1980; Foster-Powell and Brand Miller, 1995; FAO, 1998) and hypocholesterolemic effect (Zulet and Martinez, 1995; Anderson et al., 1984).

Therefore, the purpose of this work was to study the effect of microwave cooking on cooking quality, nonstarch polysaccharides, in vitro starch digestibility, and

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microstructural characteristics of chickpeas and common beans.

MATERIALS AND METHODS

Samples. Commercially available dried chickpeas (*Cicer arietinum* L.) and common beans (*Phaseolus vulgaris* L., variety Borlotto) cultivated in Molise (Italy) were obtained from a local market within 4 months of being harvested. The seeds, cleaned and freed from dust, broken seeds, and other foreign matter, were sealed in polyethylene bags and stored at 4 °C until they were used.

Twelve brands of canned chickpeas and seven brands of canned common beans, selected from the most representative brands, were purchased at Italian markets.

Processing Procedures. *Soaking.* Batches of dried seed were soaked for 18 h in distilled water (1:3.5 dried seed:water ratio, w/v) at room temperature and then drained.

Traditional Cooking. The soaked drained seeds (corresponding to 100 g of dried seeds) were cooked to the boiling point with 1 L of distilled water (1:10 dried seed:water ratio, w/v) on a hotplate at 350 °C and then at 250 °C until reaching the cooking point.

Microwave Cooking. The soaked drained seeds were placed in four vessels (corresponding to about 10 g of dried seed per vessel) with 40 mL of distilled water (1:4 dried seed:water ratio, w/v).

The microwave cooking conditions were as follows: power, 565 W (90% maximum power); temperature, 105 °C; and time, until the cooking point. The maximum pressure reached inside the vessels with the above conditions was ~12−15 psi.

A microwave laboratory system, model MDS-2000 from CEM Corp. (Matthews, NC), at 2450 MHz with a maximum power of 630 W was used, equipped with temperature and pressure system controls. Four PFA (perfluoroalkoxy) Teflon-sealed vessels (volume of 100 mL) were used.

Firmness. The firmness of the cooked and canned legumes was evaluated using the back-extrusion test, by means of an Instron Universal Testing Machine (model 1140, Instron Co., Canton, MA) equipped with a 500 kg load cell and an extrusion cell cup. The crosshead speed was 20 mm/min, and 150 g of cooked or canned seeds was assessed each time. The force (kilonewtons) at the onset of back-extrusion was taken to indicate the degree of firmness of the processed legumes.

Cooking Time. Cooking time was reported as the time taken for the chickpea and common bean seeds to reach the firmness of the respective commercial canned products.

Cooking Quality. Cooking losses were assessed as the amount of dry matter, ash, and protein released in the cooking water and were determined according to AOAC procedures (1990). The dry matter in the cooking water was determined gravimetrically by evaporating 25 mL of cooking water to dryness in an air oven at 105 °C. The residue was weighed and reported as a percentage of the original weight of the raw dried seeds.

Total splitting was calculated as the sum of split, butterflied, and broken seeds. The split seeds were manually separated, then counted, and reported as a percentage of the total seeds.

The cooking yield of the seeds after cooking was expressed by dividing the drained cooked weight by the initial weight of raw dried seeds.

Proximate Analysis. Levels of moisture, crude protein (Nx6.25), fat, and ash were estimated following the procedures described by the AOAC (1990).

Nonstarch polysaccharides (NSP) were assessed via the Englyst method, using colorimetric detection (Englyst et al., 1988). Cooked samples were drained, vacuum-dried, and ground to ensure homogeneity and uniform particle size. Starch was enzymatically removed by heat-stable α-amylase (Sigma Chemical Co., St. Louis, MO), pancreatin (Sigma), and pullulanase (Sigma) after solubilization in dimethyl sulfoxide. The total and insoluble NSP residues from the enzymic digestion were assessed after alcoholic precipitation (for the insoluble residue, it was necessary to first remove the soluble NSP by adding a buffer and centrifuging). The residues were acid hydrolyzed, thus releasing uronic acids and neutral sugars which were assessed colorimetrically. The amount of soluble NSP was calculated as the difference between total and insoluble NSP (soluble NSP = total NSP − insoluble NSP).

Total Starch and in Vitro Starch Digestibility. The amounts of total starch and starch fractions of the raw and processed legumes were determined according to the Englyst procedure (Englyst et al., 1992). Cooked seeds were drained and analyzed immediately to prevent possible retrogradation of the starch that could happen after and independently from the thermal treatment.

Rapidly digestible starch (RDS) and slowly digestible starch (SDS) were assessed as the amount of glucose released after incubation for 20 and 120 min with pancreatin and amyloglucosidase at 37 °C. The amount of total starch (TS) was determined as the amount of glucose released by enzymatic hydrolysis, following gelatinization in boiling water and treatment with potassium hydroxyde to solubilize the resistant starch. The amount of resistant starch (RS), the starch that was unaffected by hydrolysis after incubation for 120 min, was calculated as the difference between the amount of total starch and digestible starch [RS = TS − (RDS + SDS)]. Starch fractions were corrected for free glucose (FG), including glucose from the sucrose hydrolysis, with invertase. The amounts of released glucose and free glucose were determined using a glucose oxidase colorimetric kit (GOD-PAP, Boehringer Mannheim). Heat-stable α-amylase, pancreatin, pepsin, and amyloglucosidase were obtained from Sigma.

The starch digestible rate index (SDRI = RDS expressed as a percentage of TS) and rapidly available glucose (RAG = RDS + 2FG) were also calculated to express the nutritional value of starch more effectively (Periago et al., 1996, 1997).

Scanning Electron Microscopy (SEM). For SEM observation, cotyledons of raw, traditionally cooked, and microwave cooked common beans and chickpeas were fractured with a razor blade and fixed for 2 h with 3% glutaraldehyde in a 0.2 N phosphate buffer at pH 7.2, washed three times in the buffer, and postfixed in 1% (w/v) osmium overnight at 4 °C. After buffer washing and dehydration in an ethanol series, samples were dried to the critical point, mounted on stubs, gold sputtered, and observed under a scanning electron microscope (Zeiss DSM 950, Carl Zeiss, Ltd., Montreal, PQ) at 15 kV.

Statistical Analysis. Results were expressed as mean values ± the standard deviations of three separate determinations. Data sets were evaluated using the one-way analysis of variance (ANOVA) followed by Duncan's multiple comparison test to assess the differences between canned samples and the Student's *t* test to compare the effects of the cooking treatments on the physicochemical properties.

RESULTS AND DISCUSSION

Cooking Time. Optimal cooking time is when the firmness of the cooked legumes reaches appropriate values. To define the range of cooking acceptability, the degree of firmness of various commercially canned products was assessed using an objective and instrumental method, the back-extrusion test (Wang et al., 1988).

The back-extrusion test, used on 12 brands of canned chickpeas and 7 brands of common beans, is reported in Table 1. Seed firmness varied between 1.11 and 2.78 kN for chickpeas (CV = 35.8) and between 0.81 and 1.75 kN for common beans (CV = 30.4). The considerable variability of the commercially canned samples can be explained by the lack of standardization in canning processes (soaking, blanching, and sterilization) and by differences in their length of preservation (Andreotti et al., 1973). The average values of 1.95 and 1.25 kN were used as a reference cooking degree for dried chickpeas and common beans, respectively.

Table 1. Firmness of Different Commercial Brands of Canned Chickpeas and Common Beans[a]

canned chickpeas		canned common beans	
brand	firmness (kN)	brand	firmness (kN)
CP1	2.03 ± 0.15^{b}	CB1	1.75 ± 0.11^{a}
CP2	2.68 ± 0.10^{a}	CB2	0.81 ± 0.02^{c}
CP3	1.13 ± 0.09^{d}	CB3	1.12 ± 0.15^{b}
CP4	2.78 ± 0.11^{a}	CB4	1.71 ± 0.13^{a}
CP5	1.94 ± 0.16^{b}	CB5	1.32 ± 0.07^{b}
CP6	2.78 ± 0.11^{a}	CB6	1.21 ± 0.15^{b}
CP7	1.16 ± 0.15^{d}	CB7	0.81 ± 0.02^{c}
CP8	1.14 ± 0.02^{d}		
CP9	1.63 ± 0.07^{c}		
CP10	2.57 ± 0.14^{a}		
CP11	1.91 ± 0.13^{b}		
CP12	1.11 ± 0.07^{d}		
mean	1.91	mean	1.25
CV	35.8	CV	30.4

[a] Different superscript letters within a column indicate statistically significant differences ($P \leq 0.05$).

Therefore, a series of both conventional and microwave cooking tests were carried out on the two commercial lots of dry chickpeas and beans to identify the firmness values around the average firmness previously assessed in canned legumes that provided better characteristics for splitting, butterflying, and broken seeds. The firmness values of 2.2 and 1.5 kN for chickpeas and common beans, respectively, were selected to fix their cooking time. The cooking time for chickpeas was 110 min when traditionally cooked and only 11 min when microwaved, whereas for the beans, it was 55 and 9 min, respectively.

Cooking Quality. The chemical composition of raw chickpeas and common beans is reported in Table 2; the cooking quality, determined by the amount of solids lost (dry matter, ash, and protein) in the cooking water and by visual assessment (percentage of total splitting and intact seeds), is reported in Table 3.

The amount of dry matter lost in the cooking water was significantly reduced after microwave cooking, in both the chickpeas (from 10.6 to 6.5 g/dried seed) and the beans (from 7.5 to 4.5 g/dried seed).

It is interesting to note that when both legumes were traditionally cooked, the amount of ash lost in the cooking water was considerable, being ~30% of their initial content. Such high ash loss was also found in cooked chickpeas by Attia et al. (1994) and Carnovale and Marletta (unpublished data) and was mainly attributed to the loss of K, P, and Ca.

However, when both legumes were microwaved, ash loss was significantly lower (0.31 vs 0.93 g/dried seed and 0.54 vs 1.22 g/dried seed in chickpeas and common beans, respectively). Therefore, microwave cooking can reduce the loss of mineral content from about 30 to 10%, with regard to their initial content in dried seeds.

The amount of protein lost in cooking water was also significantly reduced after microwave cooking. With regard to the chickpeas, the amount of protein lost in the cooking water varied from 2.8 g/dried seed (conventionally cooked) to 1.6 g/dried seed (microwaved), 12.2 and 6.9% of their initial content, respectively, whereas for the beans, protein loss ranged from 1.6 to 1.0 g/dried seed, 7.7 and 4.8% of their initial content, respectively.

The use of microwave cooking enables the nutrient content of legumes to be better preserved. This is due to the fact that less cooking time is required and the seed:cooking water ratio is lower (Finot and Merabet, 1993; Lassen and Ovesen, 1995); in fact, the seed:cooking water ratio is 1:10 (w/v) for traditional cooking and 1:4 (w/v) for microwave cooking.

With regard to total splitting, no significant differences were found between the cooking processes. Also with regard to the cooking yield, similar values were found between the cooking methods (2.40 for chickpeas and 2.50 for common beans), even though the conventional cooking time is much longer and the sample:cooking water ratio is far greater. In fact, the greater loss in solutes in conventional cooking is counterbalanced by the minor cooking water absorption in microwave cooking, as confirmed by the different moisture content of the boiled and microwaved samples (Table 3).

In Vitro Starch Digestibility. The effect of microwave and conventional cooking on starch content and in vitro starch digestibility of chickpeas and common beans is reported in Table 4. The minor differences in total starch, between raw and cooked pulses, can be attributed to the balance between nonstarch and starch material lost in the cooking water.

Table 4 shows that traditional and microwave cooking produce similar changes in in vitro starch digestibility. In fact, no significant differences were found between the RS, SDS, and RDS values obtained from both cooking methods. Both cooking methods produced a similar decrease in the level of RS, in both the chickpeas (from 27% of raw seed to 10% of cooked seed) and the beans (from 32% to 9−11%). A similar trend and similar RS values in conventionally processed legumes have been found (Tovar et al., 1990; Periago et al., 1996; Bravo et al., 1998; Lintas and Cappelloni, 1992; Velasco et al., 1997). In addition to the RS, the amount of slowly digestible starch (SDS) also decreased significantly after both thermal treatments, falling from 37 to 9% in the chickpeas and from 40 to ~10−11% in the beans.

On the contrary, the rapidly digestible fraction (RDS) increased significantly after both traditional and microwave cooking, increasing from 35 to ~80% in the chickpeas and from 27 to 80% in the beans. This behavior (RDS increase and RS and SDS decrease) can be explained by the fact that starch granules are gelatinized and partly solubilized during cooking, thus becoming available to amylolitic enzymes.

The starch digestion rate index (SDRI) and rapidly available glucose (RAG) are in vitro parameters that are well-correlated with in vivo indices, such as the glycaemic index and the postprandial glucose and insulin responses (Englyst, 1992; Periago et al., 1996, 1997; FAO, 1998).

No significant differences were found for both RAG and SDRI between the two cooking processes, which shows that, even when microwaved, legumes maintain the characteristic feature consistent with a low postprandial glycaemic response in humans. Similar results were found by Velasco et al. (1997) after the microwave and traditional reheating of boiled cowpeas and black beans.

Nonstarch Polysaccharides. Table 4 lists the contents of total NSP and soluble and insoluble fractions of raw legumes as well as of traditionally and microwave cooked samples. Table 4 shows that the NSP content in raw chickpeas and common beans was both quantitatively and qualitatively quite different. In fact, the total NSP content in the beans was about 19 g/100 g dm, consisting of equal amounts of soluble and insoluble fractions, whereas the total NSP content in the chick-

Table 2. Proximate Composition of Raw Chickpeas and Common Beans (g/100 g of Dry Seed)

legume	moisture	protein	fat	starch	ash	nonstarch polysaccharides
chickpea	10.4 ± 0.3	22.9 ± 0.2	6.4 ± 0.1	40.4 ± 0.4	2.83 ± 0.02	10.4 ± 0.3
common bean	10.1 ± 0.1	20.8 ± 0.3	2.6 ± 0.0	37.9 ± 0.5	3.68 ± 0.03	17.1 ± 0.4

Table 3. Comparison of Cooking Losses, Total Splitting, Moisture, and Cooking Yield for Chickpeas and Common Beans Subjected to Conventional and Microwave Cooking[a]

sample	cooking losses (g/100 g of dry seed)			total splitting (%)	moisture (%)	cooking yield[b]
	dry matter	ash	protein (Nx6.25)			
chickpea						
conventionally cooked	10.6 ± 0.9[a]	0.93 ± 0.03[a]	2.8 ± 0.4[a]	40 ± 5[a]	73.7 ± 0.6[a]	2.41 ± 0.07[a]
microwave cooked	6.5 ± 0.4[b]	0.31 ± 0.02[b]	1.6 ± 0.2[b]	44 ± 6[a]	71.7 ± 0.7[b]	2.35 ± 0.14[a]
common bean						
conventionally cooked	7.5 ± 0.7[a]	1.22 ± 0.04[a]	1.6 ± 0.1[a]	49 ± 6[a]	72.9 ± 0.2[a]	2.48 ± 0.09[a]
microwave cooked	4.5 ± 0.4[b]	0.54 ± 0.01[b]	1.0 ± 0.1[b]	53 ± 3[a]	71.6 ± 0.6[b]	2.48 ± 0.10[a]

[a] Different superscript letters within a column indicate statistically significant differences ($P \leq 0.05$) for each legume. [b] Expressed as drained cooked weight/raw dried seed weight.

Table 4. Effects of Conventional and Microwave Cooking on the in Vitro Starch Digestibility and Nonstarch Polysaccharides of Chickpeas and Common Beans[a]

sample	starch					nonstarch polysaccharides (g/100 g dm)				
	TS (g/100 g dm)	RS (% TS)	SDS (% TS)	RDS (=SDRI) (% TS)	RAG	total (*T*)	soluble (*S*)	insoluble (*I*)	*I*/*S*	*S*/*T*
chickpea										
raw	45.1 ± 0.4[a]	27.2	37.2 ± 0.3[a]	35.6 ± 0.4[a]	17.1	11.58 ± 0.32[a]	2.82	8.76 ± 0.25[a]	3.11	0.24
conventionally cooked	44.5 ± 0.9[a]	10.5	9.5 ± 0.7[b]	80.0 ± 1.2[b]	37.3	11.58 ± 0.41[a]	3.05	8.53 ± 0.39[ab]	2.80	0.26
microwave cooked	44.3 ± 1.1[a]	10.8	9.6 ± 0.9[b]	79.6 ± 1.7[b]	37.5	11.73 ± 0.08[a]	3.36	8.37 ± 0.28[b]	2.49	0.29
common bean										
raw	42.2 ± 0.5[a]	32.5	40.0 ± 0.4[a]	27.5 ± 0.5[a]	12.6	18.98 ± 0.41[a]	9.34	9.64 ± 0.23[a]	1.03	0.49
conventionally cooked	40.7 ± 0.7[b]	10.5	11.6 ± 1.1[b]	77.9 ± 1.8[b]	33.5	19.24 ± 0.72[a]	10.27	8.97 ± 0.38[b]	0.87	0.53
microwave cooked	40.3 ± 1.2[b]	9.1	10.2 ± 0.8[b]	80.7 ± 1.5[b]	35.3	19.39 ± 0.59[a]	11.03	8.36 ± 0.43[c]	0.76	0.57

[a] Different superscript letters within a column indicate statistically significant differences ($P \leq 0.05$) for each legume. TS, total starch; SDS, slowly digestible starch; RS, resistant starch; RDS, rapidly digestible starch; SDRI, starch digestibility rate index; RAG, rapid available glucose.

peas was about 12 g/100 g dm and mainly consisted of the insoluble fraction (3.11 insoluble:soluble ratio).

Table 4 shows that the cooking processes did not substantially alter the total NSP content. The apparent increase in total NSP content in the beans, after cooking, might be due to a greater loss of nonfiber components (mainly sugar, oligosaccharides, protein, etc.) in the soaking and cooking water (Carnovale and Lintas, 1995; Mongeau and Brassard, 1995; Periago et al., 1996, 1997; Perez-Hidalgo et al., 1997).

Table 4 also shows that both cooking processes caused a redistribution of the NSP's insoluble to soluble fractions. In particular, the soluble fraction content was higher in the cooked legumes than in the raw legumes, to the detriment of the insoluble fraction. This redistribution could be caused by a partial solubilization and depolymerization of hemicellulose and insoluble pectic substances (Lintas et al., 1995; Carnovale and Lintas, 1995; Vidal-Valverde et al., 1992).

The decrease in the insoluble NSP content and the increase in the soluble NSP fractions were more pronounced after microwave cooking, as the ratio between the insoluble and soluble fiber fractions shows. This ratio, which in the raw chickpeas was 3.11, reached 2.80 after traditional cooking and 2.49 after being microwaved. However, in the raw beans, the insoluble:soluble ratio was 1.03 and reached 0.87 after traditional cooking and 0.76 after being microwaved. This suggests that the depolymerization of cell wall polysaccharides could be more extensive during microwave cooking than during conventional cooking. The higher temperature and pressure used in microwave cooking may contribute toward breaking down the linkages in cell wall polysaccharides and therefore increasing the soluble NSP content. This is in accordance with Svanberg et al. (1999) and Nyman et al. (1994), who reported that repeated microwave reheating of blanched/frozen green beans and peas brought about a partial solubilization of insoluble dietary fiber. However, Chang and Morris (1990) found no differences between autoclaved and microwaved soya fiber, with regard to their total, soluble, and insoluble fibers. Some qualitative modifications found in the fiber components (insoluble:soluble ratio) of cooked legumes can also be due to the leaching of the soluble fiber fractions and/or the depolymerization of insoluble fiber into smaller particles which are washed away when drained (Zyren et al., 1983; Carnovale and Lintas, 1995; Mongeau and Brassard, 1995).

SEM Observations. Cotyledon cells of raw common beans and chickpeas are shown in panels 1.1 and 1.3 of Figure 1, respectively. Panels 1.2 and 1.4 show a detail of a bean and a chickpea cell, respectively. Both in beans (panels 1.1 and 1.2 of Figure 1) and more evidently in chickpeas (panels 1.3 and 1.4 of Figure 1), cell walls create a regular structure in which starch granules are enclosed. The starch granules of both raw common beans and raw chickpeas tend to be elliptic and/or globular, smooth-surfaced and ranged from about 11 × 13 to 29 × 15 μm in beans (Figure 1.2) and from 10−14 to 19 × 10 μm in chickpeas (Figure 1.4). In both legumes, the starch granules, which as other TEM and SEM studies have also pointed out (Otto et al., 1997; Hsieh et al., 1999) are the most representative storage components, appear to be embebbed in a protein matrix.

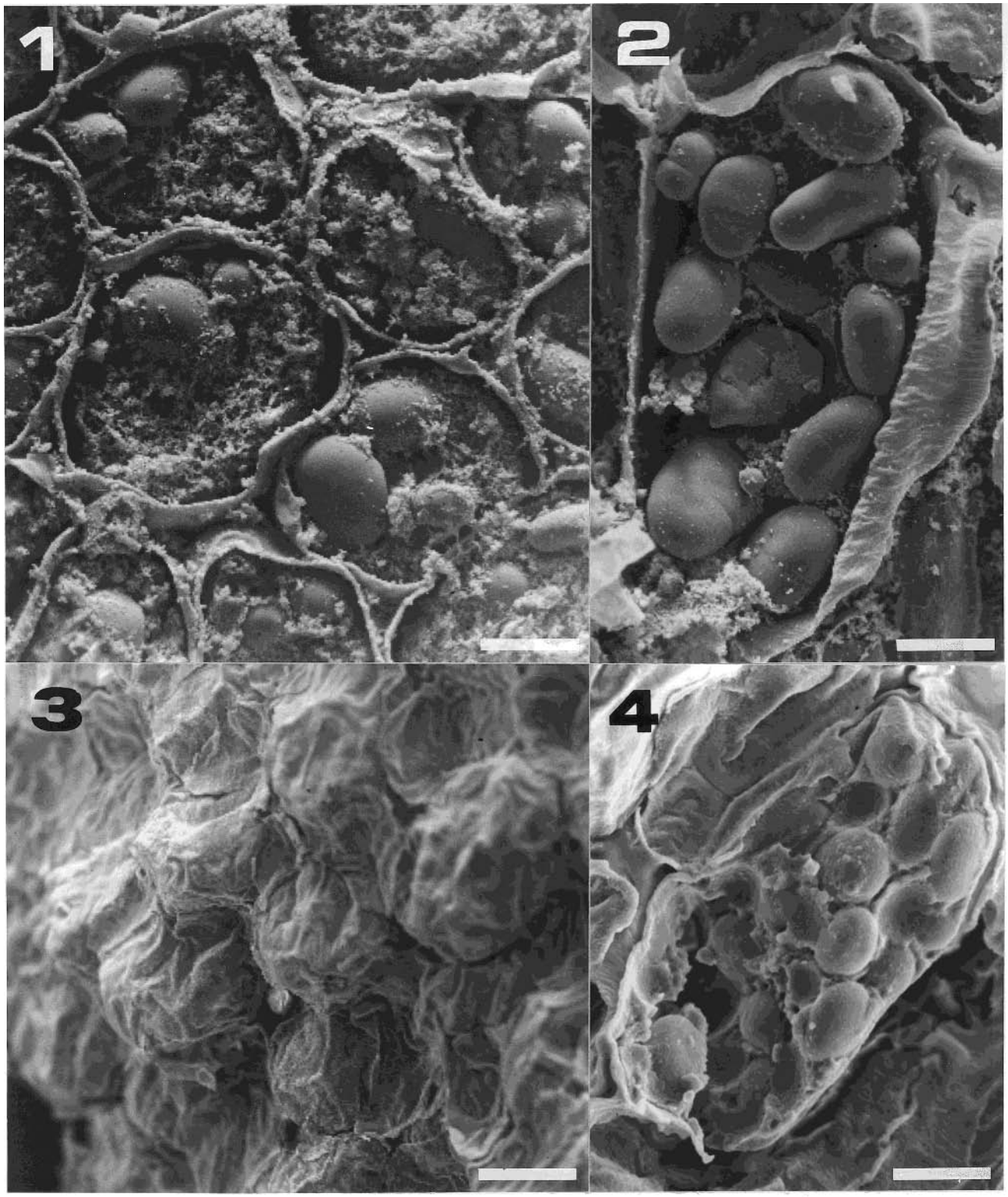

Figure 1. (1.1) Cotyledon parenchima of raw beans (cross section). Bar = 20 μm. (1.2) Cell of raw bean's cotyledon containing starch granules. Bar = 20 μm. (1.3) Cotyledon parenchima of raw chickpeas (cross section). Bar = 20 μm. (1.4) Cell of raw chickpea's cotyledon containing starch granules. Bar = 20 μm.

SEM micrographs of the traditionally and microwave cooked common beans are shown in panels 2.5 and 2.7 and in panels 2.6 and 2.8 of Figure 2, respectively. A regular structure of cotyledons appears to have been maintained, to some extent, after both cooking procedures, even if most of the cell walls had been broken down and shattered. Residues of the middle lamella (arrowheads) are evident on the surface of the bean cells (panels 2.7 and 2.8 of Figure 2). After traditional cooking (Figure 2.7), cells appear to be more tightly packed and there is more amorphous extracellular material, compared with the microwaved samples (Figure 2.8). This is probably due to the dispersion of soluble sugars, protein, and/or fragments of nonstarch polysaccharides, which could be related to the considerable amount of solid matter lost in the cooking water (Table 3).

SEM micrographs of traditionally and microwave cooked chickpeas are shown in panels 3.9 and 3.11 and

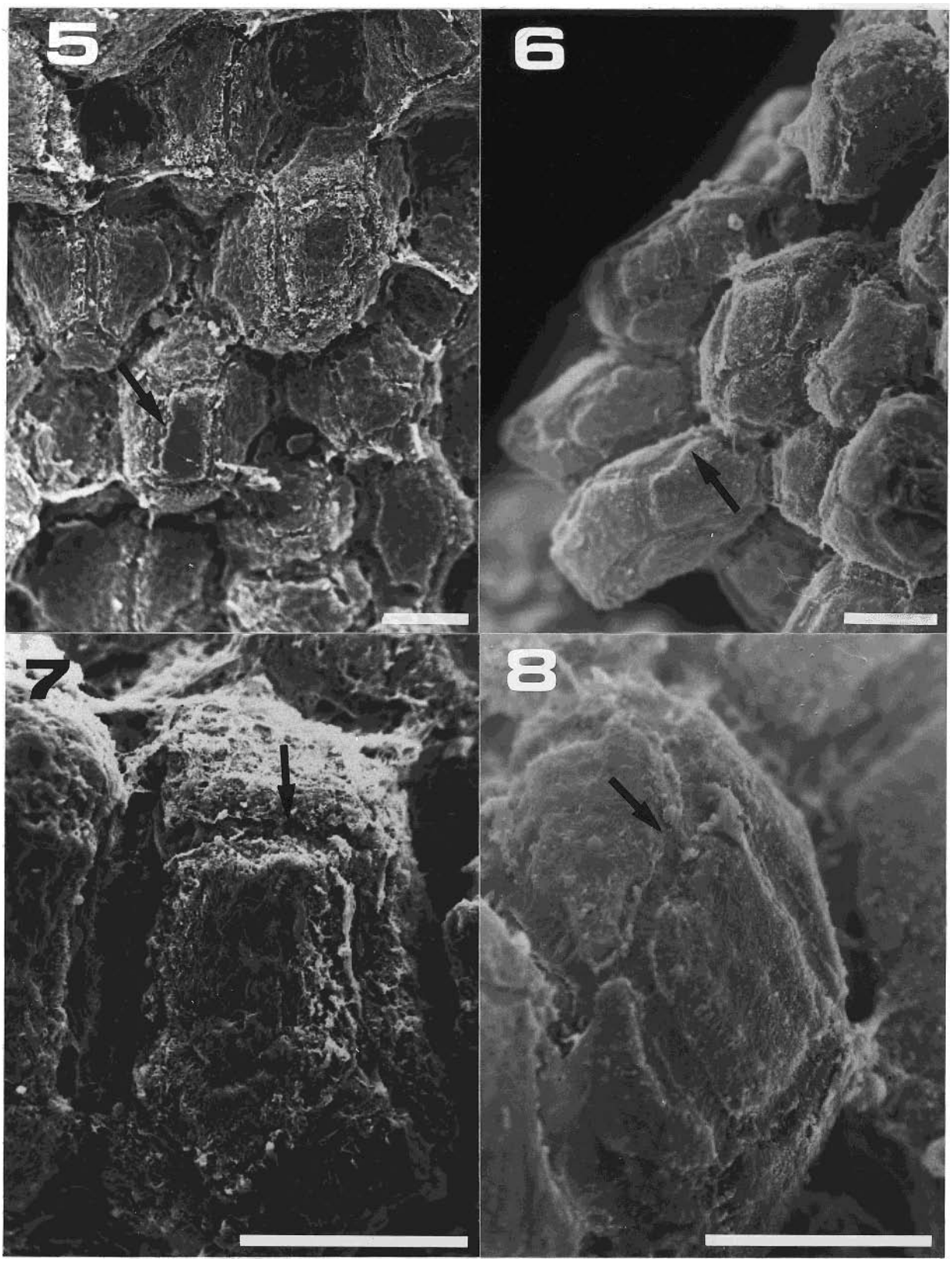

Figure 2. Common beans: (2.5) Cotyledon parenchima after traditional cooking. Bar = 50 μm. (2.6) Cotyledon parenchima after microwave cooking. Bar = 50 μm. (2.7) Cotyledon cell after traditional cooking showing cell wall and middle lamella residues (arrowheads). Bar = 20 μm. (2.8) Cotyledon cell after microwave cooking showing cell wall and middle lamella residues (arrowheads). Bar = 20 μm.

in panels 3.10 and 3.12 of Figure 3, respectively. As in the beans, the major changes observed between raw and cooked chickpeas were the loss of the rigid structure and middle lamella; in addition, no significant differences were observed in the cotyledon structure of conventionally and microwave cooked samples (panels 3.9 and 3.10 of Figure 3, respectively).

Thus, microscopic studies such as SEM, which show the ultrastructural modifications in the cotyledon's parenchyma and cells, are consistent with the chemical

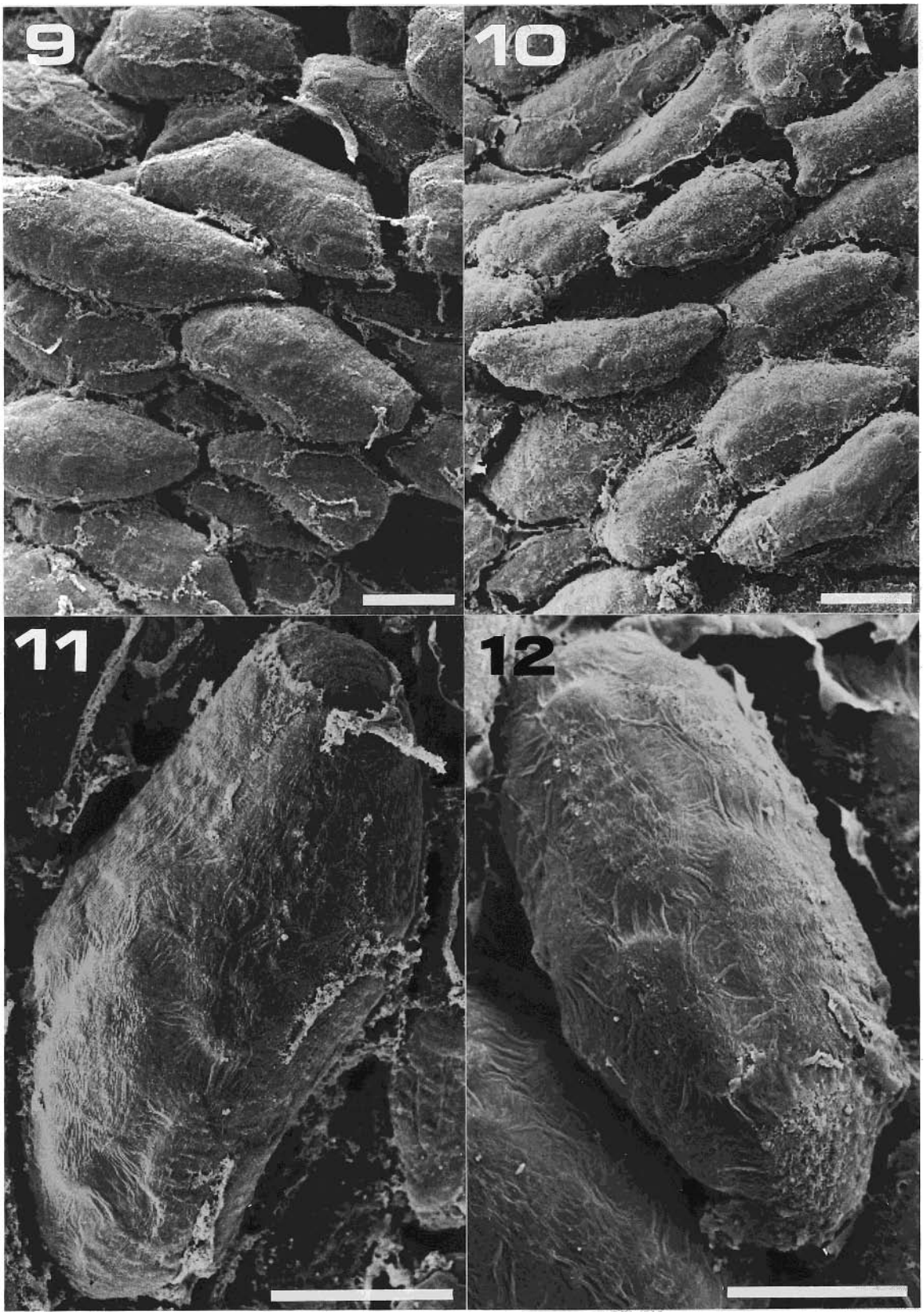

Figure 3. Chickpeas: (3.9) Cotyledon parenchima after traditional cooking. Bar = 50 μm. (3.10) Cotyledon parenchima after microwave cooking. Bar = 50 μm. (3.11) Cotyledon cell after traditional cooking. Bar = 20 μm. (3.12) Cotyledon cell after microwave cooking. Bar = 20 μm.

modifications in NSP and the increase in starch digestibility of legumes after cooking. During soaking and cooking, the legumes swell and the pectins, which constitute the middle lamella, are only partially degraded. This can, in part, explain the increase in the level of soluble polysaccharides after cooking, with respect to the uncooked samples. In addition, starch gelatinization and the partial breakdown of the cell walls make starch granules more susceptible to amylolytic enzymes. These phenomena contribute to signifi-

cantly increasing starch digestibility in cooked samples, but the rigidity of the cell walls and the consequent incomplete swelling of the starch do not permit complete starch availability (Tovar et al., 1991; Wursh et al., 1986).

CONCLUSION

These results therefore demonstrate the advantages of applying microwave technology to legume cooking, since it remarkably reduces processing time and cooking losses, without substantially altering the microstructural characteristics of legumes.

With regard to the heating treatments, it is interesting to note that despite the considerable differences between both heating methods (heating principle, pressure, temperature, and speed), microwaving and traditional heating had similar effects on in vitro starch digestibility and total NSP content with little difference in insoluble and soluble fractions.

ABBREVIATIONS USED

NSP, nonstarch polysaccharides; TS, total starch; RDS, rapidly digestible starch; SDS, slowly digestible starch; RS, resistant starch; FG, free glucose; SDRI, starch digestion rate index; RAG, rapidly available glucose; SEM, scanning electron microscopy; CV, coefficient of variation.

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