Effects of Roasting and Malting on Physicochemical Properties of Select Cereals and Legumes

L. D. Griffith[1,2] and M. E. Castell-Perez[1,3]

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ABSTRACT

Pearl millet, teff, cowpea, and peanut used in the formulation of experimental weaning foods were evaluated for changes in physicochemical properties resulting from roasting and malting. The particle size index (PSI) value for cowpea was significantly higher, indicating a finer flour than that obtained from pearl millet. Pearl millet and teff flours did not have significantly different PSI values, water absorption index values, or gruel viscosities. Viscosities for control and roasted cowpea gruels (15%, w/v) were significantly higher than those obtained from peanut gruels. Malting had the greatest impact on physicochemical properties for all grains, whereas roasting produced no significant differences from control flours. Malting yielded apparent increases in grain protein content, and malted seeds yielded finer flours with reduced water absorption and pasting qualities.

Pearl millet, teff, cowpea, and peanut are major food crops cultivated in many regions of the world. A variety of foods, including those for infants, are made from these grains using traditional processing techniques such as roasting and malting (Boeh-Ocansey 1989, Walker 1990). Nout (1993) described roasting as a method that uses dry heat for short periods of time. Traditional roasting of grains is used primarily to enhance flavor, but other benefits include reduction of antinutritional factors (D'Appolonia 1978, Khan et al 1988, Gahlawat and Sehgal 1992) and extension of storage life (Huffman and Martin 1994). Flours milled from roasted legumes showed increased water retention capacity (D'Appolonia 1978, Han and Khan 1990) and viscosity (Han and Khan 1990). Heat treatment of cowpeas at 110–130°C yielded fried pastes (*akara*) with reduced functional, sensory, and textural properties (Hung et al 1988, McWatters et al 1988).

Malting consists of germination and subsequent drying of seeds. The nutritional benefits of germination are reviewed elsewhere (Chavan and Kadam 1989, Lorenz 1980). Germination alters the functional properties of bread flours (Hwang and Bushuk 1973, Ranhotra et al 1977, Morad and Rubenthaler 1983). Nnanna et al (1990) found that germination of cowpea improved crust color of *akara* but reduced other sensory qualities, such as flavor, moistness, and tenderness. Decreased pasting qualities of germinated flours from barley (Hansen et al 1989), wheat (Gopaldas et al 1988), sorghum (Mosha and Svanberg 1983), finger millet, and green gram (Brandtzaeg et al 1981) were reported. The effects of germination on the functional properties of these flours were contributed to amylolytic and proteolytic enzyme activity.

Limited information is available regarding the physicochemical properties of flours milled from grains treated by the traditional processing methods of roasting and malting. The purpose of this study was to investigate the effects of these processing methods on particle size distribution, water absorption capacity, and viscosity of peanut paste and pearl millet, teff, and cowpea flours.

MATERIALS AND METHODS

Seeds were obtained from brown teff (*Eragrostis tef* (Zuccagni) Trotter) from Arrowhead Mills (Hereford, TX), 1994 crop year; pearl millet (*Pennisetum glaucum* L. 'HMG 100') from Coastal Plains Experiment Station (Tifton, GA), 1993 crop year; cowpea (*Vigna unguiculata* L. 'California Blackeye No. 5') from Pennington Seed Company (Cullman, AL); and peanut (*Arachis hypogaea* L. 'Spanish') from Birdsong Peanut Co. (Gorman, TX). All seeds were stored at 4°C.

Seed Preparation and Milling

Cleaned millet seeds were decorticated mechanically to an 80% pearling index (difference in weight as percentage of original weight) with a barley pearler (Seedburo, Chicago, IL). Cowpea seed coats were removed manually after soaking for 10 min in distilled water. Dehulled, soaked cowpeas were dried in a forced-air oven at 40°C for 12 hr to <10% moisture content (wb). Due to an inability to decorticate, teff was used as a whole-seed flour. Teff, pearl millet, and cowpea seeds were milled to flour with a stone mill (model S-600, Household Flour Mill, E.M. Lee Engineering, Milwaukee, WI) adjusted to a fine setting. Peanut was ground into paste with a mill (model 4E, Straub Co., Philadelphia, PA). Milled flours and paste were stored at 4°C in plastic bags until analysis.

Processing Methods

For malting, all seeds were pretreated for 5 min with 200 ppm of 5.25% sodium hypochlorite to control microbial growth. Seeds were rinsed, soaked, and germinated at 30°C as previously described (Griffith et al 1998). Teff and pearl millet were germinated for 48 hr, the time required for increased amylase activity (Chavan and Kadam 1989). Cowpea and peanut were germinated for 24 hr, the time needed to reduce flatulence-producing oligosaccharides and minimize rootlet development (Nnanna and Phillips 1990). Sprouted seeds were dried in a forced-air oven at 50°C for 12–20 hr to <10% moisture content (wb). Cowpea seed coats were separated from sprouted seeds with a room fan. Dried malt and sprouts were stored at 4°C until ground to flour.

For roasting, all seeds were heated in a forced-air oven at 160°C on a glass (Pyrex) tray. Seed temperatures were monitored with a microprocessor thermometer (Type T, Fisher Scientific Co., Pittsburgh, PA). The larger seeds, cowpea and peanut, allowed internal placement of a naked bead thermocouple. Teff and pearl millet temperatures were measured by inserting the thermocouple between thin layers of seeds. Experimental roasting times were based on development of aroma and flavor. Final selected seed weights and roasting times were: 150 g of pearl millet (30 min), 150 g of teff (30 min), 200 g of cowpea (25 min), and 325 g of peanut (40 min).

Proximate Analysis

Moisture content was determined for teff, pearl millet, and cowpea flours by the air-oven method 925.10 (AOAC 1990), for peanut by Approved Method 44-19 (AACC 1983), and for all germinated seeds by drying to constant weight at 105°C for 5 hr (Chen et al

[1] Former graduate assistant and professor, respectively, Department of Food Science and Animal Industries, Alabama A&M University, Normal 35762.

[2] Present address: Huntsville, AL 35802. Corresponding author. E-mail: grif@traveller.com

[3] Present address: Department of Agricultural Engineering, Texas A&M University, College Station 77843.

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1975). Methods used for determination of proximate composition were protein by Kjeldahl, using a digestion system and Kjeltec Auto 1030 Analyzer (Tecator AB, Höganäs, Sweden); crude fat by ether extraction, using method 920.39 (AOAC 1990); ash by method 923.03 (AOAC 1990); and carbohydrate as percent difference (Livesey 1995). Nonstarch polysaccharides were determined by a colorimetric, enzymatic method described by Englyst and Hudson (1987). Enzymes used were pullulanase (Promozyme 200L, EC 3.2.1.41, obtained from Novo Nordisk Bioindustrials, Danbury, CT) and α-amylase (EC 3.2.1.1) in the form of pancreatin (P1750, hog pancrease 4 X USP, Sigma Chemical Co., St. Louis, MO).

Physical Properties

Particle size distribution of stone-milled flours was determined using procedures described by Phillips et al (1988). A weighed 100-g sample of each flour was sifted with a set of graded standard U.S. sieves (nos. 20–80, 100, and 200 mesh and collection pan). A rubber stopper placed inside each sieve served as a bouncer. The sieve stack was mechanically shaken (Ro-Tap testing sieve shaker, W. S. Tyler, Mentor, OH) until the weight of the material on the smallest screen reached equilibrium (not more than a 0.2% difference in the total sample weight). Particle size index (PSI) was calculated (Bedolla and Rooney 1984) as:

$$PSI = [(0.1)(\% \text{ on no. } 60) + (0.4)(\% \text{ on no. } 70) + (0.7)(\% \text{ on no. } 80) + (1.0)(\% \text{ through no. } 80)]$$

The water absorption capacity and index (WAI) of the flour was determined by combining a modification of the initial procedure by Kite et al (1957) and a later modification described by Anderson et al (1969). A 2.5-g sample was weighed in Nalgene centrifuge tubes, and 30 mL of distilled water was added. Tubes were heated in a water bath at 95°C for 30 min and stirred with a glass rod every 5 min. Heated samples were centrifuged at 3,000 × *g* for 15 min. The WAI was recorded as the gel weight (g)/dry sample weight (g). The water solubility index (WSI) was determined using method 920.193 (AOAC 1990). The supernatant liquid from the WAI procedure was decanted into a weighed evaporation dish, oven-dried at 100°C for 2 hr, and reweighed. The weight of dried solids recovered by evaporation of the supernatant was expressed as percent dry solids or WSI.

TABLE I
Proximate Composition of Grains[a]

Grain	Moisture	Protein[b]	Crude Fat	Ash	Carbohydrate	Nonstarch Polysaccharides
Pearl millet						
Whole	12.2	12.5f	3.8c	1.8	82.0	6.0d
Decorticated	10.6	11.6f	2.9c	1.2	84.4	7.9c
Roasted	3.9	…	…	…	…	…
Malted	9.0	14.8e	…	…	…	…
Teff						
Whole	8.9	14.6e	2.9c	2.4	80.1	6.2d
Roasted	3.2	…	…	…	…	…
Malted	10.5	21.2d	…	…	…	…
Cowpea						
Whole	11.9	23.0c	0.9d	3.2	72.9	12.9a
Decorticated	8.9	25.2b	1.3d	3.1	70.4	9.5b
Roasted	4.3	…	…	…	…	…
Malted	8.6	26.0b	…	…	…	…
Peanut						
Whole	6.1	29.7a	44.8b	2.4	23.4	4.3e
Decorticated	6.0	30.5a	51.0a	2.5	16.0	3.3e
Roasted	1.9	…	…	…	…	…
Malted	5.5	29.4a	…	…	…	…

[a] Means of two observations reported as % db, except % moisture, which is reported as wb. Values followed by the same letters in each column are not significantly different according to Tukey's honestly significant difference test ($P < 0.05$).
[b] Pearl millet, teff, and cowpea (N × 6.25); peanut (N × 5.46).

Viscosity

Individual flours and their composite blends (weaning blends) were prepared in 15% (w/v) concentrations based on a 20-mL volume. A paste was made by mixing 3 g of flour with 5 mL of distilled water in a large test tube. To the paste, 15 mL of boiling distilled water was added and mixed well with a glass stir rod. The flour slurry was heated in a boiling water bath, stirred every 5 min, and held at 95°C for 10 min. Using a graduated syringe, 8 mL of hot cooked paste (gruel) was injected into a sample adapter (Brookfield Engineering Laboratories, Stoughton, MA) for viscosity determination. Viscosity was measured with a viscometer (Brookfield HBDT [DVII+]) and spindle (SC4-21) at 50 rpm and 40°C. The temperature of the small sample chamber was controlled with a water-bath controller.

Statistical Analysis

Experimental design was based on a completely randomized 3 × 3 factorial design for PSI and a 3 × 4 factorial design for the remaining experiments. Data were collected using two samples and two replications. A two-way analysis of variance (ANOVA) was used to statistically test for differences between grain type and processing methods. Tukey's honestly significant difference test was calculated to separate mean main effects for grain type and processing method (Pedersen 1985).

RESULTS AND DISCUSSION

Proximate Composition

The proximate compositions of milled grains are reported in Table I. Cowpea and peanut contained 23 and 29.7% protein, respectively, nearly twice that of teff and pearl millet at 14.6 and 12.5%, respectively. Malting significantly increased the protein content of pearl millet, teff, and cowpea. Apparent protein increases observed in germinated seeds were reported by other researchers and were attributed to a loss of total dry matter through seed respiration (Lorenz 1980, Chavan and Kadam 1989). Whole peanut, an oilseed, yielded a significantly higher crude fat content (44.8%) compared to whole cowpea (0.9%). Grain decortication significantly reduced the nonstarch polysaccharides (dietary fiber) content of cowpea but not of peanut or pearl millet.

Seed Roasting

Although a variety of temperatures and procedures are reported for roasting seeds, little information is available on the changes in seed temperature with cooking time shown in Fig. 1. All seed temperatures exceeded 80°C within 10 min, which corresponded

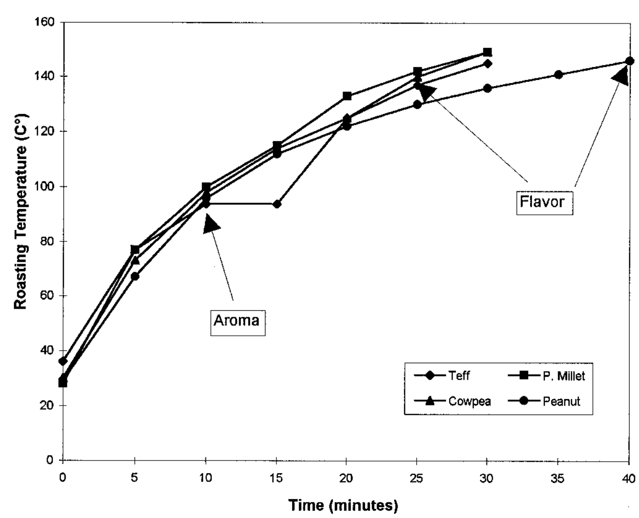

Fig. 1. Changes in whole-grain seed temperature with time during oven roasting at 160°C. Temperatures are means of triplicate measurements.

to aroma development. A pleasant roasted flavor developed when seeds approached 140°C, which established experimental roasting times. Peanut required the longest roasting time due to its larger seed size. All seeds followed a similar heating pattern, and roasting was discontinued when seed temperatures exceeded 145°C. Higher seed temperatures produced undesirable flavors and darkened colors due to heat-enhanced chemical reactions. The goal of roasting is to improve sensory qualities and achieve inactivation of destructive enzymes, which improves the storage and nutritional quality of the product. Rackis et al (1986) reported reduced trypsin inhibitor activity when seed temperatures reached 90–100°C. Lipoxygenase activity was lost at temperatures of 75–80°C (Al-Obaidy and Siddiqi 1981, Chen and Whitaker 1986). All seeds reached these temperatures before changes in sensory quality were noted.

PSI

Table II shows the specific particle distribution (PD) or percentage of teff, pearl millet, and cowpea flour retained on each sieve size. All flours were classified as fine, because 99% of all particles passed through the no. 30 (595 µm) sieve. Malted flours produced a higher percentage of particles that passed through the 210-µm opening (teff 90.8%, pearl millet 89.3%, and cowpea 83.3%) and the greatest percentage of very fine particles, <74 µm in diameter, as seen in the collection pan values. Control pearl millet flour was most evenly distributed, with a PD of 51% >210 µm and 49% <210 µm.

A comparison of the degree of fineness was made using the PSI, which provides a mathematical representation of PD. Table III lists mean PSI values. A higher PSI value indicates finer flour. PSI values obtained varied significantly among grain type, processing method, and interactive effects. Pearl millet produced the widest range of PSI (49.9–89.4) values and the largest and most uniform rate of change between each processing method. Cowpea flours showed the narrowest range of PSI (76.2–84.0) values, with a small, insignificant decrease for roasted flour. Teff ranged from 65.4 to 89.5, and the increases between each process were the least uniform.

In comparing PSI values due to grain type main effects, teff was not significantly different from cowpea or pearl millet. Cowpea flour yielded a significantly higher PSI (80.4) and a finer flour than pearl millet (70.0). Processing method effects on PSI values showed roasting did not contribute to significant changes in PSI. Malted flours, overall, had a significantly ($P < 0.01$) higher PSI value (87.6) compared to control (65.4) or roasted (73.0) flours. Factors influencing flour particle size include milling and softness of grain endosperm (Abdelrahman et al 1983, Williams et al 1988, Rogers et al 1993). The process of germination produces physiologic changes in the endosperm, allowing seeds to be milled to a finer flour. Particle size is an indication of grain hardness, with softer grains yielding finer flours (Williams et al 1988). Softening of grain by malting allows easier manual grinding of seed to flour, a practice common in many developing countries. A flour's particle size distribution influences dry flour flow characteristics (White et al 1967), water absorption rate during mixing, and final food product sensory qualities (McWatters 1983). Finer flours milled from malted grains offer advantages for infant feeding. Infants require smoother, softer foods because of poorly developed oral motor skills.

WAI and WSI

Among grain type main effects for WAI (Table III), peanut exhibited significantly lower water absorption capacity than cowpea, pearl millet, and teff. In comparing only control flours, cowpea had the highest WAI value (10.6) and peanut the lowest WAI value (2.1) of all grains. Water absorption capacities are related to the starch and protein contents and the particle size distribution of the ingredient. The high fat, high protein, low carbohydrate content of peanut (Table I) corresponds to the reduced WAI observed. Although cowpea flours exhibited a higher PSI, no significant difference in WAI was noted compared to pearl millet and teff. Phillips et al (1988) reported that water absorbance of cowpea meal was related more to protein and starch composition than to particle size distribution. McWatters (1983) observed that very fine cowpea flours tended to bind water less efficiently and yielded thinner pastes than coarser meals. Gomez et al (1991) observed similar results in corn masa. Corn masa flours with a smaller particle size exhibited greater mechanical starch damage and lower viscosities. When considering processing method main effects, malting reduced WAI to almost half that of control and roasted flours. During the malting process, amylase enzymes hydrolyze seed starch to sugars, thereby, making less starch available for gelatinization (Parvathy and Sadasivam 1982).

Grain types were significantly different in WSI values (Table III). WAI and WSI assumed an inverse relationship (r = –0.916). Peanut WSI greatly exceeded other grain WSI values. The high protein content of peanut produced a greater loss of water-soluble fractions within the supernatant. There was no difference in WSI between control and roasted grains. WSI increased by more than 100% with malting, which can be attributed to increases in soluble sugars resulting from starch hydrolysis (Chavan and Kadam 1989) and changes in protein solubility properties (Hwang and Bushuk 1973).

Gruel Viscosity

Figure 2 illustrates the viscosities of single-grain gruels (15%, w/v). Viscosity was >3,000 cps for all gruels, except for peanut and malted flours. Peanut consistently measured low viscosities (<50 cps)

TABLE II
Particle Size Distribution of Flours[a]

	Sieve No./Mesh Size (µm)[b]									
Flour	**20/841**	**30/595**	**40/420**	**50/297**	**60/250**	**70/210**	**80/177**	**100/149**	**200/74**	**Collection Pan**
Teff										
Control[c]	0.0	0.1	0.9	10.6	14.6	8.8 (35.0)	15.6	13.2	24.2	12.0 (65.0)
Roasted[c]	0.0	0.0	0.4	7.4	13.9	8.6 (30.3)	15.2	8.4	21.8	26.1 (71.4)
Malted[c]	0.0	0.0	0.2	1.7	4.0	3.8 (9.7)	11.4	8.5	40.8	30.1 (90.8)
Pearl Millet										
Control[d]	0.0	0.1	6.0	31.5	8.3	5.5 (51.4)	6.4	8.8	25.0	8.6 (48.8)
Roasted[d]	0.0	0.0	0.7	7.6	10.8	3.4 (22.5)	38.3	14.4	18.8	8.0 (79.5)
Malted[c]	0.0	0.1	0.5	2.6	4.7	2.8 (10.7)	6.9	4.6	25.4	52.9 (89.3)
Cowpea										
Control[d]	0.0	0.1	1.3	6.5	6.7	5.3 (19.9)	6.3	5.7	15.2	52.9 (80.1)
Roasted[d]	0.0	0.8	4.1	8.8	7.2	5.4 (26.3)	5.8	5.8	13.8	49.5 (74.9)
Malted[d]	0.0	0.1	1.0	5.5	6.3	3.8 (16.7)	5.2	5.0	19.1	54.0 (83.3)

[a] Means of two samples and two replicates. Values indicate % flour retained on each sieve.
[b] Values in parentheses are total sums of % particles >210 µm (sieve nos. 20 –70) and <210 µm (sieve no. 80 –200 and collection pan).
[c] Whole grain.
[d] Decorticated grain.

among all processing methods, indicating lower cooked pasting qualities. Reduced peanut viscosity is attributed to the availability of less starch for gelatinization and the higher fat content of the seed (Table I). The inverse was observed in decorticated cowpea flours, which produced gruels with significantly higher viscosities corresponding to the high carbohydrate (70.4%), high protein (25.2%), and low fat (1.3%) seed composition (Table I). Roasting did not significantly increase viscosity among individual grain gruels (Fig. 2), although a significant increase in viscosity was observed in the millet-cowpea gruel blend (Fig. 3). The drying effect of roasting reduces the moisture content (Table I) of the flour. Reduced moisture allows a larger concentration of solids by weight, resulting in an increased viscosity. Malting produced the most significant change in viscosity. Although roasting increased pearl millet viscosity by 27% over control flours, malting decreased viscosity by >300%. Malleshi and Desikachar (1986) reported that the amylase activity of pearl millet tripled with 48 hr of germination, while producing a 20-fold decrease in viscosity in malted pearl millet flours. Malted cowpea flour yielded viscosity levels comparable to those of pearl millet. Nnanna et al (1990) reported that the variations in viscosity of germinated cowpeas were the result of proteolysis of proteins rather than starch reduction. Cowpea amylase activity during the first 24 hr of germination remained low and produced only minimum starch breakdown. Teff had lower viscosity levels with malting but not to the same extent as seen with the other grains. Amylase activity of teff may be lower than was observed for pearl millet. Umeta and Faulks (1988) reported high tannin levels in brown teff, which also may inhibit amylase activity.

Figure 3 shows viscosity measurements for composite blends formulated from teff, pearl millet, cowpea, and peanut at a 60:4% cereal-to-legume ratio. The appropriate viscosity for infant weaning foods is suggested to be 1,000–3,000 cps, which indicates the semiliquid consistency needed to prevent infant choking (Mosha and Svanberg 1983). Pasting characteristics of any individual flour varies due to differences in starch granule size, ratio of amylose to amylopectin, and proximate composition. Composite blends of flours develop pasting characteristics unique to that blend. Roasted cowpea-based blends (millet-cowpea and teff-pearl millet-cowpea) showed increased viscosity (>4,500 cps), exceeding the targeted range (1,000–3,000 cps). Malting reduced blend viscosities to a liquid consistency (<50 cps). Gruel blends containing peanut showed significantly lower viscosities than those with cowpea as the legume component. Reduction of viscosity in gruel blends used for infant feeding not only facilitates easier, more flexible infant feeding, but eliminates the need for diluting thicker products to an appropriate consistency. Dilution reduces nutrient density and often introduces pathogens into the food supply.

TABLE III
Physical Properties of Flours[a]

Index and Grain	Processing Method: Control	Roasting	Malting	Grain Type Mean[b]
Particle size index				
Teff	65.4 ± 2.3b	71.9 ± 5.3a	89.5 ± 0.5a	75.6AB
Pearl millet	49.9 ± 3.2c	70.8 ± 7.6a	89.4 ± 0.5a	70.0B
Cowpea	80.9 ± 1.2a	76.2 ± 7.3a	84.0 ± 0.2a	80.4A
Peanut	…	…	…	…
Process mean[b]	65.4Y	73.0Y	87.6X	
Water absorption index				
Teff	8.3 ± 0.6c	7.5 ± 0.5b	6.2 ± 0.4a	7.3A
Pearl millet	9.4 ± 0.7b	9.6 ± 0.4a	3.8 ± 0.2b	7.6A
Cowpea	10.6 ± 0.5a	9.1 ± 1.0a	4.2 ± 0.2b	8.0A
Peanut	2.1 ± 0.0d	1.6 ± 0.0c	2.2 ± 0.1c	2.0B
Process mean	7.6X	7.0X	4.1Y	
Water solubility index				
Teff	7.3 ± 0.1c	8.7 ± 0.6c	38.2 ± 1.4d	18.1D
Pearl millet	4.2 ± 0.2c	5.0 ± 0.0d	53.5 ± 0.8b	20.9C
Cowpea	11.8 ± 1.7b	13.4 ± 0.2b	47.6 ± 2.1c	24.3B
Peanut	67.8 ± 0.7a	62.3 ± 1.9a	59.3 ± 0.5a	63.1A
Process mean	22.8Y	22.4Y	49.7X	

[a] Mean of two replicates ± standard deviation. Significance of mean separation assessed, using Tukey's honestly significant difference test, at $P < 0.01$. Values followed by the same lowercase letter within each index column are not significantly different ($P < 0.05$).

[b] Mean of grain type and processing method. Significance of interaction of grain type and processing method assessed at $P < 0.01$. Significance of mean separation assessed, using Tukey's honestly significant difference test, at $P < 0.01$. Values followed by the same uppercase letter within the same parameter grouping are not significantly different. Mean comparison of grains is indicated within columns. Mean comparison of processing methods is indicated within rows.

CONCLUSIONS

The most significant changes in physicochemical properties of the grains evaluated were the result of malting. Although the use of sprouted flours is considered a hindrance to the baking industry, malted flours offer unique advantages for some food products. Malted seeds produce finer flours with diminished starch-swelling capacity and reduced gruel viscosities. Lower viscosities allow greater flexibility in adjusting flour concentrations. Roasting resulted in no significant effects on the physicochemical properties of any of the grains studied. The primary advantage of roasting continues to be contributions to sensory and storage qualities.

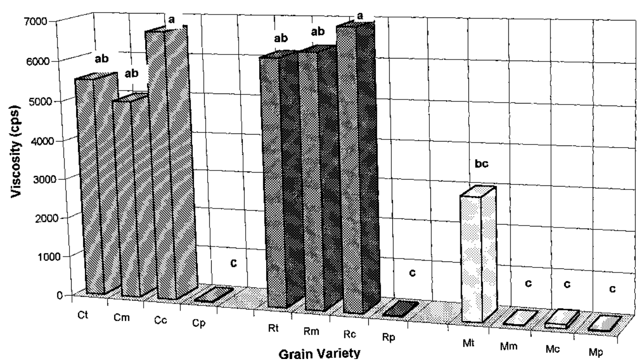

Fig. 2. Viscosity of gruels (15%, w/v) measured by a viscometer (Brookfield HBDT) at 50 rpm and 40°C. Processing methods noted as C = control, R = roasted, and M = malted. Grains noted as t = teff, m = pearl millet, c = cowpea, and p = peanut. Mean separation assessed using Tukey's honestly significant difference test. Grains with the same letter atop columns are not significantly different ($P < 0.05$).

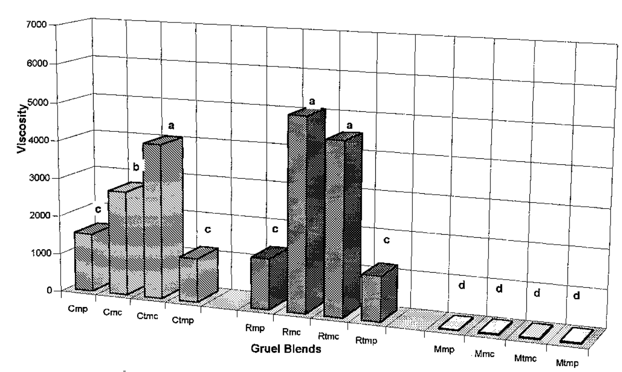

Fig. 3. Viscosity of blends (15%, w/v) measured with a viscometer (Brookfield HBDT) at 50 rpm and 40°C. Processing methods noted as C = control, R = roasted, and M = malted. Blends noted as mp = 60% millet + 40% peanut, mc = 60% millet + 40% cowpea, tmc = 20% teff + 40% millet + 40% cowpea, tmp = 20% teff + 40% millet + 40% peanut. Mean separation assessed using Tukey's honestly significant difference test. Blends with the same letter atop columns are not significantly different ($P < 0.05$).

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