Effect of ingredients on the quality characteristics of gluten free snacks

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Abstract Grain-based fabricated snacks from non-wheat grains (amaranth, finger millet, sorghum and black gram) were used to prepare puffed snacks employing the method of hot air toasting. The functional characteristics and sensory attributes of the snack were determined by varying the moisture content and time of toasting. The quality attributes of the snacks like the instrumental color parameters, peak force and puff thickness of the snack correlated well with the sensory attributes (appearance/color, texture and overall acceptability). A snack made from amaranth showed a bright reddish brown colour at a moisture content of 20–40%; the product had a good puffing and high overall acceptability. The moisture content of all the snacks was around 3% and had a fat content of 1–2%; protein and dietary fiber contents were in the ranges of 22–23 and 10–11%, respectively. The principal component analysis (PCA) accounted for a total of 89.6% variation. The PCA biplot showed that sensory appearance, sensory texture and sensory overall acceptability were closely related to the puff thickness. The microstructure of the snack indicated the presence of air cells to offer a porous structure. On toasting, the flakes increased their thickness creating a porous microstructure such that the toasted snacks were crispy having a brittle texture. Popped sorghum and gelatinized starch added doughs exhibited good puffing when toasted at 20–30% moisture content while popped amaranth samples required higher moisture content (30–40%). The grain based gluten-free snacks with improved sensory

and nutritional characteristics can be prepared by using different ingredients.

Keywords Snack · Amaranth · Sorghum · Black gram · Microstructure

Introduction

Snack foods may be defined as the large proportion of foods which are eaten between the regular meals. The rapid establishment in consumption of different snack foods causes a breakdown in the traditional pattern of eating three times a day (Booth 1990). Global launches of various snack foods are happening every year of which savory and salty snacks account for about two-third, and the remainder is snack nuts and seeds (Anon 2017). A number of released products is gluten-free snacks and fortified with vitamins and minerals.

The market potential for healthy food is increasing at a fast pace in the recent years due to the consumers' focus shifting towards a positive approach to remain healthy. Further, the celiac disease (CD) is a disorder which disturbs the human digestion and the absorption of nutrients in the intestine (de la Hera et al. 2013). Persons suffering from CD have to evade gluten-containing foods. Thus, there is a need to develop gluten-free snacks which match the product characteristics made using wheat. The raw materials to make such products may include black gram, sorghum, amaranth and finger millet. Black gram, also known as black lentil, is a popular legume in the south-east Asian countries. It provides protein, carbohydrates, and several vitamins and minerals, and rich in lysine (Singh et al. 2017). Black gram consumption is reported to be highly correlated with a reduced risk of coronary heart disease; it

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is high in amylose starch making them a good source of probiotics resistant starch and helps to control blood glucose management by lowering the glycemic index (Berrios et al. 2010). The legume is conventionally consumed as the cooked whole grain or split sample called *dhal*. It contains an unusual mucilaginous ingredient (Siddhuraju and Becker, 2005) which helps in the preparation of several traditional food products. Ground flour and paste are extensively used in culinary preparations, such as *dosa*, *idli*, *vada*, and *pappadam/papad* and other breakfast snacks and extruded products (Siddhuraju and Becker 2005). Toasting or puffing processing of black gram has been reported not to significantly affect the total available carbohydrates (TAC) but decreases the concentration of oligosaccharides (raffinose and stachyose) in the pulse product. Sorghum may be another health food due to the presence of a good amount of phytochemicals such as polyphenols, dietary fibre and minerals (Sanddhyia et al. 2013). It is also called a pseudo-cereal and an underutilised plant seed but has a promising economic value and has a potential to incorporate it into existing food products, as well as to create new products. The high lysine content of amaranth is particularly beneficial for infants, children, and pregnant and lactating women (Punia 2000). Finger millet (*Eleusine coracana*) is widely grown as a cereal in the arid areas of Africa and Asia. It is rich in minerals and nutrients and can be used to make flatbreads, including thin, leavened *dosa*, unleavened *roti*, thick porridge and malted flour (Vidya et al. 2013).

Preparation of shelf-stable food products utilizing whole grain requires a processing technology which minimizes the loss of the food grain. Popping, a high-temperature processing method, is often employed for a short time. It is a manufacturing step to enhance the protein digestibility, bio-availability of minerals and dietary fiber content (Sanddhyia et al. 2013). Popped grains offer potential health benefits including reduced risk of heart disease and certain cancers that are mainly because of high fiber and antioxidant contents (Sharma et al. 2014). The hot-air popping of amaranth results in an apparent nitrogen digestibility of 77% and a protein efficiency ratio (PER) of 1.7 which are not significantly different from those of the raw grain. Hence, there is a scope to use different grains having diversified health properties to formulate the multigrain snack.

The objectives of the present investigation are (a) to study the functional and textural properties of the thermally treated grains such as sorghum, amaranth, finger millet and black gram blended flour and dough, and their effect on snack quality, and (b) to relate the instrumental and sensory attributes of the dough and the snack product.

Materials and methods

Materials

Grains such as black gram, sorghum, amaranth and finger millet were procured from a local supermarket in Mysore, India and cleaned manually to remove impurities if any. Sorghum, amaranth and finger millet at a moisture content of 12% were individually popped in a domestic popcorn maker at 260 °C for 30 s. The time and temperature of popping were decided after conducting the preliminary trials to obtain the popped samples. The popped seeds were then ground in a laboratory model vertical grinder (Surabhi, Mysore, India) to obtain flour that passed through a 60 mesh British Standard sieve (BSS) with an opening of 250 microns. Unprocessed native grains were also pulverized to flour and passed through a 60 mesh BS sieve. The temperature of the sample was always kept below 40 °C during grinding to avoid starch gelatinization. Gelatinized corn starch was procured from the supermarket. The proximate composition of the raw flour and dietary fiber, in triplicates, were determined following the methods of AOAC (2002) and Asp et al. (1983), respectively.

Total amylose

Total amylose content was determined following the method of Sowbhagya and Bhattacharya (1979). The blue colour developed was measured at 630 nm. Pure amylose (from potato, type III, Sigma, USA) was used as the standard. Triplicate samples were used for measurements.

Water absorption capacity

Water absorption capacity of the flour was determined according to the procedures of Elhardallou and Walker (1993). The values were reported as g of water absorbed per 100 g of dry flour. All determinations were repeated thrice.

Preparation of snacks

Four doughs were made with the blended flours; these were # 1 (BLC + PF) (black gram + popped finger millet), # 2 (BLC + PS) (black gram + popped sorghum), # 3 (BLC + GS) (black gram + gelatinized starch) and # 4 (BLC + PA) (black gram + popped amaranth) all with a ratio of 80:20 with the required quantity of water; the moisture content of the doughs were varied at 34, 37 and 40%. The four formulations required different quantities of water to form dough that could be pressed through the pasta press. The selection of these four formulations was

based on preliminary trials to obtain acceptable snacks. The doughs were allowed to pass through the extruder/shaping machine (laboratory model pasta press) and were cut into the desired rectangular shape 10 mm × 10 mm. They were then dried in an air oven at 60 °C for different times to obtain flakes with the moisture contents of 10, 20, 30 and 40%. Flakes were then toasted at a temperature of 180 ± 4 °C for 3 min by employing a laboratory model hot air toasting machine as detailed elsewhere (Sumithra and Bhattacharya 2008). The thickness of the untoasted and toasted flakes was measured individually using a dial thickness gauge, and average thicknesses were calculated by measuring at 5 different locations of ten flakes.

Textural characteristics of dough

The doughs were shaped as short cylindrical samples of about 35 mm in diameter and 20 mm in height as described earlier by Bhattacharya (2012). The samples were compressed up to 50% strain at a crosshead speed of 50 mm min⁻¹ to obtain the peak force (hardness), compression energy and firmness according to Rajesh et al. (2015). A load cell of 1 kN was used while employing a Universal Testing machine (model # 5R, Lloyd, West Sussex, UK). The two-cycle compression was conducted by compressing up to a strain of 0.80 to obtain the parameters of texture profile analysis (TPA). The software provided by the manufacturer was used to calculate the TPA parameters like cohesiveness, springiness and adhesiveness. Five samples were prepared for each testing and the process of dough making was replicated twice.

Color of snack

The color of the toasted snacks was determined by employing a colour meter (model # CM5, Minolta, Osaka, Japan) using the illuminant D₆₅ with a view angle of 10° and slit diameter of 10 mm. The CIE Lab method was employed to obtain L*, a*, b* and ΔE values. The L* values indicated the lightness or reflecting ability, a* and b* were the color parameters, and the total color difference (ΔE) denoted the difference in color using a white ceramic plate, supplied by the instrument manufacturer, as the standard white.

Sensory assessment

The toasted snacks were assessed by 20 trained panelists by using their hands, fingers and mouth to determine the sensory attributes such as texture, appearance (color) and overall acceptability (Bhattacharya and Narasimha 2008). The selection and training of the panelists were described

by Tiwari et al. (2012). Sensory assessment of the product was conducted by employing a 9-point hedonic scale (9: like extremely, 1: dislike extremely) with 5 as the limit of acceptance. The assessment was repeated thrice.

Microstructure

The dehydrated flake samples, obtained by dehydrating with the serial dilution of alcohol, were mounted on aluminium stubs with conductive adhesive tapes followed by coating with gold in a sputter coater. The samples were examined under a scanning electron microscope (model # 435 VP, Leo Electron Microscopy, Cambridge, UK) as described by Bhat and Bhattacharya (2001). The magnification employed was 200× and 1000×, and representative photomicrographs of the samples were reported here.

Results and discussion

Proximate composition

The proximate composition of different raw materials, used for the preparation of the snacks is shown in Table 1. The carbohydrate content of finger millet is highest followed by sorghum and amaranth but is least for black gram. Fat content is highest in amaranth and finger millet, and lowest in black gram. Ash content is highest in black gram and amaranth but is least in sorghum. Amaranth contains markedly higher dietary fiber ($p \leq 0.05$) compared to all other cereals and millets used in the present study.

Amylose content

Table 2 shows the amylose content of the raw and popped grains. Among the raw grains, finger millet contains the highest amylose (25.5%) followed by sorghum and amaranth. A similar trend is found for their popped grains. Black gram contains the least content of amylose possibly due to its high protein level and less starch content as compared to other cereal grains. Popped grains contain more amylose (Table 2) possibly due to the transformation of amylopectin into amylose (Lai and Kokini 1991). Amylose content in the samples is popped finger millet > gelatinized starch > popped sorghum > popped amaranth. De Pilli et al. (2008) have shown that amylopectin leads to more absorption of water due to the branched structure, and accordingly, more water is absorbed by raw grains having a high level of amylopectin. However, popped grains absorb more water than their corresponding raw grains possibly because of gelatinization of the native starch due to high-temperature treatment

Table 1 Proximate composition of the raw materials

Material	Moisture (%)	Fat (%)	Protein (%)	Ash (%)	Carbohydrate (by difference) (%)	Dietary fibre (%)
Blackgram	9.9 ± 0.4	1.2 ± 0.1	23.8 ± 0.6	3.1 ± 1.4	63.0	9.5 ± 0.4
Sorghum	10.6 ± 0.3	1.9 ± 0.1	10.2 ± 0.4	1.6 ± 1.4	75.7	13.2 ± 0.5
Finger millet	8.5 ± 0.4	7.3 ± 0.3	7.4 ± 0.3	2.6 ± 1.4	78.2	11.7 ± 0.6
Amaranth	10.9 ± 0.3	8.0 ± 0.2	16.5 ± 0.3	3.0 ± 1.4	66.0	14.5 ± 0.6

Table 2 Amylose content and water absorption capacity of the grains and their mixtures

Materials	Amylose content (%)	Water absorption capacity (%)
Black gram (BLC)	2.5 ± 0.4 ^a	296.0 ± 4.4 ^c
Raw finger millet	25.5 ± 1.0 ^e	180.5 ± 6.2 ^a
Popped finger millet (PF)	38.3 ± 1.4 ^h	403.3 ± 4.2 ^g
Raw sorghum	21.8 ± 1.1 ^d	190.8 ± 2.2 ^b
Popped sorghum (PS)	29.7 ± 1.2 ^f	442.1 ± 2.8 ^h
Gelatinized starch (GS)	33.1 ± 1.3 ^g	696.6 ± 8.7 ⁱ
Raw amaranth	4.3 ± 0.6 ^b	230.9 ± 9.2 ^b
Popped amaranth (PA)	12.7 ± 0.8 ^c	552.7 ± 32.0 ⁱ
BLC + PF	–	317.3 ± 8.6 ^d
BLC + PS	–	315.3 ± 5.1 ^d
BLC + GS	–	356.8 ± 5.8 ^f
BLC + PA	–	339.7 ± 7.7 ^e

^aMeans with different superscripts within the same column are significantly different at $p \leq 0.05$

(Abbas et al. 2010) and increased surface area due to expansion.

Functional property

The functional property such as the water absorption capacity (WAC) of different grains employed in the present study is shown in Table 2. The WAC of the gelatinized starch is higher than that of all raw and processed grains. A similar observation has been indicated by Abbas et al. (2010) for starches. Amaranth possesses a high WAC among the grains because it contains a low amylose content (12.7%) but a high level of amylopectin; the latter has a branched structure. The same reason is also true for WAC of sorghum than that of finger millet. Black gram, being a legume, has a low WAC than other popped cereals or millets because it has a high content of protein but a low level of carbohydrate (Ituen et al. 1986; McEntyre et al. 1998).

Physical properties of dough

Compression characteristics of dough samples

Compression characteristics of various dough samples made from different cereals and legume at different

moisture contents are presented in Table 3; the photographs of the developed samples are shown in Appendix (Fig. 3). Hardness, firmness and compression energy of doughs are highest for black gram blended with popped finger millet followed by gelatinized starch, sorghum and amaranth samples. Popped finger millet contains the highest level of amylose level (38.3%) which restricts the absorption of water leading to the formation of a hard dough showing a high hardness and thus requires a high level of energy for compression (1240 mJ) (Table 3). Park and Baik (2002) have shown that a high WAC of flour can lead to the formation of a soft dough and influences the hardness, firmness and other rheological characteristics of the dough. The BLC + PA dough has the least hardness, firmness and compression energy as it absorbs a high quantity of water because of a low amylose content but a high level of dietary fibre (Wang et al. 2002). An increase in moisture content of dough (such as 39%) leads to a soft sample imparting reduced compression energy (1240 mJ) compared to a low moisture (34%) dough which imparts a higher compression energy (1513 mJ) for the blend of black gram and finger millet. The black gram-gelatinized starch dough is the softest sample and imparts the least hardness, firmness and compression energy.

Table 3 Instrumental compression characteristics of different doughs

Material	Moisture content (%)	Compression energy (mJ)	Hardness (N)	Firmness (N/mm)	Cohesiveness (–)	Springiness (mm)	Adhesiveness (mJ)
BLC + PF	40	1239.5 ± 24.8 ^b	457.4 ± 16.9 ^f	236.9 ± 8.0 ^d	0.169 ± 0.004 ^e	2.68 ± 0.26 ^c	22.97 ± 2.33 ^f
BLC + PS	40	923.5 ± 13.1 ^e	365.4 ± 14.4 ^d	209.0 ± 15.6 ^c	0.193 ± 0.010 ^f	2.22 ± 0.07 ^b	76.15 ± 2.31 ⁱ
BLC + GS	40	1042.7 ± 141.2 ^f	430.2 ± 7.7 ^e	222.6 ± 4.8 ^c	0.249 ± 0.013 ^g	2.25 ± 0.05 ^b	88.34 ± 4.91 ^j
BLC + PA	40	37.4 ± 3.2 ^a	108.5 ± 9.8 ^a	45.5 ± 4.9 ^a	0.065 ± 0.002 ^c	0.67 ± 0.05 ^a	0.018 ± 0.002 ^b
BLC + PF	37	1346.5 ± 21.0 ^j	561.2 ± 6.3 ^h	269.2 ± 1.7 ^f	0.137 ± 0.009 ^d	6.05 ± 0.43 ^f	17.79 ± 1.98 ^e
BLC + PS	37	745.7 ± 47.0 ^d	496.1 ± 11.9 ^f	246.8 ± 6.4 ^d	0.160 ± 0.002 ^e	3.20 ± 0.27 ^d	50.14 ± 2.58 ^g
BLC + GS	37	1176.5 ± 18.3 ^g	535.9 ± 9.5 ^g	265.9 ± 5.7 ^f	0.239 ± 0.023 ^g	4.16 ± 0.04 ^g	62.47 ± 2.83 ^h
BLC + PA	37	63.1 ± 7.3 ^b	179.7 ± 19.8 ^b	82.7 ± 1.3 ^b	0.056 ± 0.005 ^b	2.65 ± 0.07 ^b	0.018 ± 0.006 ^b
BLC + PF	34	1513.2 ± 26.9 ^k	586.4 ± 16.5 ⁱ	295.6 ± 6.5 ^g	0.144 ± 0.010 ^d	7.02 ± 0.14 ^f	4.29 ± 0.58 ^c
BLC + PS	34	733.6 ± 23.0 ^d	477.5 ± 24.9 ^f	258.7 ± 1.1 ^e	0.162 ± 0.005 ^e	2.53 ± 0.06 ^c	8.82 ± 0.46 ^d
BLC + GS	34	1285.5 ± 15.3 ⁱ	561.5 ± 7.5 ^h	277.5 ± 8.8 ^f	0.230 ± 0.005 ^g	3.22 ± 0.32 ^d	9.67 ± 1.08 ^d
BLC + PA	34	93.1 ± 7.3 ^c	198.0 ± 1.3 ^c	86.5 ± 11.4 ^b	0.045 ± 0.002 ^a	3.13 ± 0.21 ^d	0.006 ± 0.001 ^a

Abbreviations are mentioned in Table 2

^aMeans with different superscripts within the same column are significantly different at $p \leq 0.05$

Non-oral sensory assessment of dough samples

The high extent of water absorption of the flour generally leads to an increase in cohesiveness and adhesive nature of the dough to a certain extent. However, if a high level of water absorption occurs as in the case of amaranth sample, then water molecules lead to the disruption of cells and hasten cohesiveness and the adhesive property. Cohesiveness is the attraction within the same type of molecules and is based on the phenomenon of capillary action (Labuza 1977). When one water molecule is filled in the capillary, it tends to pull another water molecule. Hence, it imparts more adhesion characteristics in the structure of the dough; if the water content decreases significantly, cohesiveness also decreases. Similarly, adhesive nature also decreases with a decrease in moisture content. Labuza (1977) has indicated that water contributes to the structure of the dough and thus controls the sensory, physical and chemical properties by improving the binding property of the molecules.

The non-oral sensory analysis (Appendix Fig. 4) shows that the hardness of dough samples increases with a decrease in moisture content whereas stickiness is more in the dough with higher moisture contents compared to that of lower moisture samples. The BLC + PF dough is the hardest and most sticky sample followed by BLC + PS and BLC + GS doughs, whereas BLC + PA dough is the least hard and sticky. The stickiness of black gram (BLC) samples can be attributed to the presence of mucilage compound called arabinoglucan (Siddhuraju and Becker 2005). The high stickiness of the BLC + PF dough has a

poor machinability features and thus possesses undesirable handling properties compared to other dough samples.

Characteristics of snack

Texture

The texture of snack, prepared after shaping the dough at 40% moisture content and consequent drying at 60 °C, shows that BLC + GS and BLC + PS dough give the best snack in terms of their puff thickness and sensory texture (Table 4); these ribbon-shaped flakes are toasted at a moisture content range of 10–40%. A different trend is noticed in the case of BLC + PA dough. Good quality puffed snacks are obtained when the moisture content of the dough is high (30–40%). The quality attributes decrease as the moisture content of BLC + PA dough decreases. The hardness (peak force) of all the snacks increases (Table 4) with a decrease in the moisture content of the ribbon-shaped flakes. At a low moisture content, the hardness is markedly high, which implies that the product becomes hard when toasted at a low moisture content. The hardness of snack product ranging between 10 and 20 N is the most desirable one because it gives a good crispness feature and attractive mouth feel of the product.

Puff thickness (Table 4) also increases with an increase in the moisture content of the flake. Since starch granules in amaranth have more WAC (Table 2) compared to other grains, a low moisture containing dough possibly restricts puffing because of the presence of insufficient water present in the starch granules; the good puffing of the snack occurs when the moisture content is between 30 and 40%

Table 4 Instrumental and sensory textural parameters of the snacks developed with different raw materials

Dough	Moisture content of flake (%)	Instrumental parameters						Sensory parameters		
		Peak force (N)	Colour parameters				Puff thickness (mm)	Texture	Visual colour	Overall acceptability
			L*	a*	b*	ΔE				
BLC + PF	40	5.8 ± 0.2 ^a	42.0 ± 1.0	10.3 ± 0.3	17.8 ± 0.5	55.7 ± 0.3	9.8 ± 0.4 ^f	8.0 ^f	6.5 ^c	8.0
	30	9.6 ± 0.0 ^d	36.0 ± 1.4	10.9 ± 0.1	19.7 ± 0.6	55.8 ± 1.1	10.1 ± 1.1 ^f	7.9 ^f	7.9 ^d	7.9
	20	13.6 ± 0.1 ^g	44.8 ± 0.1	8.3 ± 0.4	21.2 ± 0.5	56.9 ± 0.2	10.9 ± 0.6 ^f	7.9 ^f	7.7 ^d	7.9
	10	861.4 ± 1.7 ^r	46.6 ± 2.8	11.6 ± 0.1	25.3 ± 2.0	51.7 ± 2.1	2.9 ± 0.7 ^d	4.0 ^b	4.2 ^a	4.5
BLC + PS	40	10.0 ± 0.3 ^d	47.5 ± 0.1	19.8 ± 0.7	21.3 ± 5.0	73.8 ± 6.7	5.5 ± 0.4 ^c	5.1 ^c	4.0 ^a	4.2
	30	14.6 ± 0.8 ^h	55.5 ± 2.5	13.7 ± 0.5	32.2 ± 0.1	57.2 ± 0.1	8.5 ± 0.9 ^f	8.2 ^f	8.2 ^d	8.2
	20	17.1 ± 0.8 ^h	64.7 ± 0.9	16.3 ± 0.3	33.3 ± 0.0	57.0 ± 0.7	7.8 ± 0.5 ^e	7.9 ^f	7.9 ^d	8.0
	10	826.5 ± 3.6 ^p	47.8 ± 0.0	18.3 ± 0.0	42.5 ± 0.0	73.7 ± 0.0	2.2 ± 0.2 ^a	3.1 ^a	3.8 ^a	3.0
BLC + GS	40	11.6 ± 0.7 ^c	49.1 ± 0.2	19.5 ± 0.3	29.3 ± 0.1	75.1 ± 0.2	5.1 ± 0.5 ^c	5.2 ^c	5.0 ^b	5.4
	30	15.7 ± 0.9 ^h	54.6 ± 1.8	16.8 ± 0.1	33.1 ± 0.7	57.3 ± 1.2	9.5 ± 0.5 ^f	7.9 ^f	8.1 ^d	7.9
	20	15.3 ± 0.8 ^h	62.2 ± 0.7	18.1 ± 0.2	31.9 ± 0.2	50.2 ± 0.5	7.7 ± 0.7 ^d	7.8 ^e	7.9 ^d	7.8
	10	742.6 ± 12.0 ⁿ	49.2 ± 1.0	19.7 ± 0.5	31.4 ± 0.1	75.0 ± 0.9	2.5 ± 0.5 ^a	4.3 ^b	5.5 ^b	4.2
BLC + PA	40	10.7 ± 0.1 ^d	47.1 ± 1.1	11.4 ± 0.2	26.1 ± 0.5	55.0 ± 0.9	8.4 ± 0.4 ^f	7.9 ^f	7.9 ^d	7.9
	30	10.7 ± 0.3 ^d	45.7 ± 1.5	9.6 ± 0.3	23.5 ± 1.1	54.1 ± 1.1	7.2 ± 0.4 ^e	6.0 ^d	8.1 ^d	6.3
	20	24.8 ± 2.1 ⁱ	45.5 ± 0.3	11.0 ± 0.7	24.2 ± 0.7	50.8 ± 0.3	3.1 ± 0.1 ^b	3.9 ^b	6.7 ^c	4.1
	10	348.0 ± 2.2 ^m	50.1 ± 0.7	11.2 ± 0.1	25.3 ± 0.0	50.8 ± 0.7	2.4 ± 0.2 ^a	3.1 ^a	4.6 ^a	3.3

Abbreviations are mentioned in Table 2

^aMeans with different superscripts within the same column are significantly different at $p \leq 0.05$

only. The BLC + GS and BLC + PS doughs offer the good puffing characteristics in the range of 20–30% moisture content (Fig. 1). In the case of BLC + PF dough, the suitable moisture content range for toasting is 10–30% and offers a soft crispy snack; the wide range of moisture content is due to the low WAC values (because of high amylose) of finger millet starch granules. The other grains having a high WAC causes more water molecules to be trapped in the amylopectin structure leading to a rupture of starch granules. Thus, it imparts more stickiness in the dough and not allowing the flake to puff appropriately. One special phenomenon in amaranth is that a high-fat content in amaranth possibly forms a fat complex with starch, which restricts puffing. However, at high moisture content, water molecules control this complex formation and helps in puffing so that amaranth dough strips puff more at high moisture content (Fig. 1) (Gomez et al. 1992). The BLC + PA dough offers a good puffed snack product with high moisture content. However, the high WAC makes the dough too sticky and thus shaping and machinability are difficult. On the other hand, at a low moisture content, the shaping/machinability is better but puffing characteristics are poor and the surface of snack product is rough (De Pilli et al. 2008) as compared to other snacks. The snack product is less crispy in this case compared to other three samples.

A snack made from BLC + PF dough is crispier and crunchy and requires the least amount of force to break; the snack shows several peaks in the compression graph indicating fractures (graphs not shown here). In the case of BLC + PF snack, the hardness or peak force is slightly higher compared to BLC + PS and BLC + GS snacks, but the product is soft and crispy, and possess higher puff thickness compared to other samples.

Table 4 represents the colour parameters (L^* , a^* , b^* and ΔE) of the snack when toasted at different moisture contents. There is no significant ($p \leq 0.01$) influence of the moisture content of the dough on these colour parameters. For the BLC + PF dough (10–30% moisture content) produces a dull reddish brown snack ($L^* < 50$); at a high moisture content of 40%, L^* is low and E is markedly high meaning that the product is dark in colour and is far away from the standard white. Further, at a low moisture content (10%), the snacks possess a high peak force producing a too hard unacceptable product (Table 4). Hence, for finger millet, the acceptable ranges are L^* between 36 and 50, a^* between 8 and 11, b^* between 20 and 22 and ΔE between 54 and 58 (Table 4) which correspond to a dull reddish brown colour. For BLC + PS and BLC + GS doughs, the suitable range of moisture content is between 20 and 30% (Fig. 1) because of high puff thickness, low peak force and

Fig. 1 Photomicrographs of the cross-sectional views of amaranth (top row) and finger millet (bottom row) Top row: **a** raw amaranth, **b** popped amaranth, and **c** toasted amaranth snack. Bottom row: **a** raw finger millet, **b** popped finger millet, and **c** toasted finger millet snack

high overall acceptability. At this moisture content, snack samples have L^* values between 53 and 64, a^* between 13 and 18, b^* between 30 and 33 and ΔE between 50 and 57; the sample possesses a golden brown color which is the most desirable and acceptable product. A snack made from amaranth shows a bright reddish brown colour (L^* : 46–55, a^* : 10–13, b^* : 23–30 and ΔE : 54–59) at a moisture content of 20–40%; the product has sufficient extent of puffing and a high overall acceptability at this condition (Table 4). The final moisture content of all the snacks is around 3% and has a fat content of 1–2%. Protein and dietary fiber contents are in the ranges of 22–23 and 10–11%, respectively for all the snacks.

Microstructure

The cross-sectional views of the raw amaranth and finger millet grains (Fig. 1) appear to have a compact endosperm with the hull attached. The photomicrographs of popped

amaranth and finger millet show a porous having organised hexagonal cells and vacuoles. The amaranth flaked snack also has the pores and vacuoles that are created during the process of toasting; the dough flakes experience expansion due to sudden exposure to high air temperature. On hot air toasting of finger millet flake, a porous structure result as shown in the micrograph where elongated cells are created perpendicular of outer flake surface. The vacuoles are formed by the fusion of a number of small pores making the product expanded such that the toasted flakes appear to be crispy and crunchy. As the steam is suddenly produced and released during air toasting, the thin flakes attain a low-density structure.

Mariotti et al. (2006) have observed a similar effect on microstructure; compacted internal structure of the raw flakes gets a radical change during puffing. In the present study, the high temperature of toasting causes the flake moisture content to decrease to 3% in a short time, and hence, drastically decreases the bulk density of the puffed

flakes. In the raw flake or dough, the starch granules appear to be uniformly spread and intact; in the toasted sample, the granules undergo the process of gelatinization to show a collapsed structure (Ma et al. 2011). Owusu et al. (1984) have observed that crispness of an extruded product is directly related to the expansion ratio. The greater the open pores more are the volume expansion resulting in a highly porous expanded product. Jones et al. (2000) have also observed that higher pore volumes are synonymous with the greater expansion ratio of the cereal product. The surface area of the flake influences the crispness of the product and water absorption and is related to the retention of crispness when soaked in milk for serving.

Inter-relationship

The principal component analysis (PCA) shows the inter-relationship among the variables and the parameters obtained on subjective and objective indices (Fig. 2) of different grain based snacks. The principal components PC 1, PC 2, PC 3 and PC 4 account for 47.2, 15.5, 13.5 and 13.4% of the variations, respectively such that a total of 89.6% variation is accounted by these four principal components. In the present situation, only the PCA biplot of PC 1 against PC 2 is presented here and other biplots are not presented to avoid repetition. Sensory appearance (SA),

sensory texture (ST) and sensory overall acceptability (SOA) are closely related to the puff thickness meaning that a snack having a good expansion is liked by the sensory panellists. The moisture content and black gram-gelatinized starch (BLC + GS) are in the neighborhood which indicates that high moisture in the flake before toasting for BLC + GS sample is suitable. The peak force lies diagonally in the other quadrant to those of sensory attributes indicating that a high peak force is unsuitable for the acceptance of the product. The black gram-puffed sorghum (BLS + PS) snack is near the peak force in the third quadrant meaning that the sample is hard. Puffed amaranth-based snack (BLC + PA) appears to be an outlier in the PCA plot.

Conclusion

Grain-based gluten-free fabricated snacks can be prepared by using different ingredients (black gram, amaranth, finger millet and sorghum) in concert with the method of hot air toasting. These products possess a decent level of dietary fibre. The amylose content affects the WAC of the grain flours and it has a significant effect on the quality of the snack. Popped finger millet added dough is the hardest while the amaranth-based sample is the softest sample. Hardness, firmness and compression characteristics of snacks increase with a decrease in the moisture content of doughs. Black gram-popped finger millet doughs impart more hardness, firmness, cohesiveness, springiness and compression energy but less adhesiveness compared to other combinations; the sample shows a good puffing characteristic when toasted at a moisture content between 10 and 30%. Popped sorghum and gelatinized starch added doughs exhibit a good puffing phenomenon when processed at 20–30% moisture content while popped amaranth added dough shows similar behaviour at high moisture content (30–40%). The results presented in this investigation indicate that sorghum-black gram and gelatinized starch-black gram blended doughs can produce good quality snacks when toasted at a short range of moisture content in the flaked dough pieces. The finger millet-black gram blended doughs can yield attractive snacks at a wide range of moisture content.

Fig. 2 PCA plot of the textural and sensory attributes of different snacks. *PT* puff thickness, *SA* sensory appearance, *SOA* sensory overall acceptance, *ST* sensory texture

Appendix

See Figs. 3 and 4.

a Snacks prepared from black gram and puffed finger millet

At 40% moisture content

At 10-30% moisture content

At 10% moisture content

b Snacks prepared from black gram and puffed sorghum

At >30% moisture content

At 20-30% moisture content

At <20% moisture content

c Snacks prepared from black gram and gelatinized starch

At >30% moisture content

At 20-30% moisture content

At <20% moisture content

d Snacks prepared from black gram and popped amaranth

At 20-40% moisture content

At <20% moisture content

Fig. 3 Photographs of snacks prepared with different raw materials toasted with different moisture contents

Fig. 4 The non-oral sensory attributes (hardness and stickiness) of dough samples at different moisture contents. *BLC* black gram, *PS* puffed sorghum, *GS* gelatinized corn starch, *PA* puffed amaranth

References

- Abbas KA, Khalil SK, Hussin ASM (2010) Modified starches and their usages in selected food products: a review study. *J Agric Sci* 2(2):90–100
- Anon (2017) Worldbaker. <http://www.worldbakers.com/business2/43-news/latest-news/1035-clean-label-and-gluten-free-add-flavour-to-savoury-snacks>. Accessed 12 July 2017
- AOAC (2002) Official methods of analysis, 17th edn. Association of Official Analytical Chemists, Washington, DC
- Asp NG, Johansson CG, Hallmer H, Siljeström M (1983) Rapid enzymatic assay of insoluble and soluble dietary fiber. *J Agric Food Chem* 31:476–482
- Berrios JDJ, Morales P, Camara M, Sanchez-Mata MC (2010) Carbohydrate composition of raw and extruded pulse flours. *Food Res Int* 43:531–536
- Bhat KK, Bhattacharya S (2001) Deep fat frying characteristics of chickpea flour suspensions. *Int J Food Sci Technol* 35:499–507
- Bhattacharya S (2012) Rheological characterization and modeling of rice flour dough: effect of parboiling time, moisture content and gum Arabic. *J Texture Stud* 43:400–412
- Bhattacharya S, Narasimha HV (2008) Effect of raw material characteristics on the properties of fried rice-blackgram dough. *Int J Food Sci Nutr* 59:502–511
- Booth RG (1990) Snack food. Van Nostrand Reinhold, New York
- de la Hera E, Martinez M, Gomez M (2013) Influence of flour particle size on quality of gluten-free rice bread. *LWT Food Sci Technol* 54:199–206
- De Pilli T, Joupilla K, Ikonen J, Kansikas J, Derossi A, Severini C (2008) Study on formation of starch-lipid complexes during extrusion-cooking of almond flour. *J Food Eng* 87:495–504
- Elhardallou SB, Walker AF (1993) The water-holding capacity of three starchy legumes in the raw, cooked and fibre-rich fraction forms. *Plant Foods Hum Nutr* 44:171–179
- Gomez MH, Lee JK, McDonough CM, Waniska RD, Rooney LW (1992) Corn starch changes during tortilla and tortilla chip processing. *Cereal Chem* 69:275–279
- Ituen EUU, Mittal JP, Adeoti JS (1986) Water absorption in cereal grains and its effects on their rupture stress. *J Food Process Eng* 8(3):147–158
- Jones D, Chinnaswamy R, Tan Y, Hanna M (2000) Physicochemical properties of ready-to-eat breakfast cereals. *Cereal Food World* 45:164–168
- Labuza TP (1977) The properties of water in relationship to water binding in foods: a review. *J Food Process Preserv* 1:167–190
- Lai LS, Kokini JL (1991) Physicochemical changes and rheological properties of starch during extrusion. a review. *Biotechnol Prog* 7:251–266
- Ma Z, Boye JJ, Simpson BK, Prasher SO, Monpetit D, Malcolmson L (2011) Thermal processing effects on the functional properties and microstructure of lentil, chickpea, and pea flours. *Food Res Int* 44:2534–2544
- Mariotti M, Alamprese C, Pagani MA, Lucisano M (2006) Effect of puffing on ultrastructure and physical characteristics of cereal grains and flours. *J Cereal Sci* 43:47–56
- McEntyre E, Ruan R, Fulcher RG (1998) Comparison of water absorption patterns in two barley cultivars, using magnetic resonance imaging. *Cereal Chem* 75:792–795
- Owusu A, van de Voort FR, Stanley DW (1984) Textural and microstructural changes in maize starch as a function of extrusion variables. *Can Inst J Food Sci Technol* 17:65–70
- Park CS, Baik BK (2002) Flour characteristics related to optimum water absorption of noodle dough for making white salted noodles. *Cereal Chem* 79:867–873
- Punia KPD (2000) Proximate composition, phytic acid, polyphenols and digestibility (in vitro) of four brown chick pea varieties. *Int J Food Sci Nutr* 51:189–193
- Rajesh D, Ravi R, Bhattacharya S (2015) Effect of hydrocolloids on quality of proso millet cookie. *Food Bioprocess Technol* 8:2298–2308
- Sanddhya NS, Meera MS, Bhattacharya S (2013) Effect of popping on sorghum starch digestibility and predicted glycemic index. *J Food Sci Technol* 50:387–392

- Sharma V, Champawat PS, Mudgal VD (2014) Process development for puffing of sorghum. *Int J Curr Res Acad Rev* 2:164–170
- Siddhuraju P, Becker K (2005) Nutritional and antinutritional composition, in vitro amino acid availability, starch digestibility and predicted glycemic index of differentially processed mucuna beans (*Mucuna pruriens* var. *utilis*): an under-utilised legume. *Food Chem* 91:275–286
- Singh J, Kanaujia R, Srivastava AK, Dixit GP, Singh NP (2017) Genetic variability for iron and zinc as well as antinutrients affecting bioavailability in black gram (*Vigna mungo* (L.) Hepper). *J Food Sci Technol* 54:1035–1042
- Sowbhagya CM, Bhattacharya KR (1979) Simplified determination of amylose in milled rice. *Starch/Stärke* 31:159–163
- Sumithra B, Bhattacharya S (2008) Toasting of corn flakes: product characteristics as a function of processing conditions. *J Food Eng* 88:419–428
- Tiwari S, Ravi R, Bhattacharya S (2012) Dehumidifier assisted drying of a model fruit pulp-based gel and sensory attributes. *J Food Sci* 77:S263–S273
- Vidya S, Ravi R, Bhattacharya S (2013) Effect of thermal treatment on selected cereals and millets flour doughs and their baking quality. *Food Bioprocess Technol* 6:1218–1227
- Wang J, Rosell CM, de Barber CB (2002) Effect of the addition of different fibres on wheat dough performance and bread quality. *Food Chem* 79:221–226