Quality Assurance and Safety of Crops & Foods

Quality Assurance and Safety of Crops & Foods 2012, **4**, 126–133

ORIGINAL ARTICLE

Functional and antioxidant properties of ready-to-eat flakes from various cereals including sorghum and millets

HameedaBanu N. Itagi, Baragi Venkatesha Rao Sathyendra Rao, Padmanabhan Appukuttan Jayadeep & Vasudeva Singh

Department of Grain Science and Technology, Central Food Technological Research Institute, Mysore, India (Council of Scientific and Industrial Research, New Delhi)

Keywords
antioxidant; blistered; cereals; flakes; hydration; nutraceutical; smillets.

Correspondence:
Vasudeva Singh, Department of Grain Science and Technology, Central Food Technological Research Institute, Mysore-570 020, India. Tel: +91 821 2510843; Fax: +91 821 2517233;
E-mail: singhva2003@yahoo.co.in

Received 15 November 2011; Revised 16 January 2012; Accepted 5 April 2012.

doi: 10.1111/j.1757-837X.2012.00136.x

Abstract

Introduction Nowadays, ready to eat snacks are gaining much importance, as they are convenient to use, easy to handle compared with ready-to-cook snacks. *Objectives* To study the effects of cereal flaking and blistering process on the properties of the starch and nutraceutical content. *Methods* Ready-to-eat flakes from cereals such as maize grits, pearled barley, hulled oats, wheat, pearl millet and sorghum were prepared by hydration, hydrothermal treatment, flaking and blistering in a fluidized bed roaster. Commercial rice flakes were also considered. *Results* Grains hydrated slowly but flakes hydrated rapidly, indicating the effect of hydrothermal treatment where parboiling was imparted. Equilibrium moisture content on soaking was very high in barley (46%, wet basis) and lowest in maize grits and sorghum (approximately 30%). Swelling power in grains was 11–17% and solubility was 8–29%. On flaking, the swelling power of different flakes remained almost the same. However, the solubility increased significantly. Maize showed the highest amylose content (~29%) and wheat had the lowest. Soluble amylose was lowest in wheat and highest in oats. Gelatinization temperature was highest in pearl millet (77.4 °C) and lowest in barley (59.5 °C). Peak viscosity was high in all the grains, except pearl millet. On flaking and blistering, the gelatinization temperature values and peak viscosity reduced to different extents. *Conclusion* These blistered cereal flakes are excellent ready-to-eat snacks, as they are rich in total polyphenols (16-58 mg gallic acid equivalents/100 g) and exhibit high anti-oxidant activity and possess good functional properties.

Itagi HBN, Sathyendra Rao BVS, Jayadeep PA, Singh V (2012). Functional and antioxidant properties of ready-to-eat flakes from various cereals including sorghum and millets. *Quality Assurance and Safety of Crops & Foods*, **4**, 126–133.

Introduction

Flaked rice or beaten rice is a very popular traditional product in India and other rice-consuming countries. Rice flakes are consumed as snack after roasting, frying or spicing. Rice flakes are soaked in water and seasoned with spices and vegetables after draining excess water and consumed as an item of breakfast (Arya, 1990). Traditionally, roasted paddy is fed into an 'edge runner' to produce rice flakes. However, a method of flaking rice using roller flaker has also been developed (Narasimha *et al.*, 1982). Properties of flakes prepared by edge runner and by roller flaker have been studied. Rolled flakes were judged to be moist, tender, with a greater tendency for lumping compared with the edge runner flakes (Ekanayake & Narasimha, 1997). Nutrient changes and functional properties of rice flakes prepared in small-scale industry were reported by Deepa & Singh (2011). In some processing units, flakes produced in an edge runner are passed through a double roller. During this process though, the flakes attain a uniform shape; nutrients and nutraceuticals are lost. Flaking of maize and oats is also gaining prominence, and sorghum flaking is also increasing because flakes add to the variety in food consumption. There is a growing demand for ready-to-eat (RTE), low-fat and multigrain-based snacks as RTE cereals have been recognized as economical, convenient and healthy.

Flaking of grains is a thermo-mechanical process. Flakes are prepared by hydrating grains to their equilibrium moisture content, steamed to gelatinize the starch, dried to about 16–20% moisture, and flattened either by hand pounding (traditional) or by mechanical means. The preparation of RTE flakes involves steeping the grains in warm water to about 20% moisture, tempering, flaking and toasting (Robie & Hilgendorf, 2001). A method of steam flaking grains involves passing them through a steam chest for a predetermined time and pressure (Brown, 2002) before subjecting them to compression and shear. Thickness of flakes varies from 0.4 mm to 0.7 mm.

Literature on the effect of different thermo-mechanical steps followed during flaking of cereals is lacking. Therefore, the objective of this study was to determine the effects of cereal flaking and blistering process on the properties of the starch and nutraceutical content.

Materials and methods

Maize grits, bajra (pearl millet), barley, jowar (sorghum), wheat, oats and commercial rice flakes were purchased from a local market in Mysore, Karnataka, India, from a single batch. The grains were then cleaned and kept in airtight polyethylene bags in a cool and dry place prior to use.

Maize grits were conditioned by adding water in split doses, steamed under pressure, tempered and partially dried and flaked in a roller flaker, dried and blistered in a fluidized bed roaster. Pearl millet grain was conditioned by the addition of water in split doses to raise moisture to 18–20%, steamed under pressure and tempered and partially dried, pearled and then treated as for maize grits. Pearled barley was conditioned as for pearl millet, steamed under pressure, tempered, partially dried and then treated as for maize grits. Sorghum was soaked in hot water overnight and excess water is drained until there was no free water on the grain surface and then treated as for pearled barley. Wheat was treated similar to sorghum. Oats was dehulled in an impact huller; the moisture content of the groats was raised to 20–22% and then treated as for pearled barley. Commercial rice flakes were cleaned and blistered.

Analyses

The moisture contents of the grains, flakes and blistered flakes were determined by drying at 130 °C until constant weight AOAC (2000). Hydration behaviour of the grains, flakes and blistered flakes was determined by soaking them in water and removing them after different time intervals. Moisture was measured after removing surface moisture by compressing between Whatman no. 1 filter papers. Unprocessed and processed and blistered flakes were pulverized to 250 μm particle size and stored at 4 °C until analysis.

Swelling power and solubility of the pulverized samples were analysed at 30, 50, 70 and 100 °C (Singh *et al.*, 2000). The

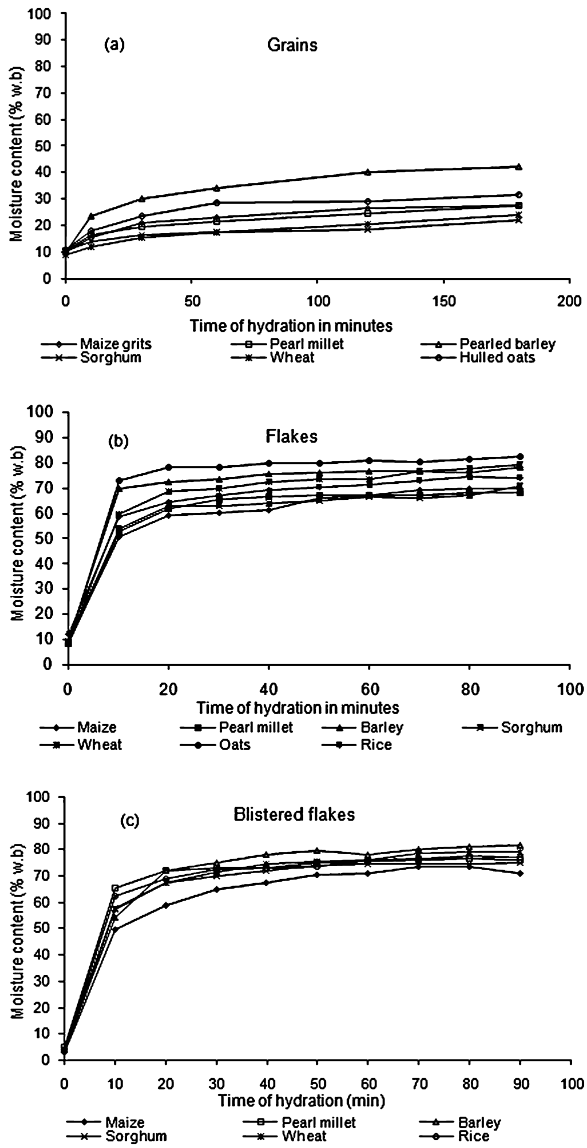

Figure 1 Moisture content (% wb) of different (a) grains, (b) flakes and (c) blistered flakes during hydration at different intervals of time.

Table 1 Equilibrium moisture content (% wb) of grains, flakes and blistered flakes

Equilibrium moisture content	Grains	Flakes	Blistered flakes
Maize	29.5 ± 0.58[a]	64.3 ± 0.55[b]	71.7 ± 0.41[c]
Pearl millet	34.7 ± 0.01[a]	73.6 ± 0.27[b]	73.9 ± 0.19[cb]
Barley	46.0 ± 0.19[a]	72.6 ± 2.75[b]	78.3 ± 0.95[c]
Sorghum	29.3 ± 0.12[a]	66.5 ± 0.22[b]	72.9 ± 0.44[c]
Wheat	37.2 ± 0.15[a]	70.9 ± 3.39[b]	73.3 ± 3.71[cb]
Oats	40.3 ± 0.06[a]	80.7 ± 0.36[b]	ND
Rice	ND	71.2 ± 0.17[a]	75.2 ± 0.83[b]

Values are mean ± standard deviation of three independent determinations.
Means with the same superscript (abc) within the same column block do not differ ($P > 0.05$).
ND, not determined.

Table 2 Soluble and total amylose in undefatted and defatted grains, flakes and blistered flakes

	Soluble amylose		Total amylose	
	Undefatted (%)	Defatted (%)	Undefatted (%)	Defatted (%)
Grains				
Maize	13.5 ± 0.24[a]	14.5 ± 0.17[b]	21.7 ± 0.06[a]	29.0 ± 0.10[b]
Pearl millet	8.3 ± 0.61[a]	13.0 ± 0.06[b]	15.5 ± 0.21[a]	21.2 ± 0.03[b]
Barley	10.9 ± 0.16[a]	16.1 ± 0.13[b]	18.0 ± 0.17[a]	23.6 ± 0.06[b]
Sorghum	9.6 ± 0.54[a]	14.7 ± 0.03[b]	18.6 ± 0.58[a]	24.6 ± 0.29[b]
Wheat	9.1 ± 0.67[a]	13.3 ± 0.02[b]	15.1 ± 0.03[a]	19.9 ± 0.05[b]
Oats	7.2 ± 1.05[a]	18.3 ± 0.32[b]	17.7 ± 0.27[a]	25.3 ± 0.11[b]
Flakes				
Maize	8.8 ± 0.01[a]	12.8 ± 0.02[b]	21.8 ± 0.02[a]	27.3 ± 0.12[b]
Pearl millet	7.5 ± 0.05[a]	12.4 ± 0.19[b]	18.5 ± 0.17[a]	23.4 ± 0.14[b]
Barley	8.5 ± 0.02[a]	15.8 ± 0.05[b]	16.7 ± 0.09[a]	22.6 ± 0.03[b]
Sorghum	8.9 ± 0.16[a]	14.0 ± 0.21[b]	19.1 ± 0.05[a]	25.4 ± 0.10[b]
Wheat	10.9 ± 0.02[a]	14.1 ± 0.05[b]	15.2 ± 0.17[a]	18.9 ± 0.11[b]
Oats	4.1 ± 0.16[a]	14.3 ± 0.29[b]	16.2 ± 0.04[a]	19.8 ± 0.07[b]
Commercial rice	7.6 ± 0.32[a]	14.0 ± 0.10[b]	17.2 ± 0.33[a]	22.3 ± 0.05[b]
Blistered flakes				
Maize	8.6 ± 0.25[a]	11.9 ± 0.08[b]	23.2 ± 0.09[a]	25.5 ± 0.01[b]
Pearl millet	8.1 ± 0.05[a]	11.5 ± 0.06[b]	19.3 ± 0.08[a]	22.9 ± 0.21[b]
Barley	9.2 ± 0.04[a]	14.2 ± 0.28[b]	17.9 ± 0.07[a]	21.8 ± 0.04[b]
Sorghum	9.5 ± 0.03[a]	13.5 ± 0.21[b]	20.0 ± 0.04[a]	24.9 ± 0.11[b]
Wheat	11.2 ± 0.24[a]	13.2 ± 0.13[b]	16.1 ± 0.03[a]	18.9 ± 0.05[b]
Commercial rice	9.2 ± 0.17[a]	12.9 ± 0.16[b]	18.1 ± 0.11[a]	20.9 ± 0.10[b]

Values are mean ± standard deviation of three independent determinations.
Means with the same superscript (ab) within the same column block do not differ ($P > 0.05$).

pasting profiles of the samples were determined using a Brabender Micro-Viscoamylograph (Duisburg, Germany). A 12% (w/v) flour slurry was heated to raise temperature from 30 °C to 92 °C at the rate of 7.5 °C per minute, maintained at 92 °C for 5 min and cooled to 50 °C at the same rate. Total amylose and soluble amylose were determined according to Kumar & Singh, (2011), before and after defatting. Polyphenol content and free radical scavenging activity were determined by extracting the flours (0.4 g) with 4 mL methanol. To extract bound polyphenols, the residue was extracted with 1% conc. HCl in methanol reagent. Polyphenols were assayed by the Folin Ciocalteu assay using ferulic acid as standard (Singleton *et al*., 1995). Free radical scavenging activity was determined using the 2,2-diphenyl-1-picrylhydrazyl free radical assay with catechin as standard (Bondet *et al*., 1997).

All the data were analysed by one-way analysis of variance followed by multiple comparison test (Tukey's test) at a 5% level of significance.

Results and discussion

Hydration of grains, flakes and blistered flakes

In the case of grains, hydration was carried out up to 3 h (Figure 1). Barley absorbed the most moisture (~40%) and

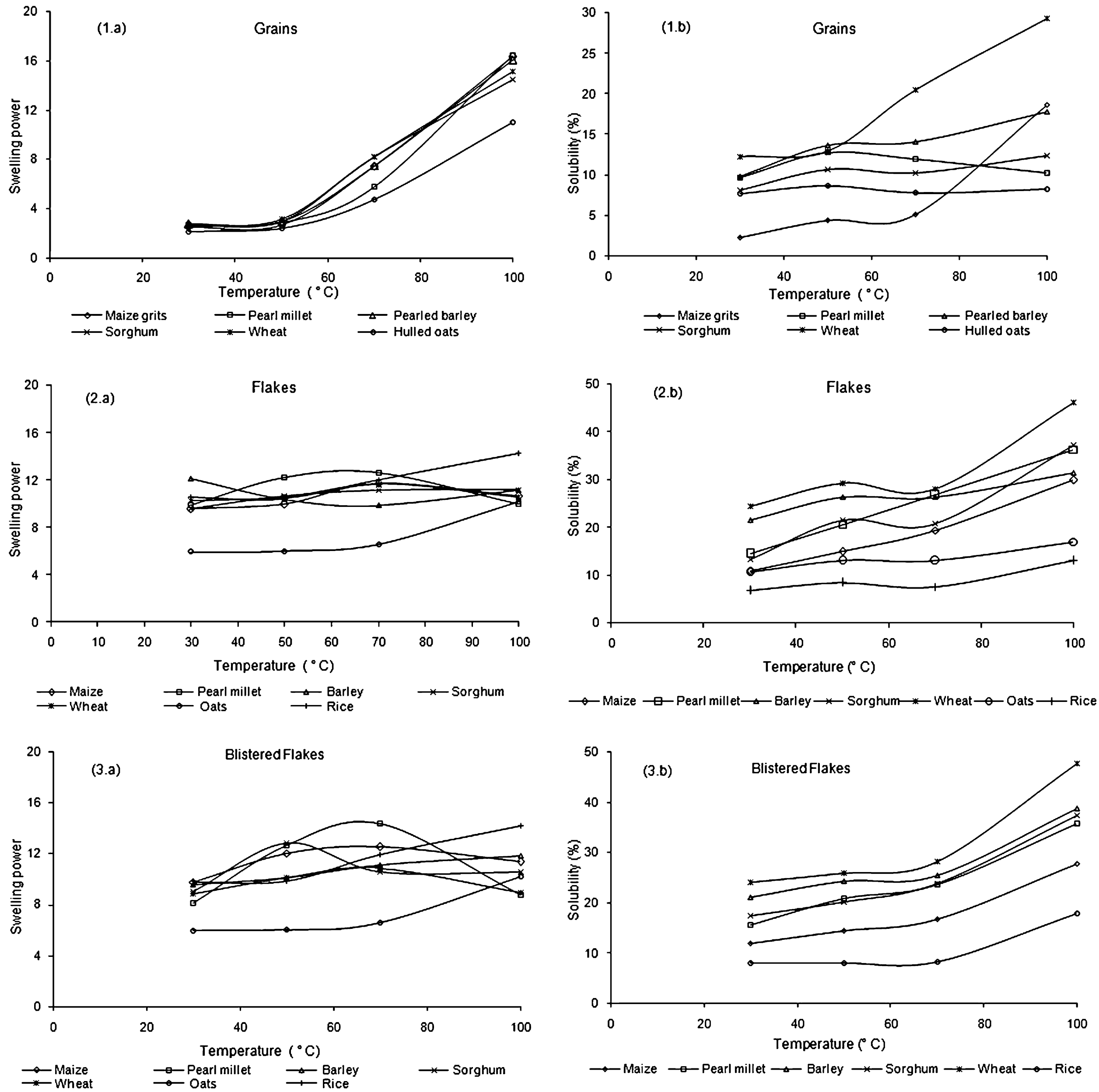

Figure 2 Swelling power and solubility patterns of (1.a) and (1.b) grains; (2.a) and (2.b) flakes; and (3.a) and (3.b) blistered flakes at different temperatures.

sorghum and wheat absorbed the least moisture (~20–23%). Flakes, being gelatinized products, rapidly absorbed moisture, even at 10 min. By 20 min, the flakes were almost saturated, 60–80% moisture, with oats absorbing the most moisture. The hydration behaviour of blistered flakes was similar to that of the flakes.

Equilibrium moisture content (EMC) for the grains varied from ~29 to 46% (wb) (Table 1). Lowest values were observed in the case of maize and sorghum, as observed by Singh *et al.* (2010). Barley showed the highest EMC, possibly because of the beta-amylase present in this grain. When these grains were flaked, their EMC increased substantially as they underwent starch gelatinization, drying and retrogradation. EMC ranged from ~64 to 81%. EMC values were also high in the case of blistered flakes because of the surface hardening phenomenon due to processing and drying, followed by high-temperature short-time treatment.

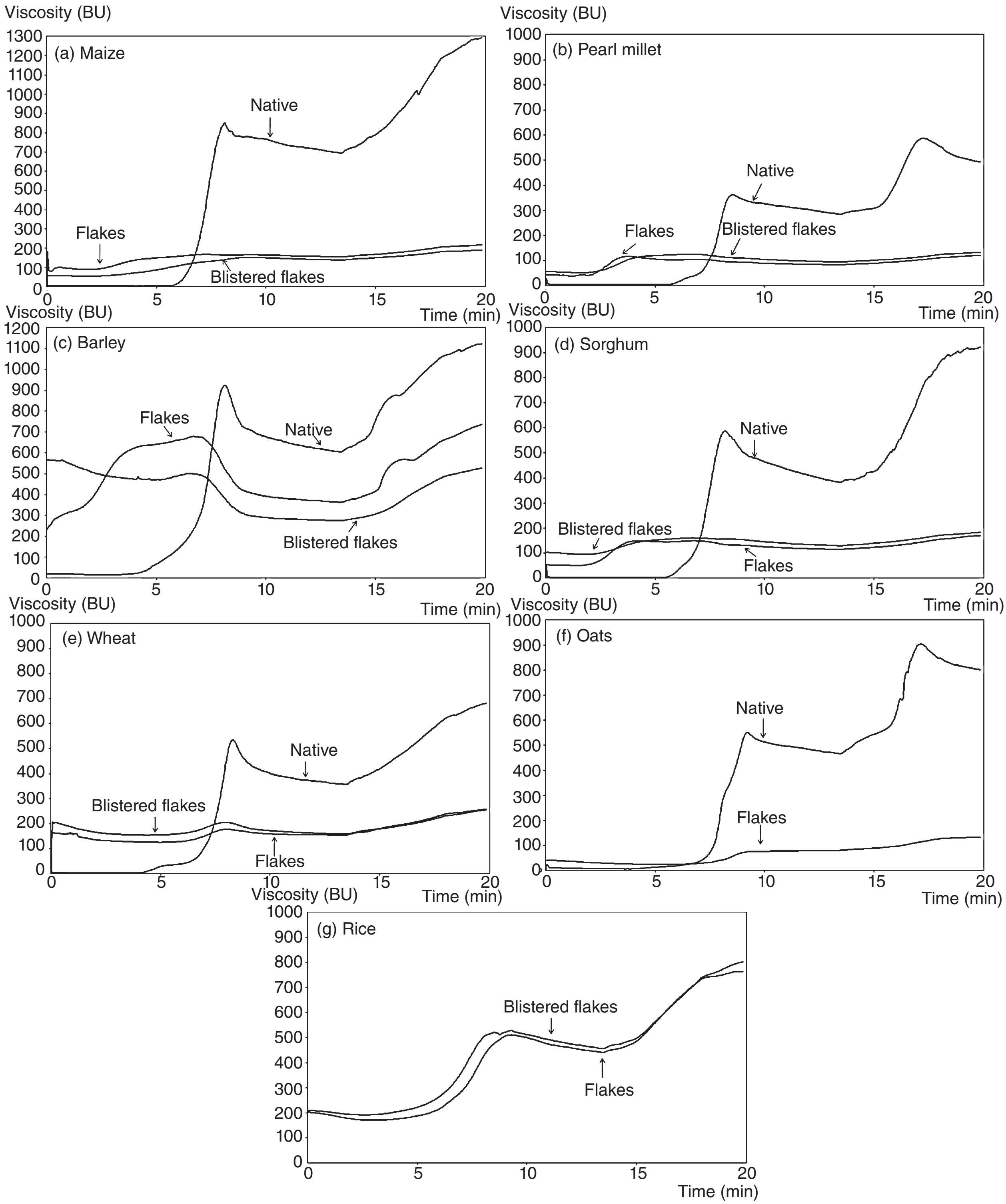

Figure 3 Pasting profile of grains, flakes and blistered flakes during hydration at different intervals of time. (a) maize, (b) bajra (pearl millet), (c) barley, (d) sorghum, (e) wheat, (f) oats, (g) commercial rice flakes.

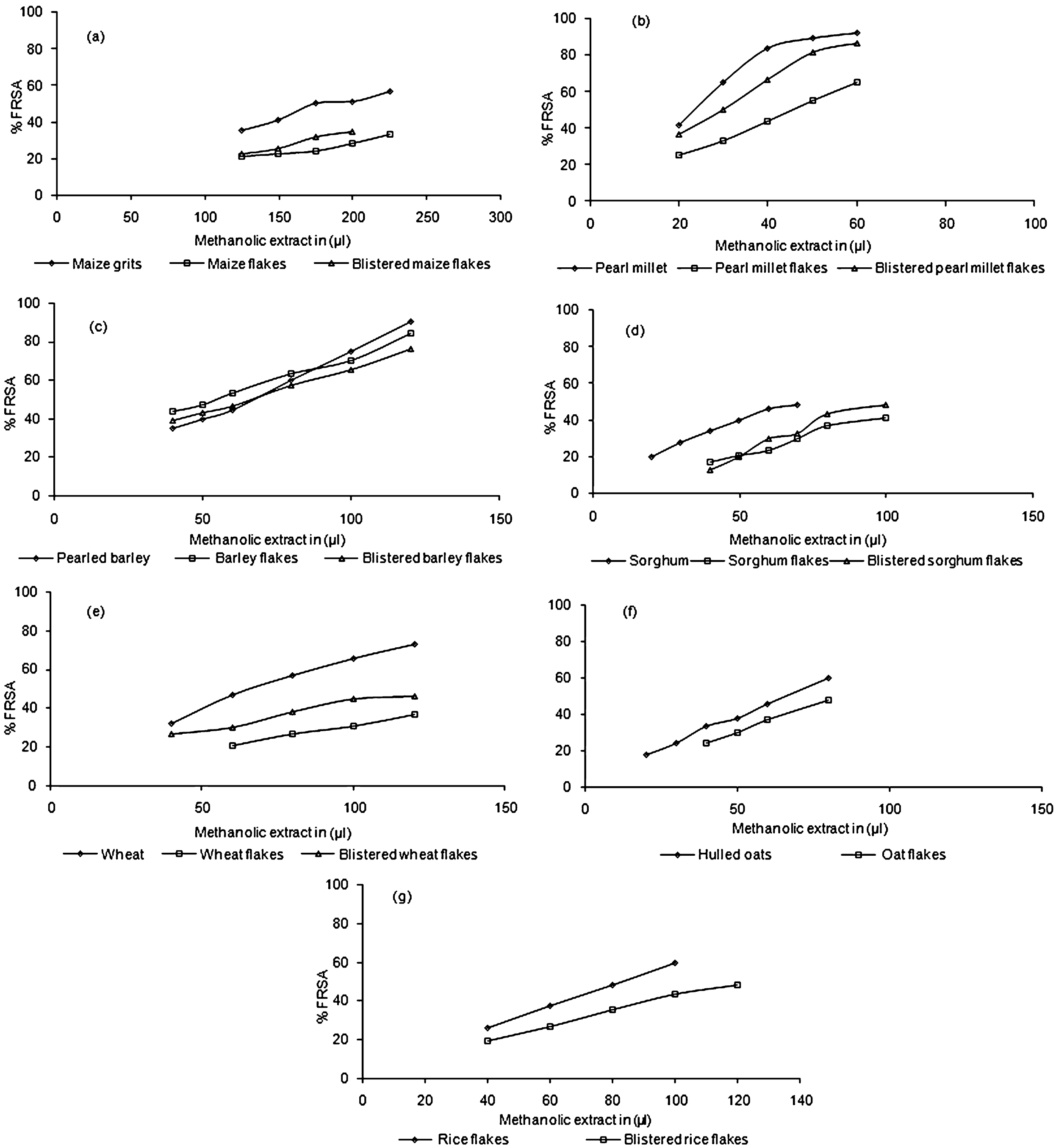

Figure 4 Free radical scavenging activity in grains, flakes and blistered flakes. (a) maize, (b) bajra (pearl millet), (c) pearled barley, (d) sorghum, (e) wheat, (f) hulled oats, (g) commercial rice flakes.

Swelling power and solubility

Swelling power (SP) of all the grains varied from ~2.5 to ~16, starting from 30 °C to boiling water temperature (BWT), except in the case of sorghum, wheat and oats (Figure 2). In sorghum and wheat, SP at BWT was around 15. In oats, the behaviour was quite different and the values were quite low. Solubility indicates the leaching out from the starch granules the linear molecules of amylose as well as the longest chain of amylopectin molecules. Solubility values ranged from 2 to 19% in maize.

Grains undergo hydrothermal treatment during flaking and hence flakes are already cooked. While drying, flakes also undergo starch retrogradation. The SP values were high, between 50 and 70 °C, around the gelatinization temperature (GT) range (Figure 2). In barley and wheat flakes, the solubility was quite high at room temperature, between 21 to ~24%, because the grains are already gelatinized during the flaking process. At BWT, the solubility was highest in the wheat flakes compared with other grain flakes. This may be due to the gluten protein in the wheat grain.

The blistered flakes behaved similarly to raw flakes with respect to swelling and solubility.

Total amylose (TA) and soluble amylose (SA)

In undefatted grains, the TA content varied from 15 to ~22% (Table 2). Wheat had the lowest level and maize had the highest level. In defatted flour, the range was from 20 to 29%. SA is the linear portion from both amylose and amylopectin molecules, which leaches out at the time of cooking. In undefatted flours, the lowest SA was in oats and highest in maize. In the flakes, TA ranged from 15 to 22%, with wheat flakes being lowest and maize being highest in undefatted form and 19 to ~ 27% in defatted form. SA in undefatted flakes ranged from 4 to 11%. In blistered flakes, TA undefatted varied from 16 to 23%, and in defatted one it ranged from 19 to 26%, with lowest values in wheat and highest in maize. SA was lower in blistered flakes (defatted) than flakes, presumably due to the high temperature and short time treatment, making the starch granules harder.

Pasting profiles

Among the native grains, apparent GT varied from ~60 °C to 77 °C, the lowest was in barley and wheat, and the highest was in pearl millet (Figure 3). Highest GT indicates the resistance to swelling and vice versa for lower GT. The highest pasting viscosity (PV) or peak viscosity occurred in maize and the lowest in pearl millet, probably due to their different starch granules sizes.

Concerning the flakes, as they are already cooked and dried or gelatinized, some of them gelatinize at a low temperature, ~38, 44 and 50 °C for barley, sorghum, pearl millet as well as maize, respectively (Figure 3). However, in wheat and oats, the GT values were high, indicating that these grains acquired parboiled nature (Ali & Bhattacharya, 1980). Similarly, the PV decreased in almost all grain flakes, indicating a parboiling effect.

In the case of the blistered flakes, GT and other pasting properties were similar to the respective flakes (Figure 3).

Effect of flaking and blistering on polyphenols

Flaking resulted in a more than 50% reduction in soluble polyphenol content. There was a general increase in the blistered flakes compared with the raw flakes. With regard to bound polyphenols, there was a general decrease with flaking except in the case of maize. With blistering, there was a decrease in all grains except pearl millet and maize (Table 3). The decrease in soluble and bound polyphenol on flaking may be due to the loss of bran layers from the whole grains, as a major portion of phenolics is present as soluble conjugated or insoluble-bound forms in cereals (Finocchiaro *et al*., 2007). Earlier research by Sinha & Kawatra (2003) also reported significant reduction in polyphenol content on hydrothermal cooking of cowpeas. Randhir *et al*. (2008) suggested that the dissociation of conjugated phenolic forms due to thermal processing was associated to a moderate reduction of hydroxycinnamic acid derivatives. The increase in soluble polyphenols on

Table 3 Polyphenol content of grains, flakes and blistered flakes (mg gallic acid equivalent per 100 g db)

	Soluble polyphenols	Bound polyphenols	Total polyphenols
Grains			
Maize grits	14.0 ± 0.39[a]	7.9 ± 0.09[a]	21.9 ± 0.48[a]
Pearl millet	82.6 ± 5.99[a]	98.1 ± 0.99[a]	180.7 ± 6.98[a]
Barley	30.9 ± 2.21[a]	37.8 ± 3.18[a]	68.7 ± 5.39[a]
Sorghum	44.3 ± 2.82[a]	24.6 ± 1.28[a]	68.9 ± 4.10[a]
Wheat	33.9 ± 0.46[a]	22.9 ± 0.94[a]	56.8 ± 1.40[a]
Oats	40.2 ± 6.30[a]	31.8 ± 2.07[a]	72.0 ± 8.37[a]
Flakes			
Maize	6.9 ± 1.00[b]	8.9 ± 0.56[b]	15.8 ± 1.56[b]
Pearl millet	19.4 ± 0.73[b]	31.8 ± 1.37[b]	51.3 ± 2.10[b]
Barley	15.5 ± 0.51[b]	29.7 ± 1.05[b]	45.3 ± 1.56[b]
Sorghum	7.7 ± 0.32[b]	9.2 ± 0.38[b]	16.9 ± 0.70[b]
Wheat	13.1 ± 0.58[b]	16.1 ± 0.73[b]	29.2 ± 1.31[b]
Oats	12.7 ± 0.53[b]	28.9 ± 0.56[b]	41.7 ± 1.05[b]
Commercial rice	15.4 ± 0.32[b]	18.3 ± 1.37[b]	33.7 ± 1.69[b]
Blistered flakes			
Maize	8.1 ± 1.02[c]	10.9 ± 0.62[c]	18.9 ± 1.64[c]
Pearl millet	22.4 ± 0.77[c]	35.5 ± 2.36[b]	57.8 ± 3.13[c]
Barley	15.3 ± 0.11[b]	18.5 ± 0.75[c]	33.8 ± 0.86[c]
Sorghum	10.7 ± 1.33[c]	5.3 ± 0.02[c]	15.9 ± 1.35[b]
Wheat	16.9 ± 0.92[c]	12.7 ± 0.20[c]	29.6 ± 1.12[c]
Commercial rice	11.9 ± 0.33[c]	11.2 ± 0.91[c]	23.12 ± 1.24[c]

Values are mean ± standard deviation of three independent determinations.
Means with the same superscript (abc) within the same column block of each grain form do not differ ($P > 0.05$).

blistering may be due to the liberation of bound polyphenols as well as higher extractability due to changes in starch structure on dry heat treatment. An increase in polyphenols due to thermal treatments have been reported by Galvez Ranilla *et al*. (2009) due to the thermal treatment-induced hydrolysis of conjugated phenolic compounds and resultant release of free phenolic acids.

Effect of flaking and blistering of flake on free radical scavenging activity

Free radical scavenging activity showed a decrease on flaking, whereas an increase was observed in most of the grains on blistering (Figure 4). There was high degree of correlation between the content of soluble polyphenols and free radical scavenging activity, except in sorghum on blistering. This may be due to the difference in the nature of the polyphenols.

Conclusions

Blistered cereal flakes have good polyphenol content and high antioxidant activity and good properties in terms of solubility and starch pasting. Because of these good nutraceutical and functional properties they make excellent RTE snacks.

Acknowledgement

The authors are grateful to the Director, CFTRI, for encouraging us to carry out this work under the 11th five-year plan project (2007–2012).

References

Ali S.Z., Bhattacharya K.R. (1980) Pasting behavior of parboiled rice. *Journal of Texture Studies*, **11**, 239–245.

AOAC. (2000) *Official Methods of Analysis*, 17th edn. Association of Official Analytical Chemists, Washington, DC.

Arya S.S. (1990) Grain based snack and convenience snack II. *Indian Food Packer*, **44** (5), 17–38.

Bondet V., Brand-Williams W., Berset C. (1997) Kinetics and mechanisms of antioxidant activity using the DPPH free radical method. *Food Science and Technology – LWT*, **30**, 609–615.

Brown D.R. (2002) Method for steam flaking grain. United States patent US 6 428831 B1.

Deepa C., Singh V. (2011) Nutrient changes and functional properties of rice flakes prepared in a small scale industry. *Oryza*, **48**, 56–63.

Ekanayake S., Narasimha H.V. (1997) Comparative properties of rice flakes prepared using edge runner and roller flaker. *Journal of Food Science and Technology*, **34**, 291–295.

Finocchiaro F., Barbara Ferrari B., Alberto Gianinetti A., Chiara Dall'Asta C., Galaverna G., Scazzina F., Pellegrini N. (2007) Characterization of antioxidant compounds of red and white rice and changes in total antioxidant capacity during processing. *Molecular Nutrition and Food Research*, **51**, 1006–1019.

Galvez Ranilla L., Genovese M.I., Lajolo F. (2009) Effect of different cooking conditions on phenolic compounds and antioxidant capacity of some selected Brazilian bean (*Phaseolus vulgaris L.*) cultivars. *Journal of Agricultural and Food Chemistry*, **57**, 5734–5742.

Kumar U., Singh V. (2011) Preparation and functional properties of noodles prepared from raw and hydro-thermally processed rice. *Oryza*, **48**, 258–266.

Narasimha H.V., Ananthachar T.K., Shankara R., Gopal M.S., Desikarchar H.S.R. (1982) Development of a continuous process for making rice flakes. *Journal of Food Science and Technology*, **19**, 233–236.

Randhir R., Kwon Y.I., Shetty K. (2008) Effect of thermal processing on phenolics, antioxidant activity and health-relevant functionality of select grain sprouts and seedlings. *Innovative Food Science and Emerging Technologies*, **9**, 355–364.

Robie S.C., Hilgendorf D.J. (2001) RTE cereal and method of preparation. United States patent US6 291008 B1.

Singh V., Okadome H., Toyoshima H., Isobe S., Ohtsubo K. (2000) Thermal and physico- chemical properties of rice grain, flour and starch. *Journal of Agricultural and Food Chemistry*, **48**, 2638–2647.

Singh V., Vishwanathan K.H., Ashwathanarayana K.N., Indudhara Swamy Y.M. (2010) Hydration behaviour of food grains and modelling their moisture pick up as per Peleg's equation : Part I. Cereals. *Journal of Food Science and Technology*, **47**, 34–41.

Singleton V.L., Orthofer R., Rosa M.L. (1995) Analysis of total phenols and other oxidation substrate and antioxidants by means of Folin–Ciocalteau reagent. *Methods in Enzymology*, **299**, 152–171.

Sinha R., Kawatra A. (2003) Effect of processing on phytic acid and polyphenol contents of cowpeas [*Vigna unguiculata* (L) Walp]. *Plant Foods for Human Nutrition*, **58**, 1–8.

