Frying of rice flour dough strands containing gum Arabic: texture, sensory attributes and microstructure of products

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Abstract The effects of rice flour (50–56%, w/w) and gum Arabic (0–5%, w/w) on the physical, sensory and structural features of the fried dough strands were investigated. Up to 25.8% reduction in oil was possible by the incorporation of gum Arabic. The wide variations in failure force (13.8–25.3 N) and failure strain (11.0–28.6%) indicated the formation of snacks varying in texture from a soft-to-bite brittle product to a hard-to-eat less brittle sample. The snacks possessed a porous microstructure with air cells, pores and vacuoles; the cell walls were more than 100 µm in thickness. The textural parameters like failure force, failure energy and failure stress behaved in a similar manner in the principal component analysis biplot. High moisture content in the dough decreased the sensory acceptance of the fried snacks. The high desirability index of 0.9 could be achieved with a high level of rice flour (56%, w/w) while gum Arabic content was between 3.50 and 3.75% (w/w).

Keywords Fried snack · Texture · Microstructure · Desirability index

Introduction

Rice is a staple food for about half of the population in the world; its importance lies with regard to human nutrition and caloric intake. In general, the whole rice grain is consumed after cooking. However, some products are also

prepared from rice of which puffed rice, popped rice, rice flakes, traditional breakfast cereals and snack foods are common. Other rice flour/broken rice-based foods are noodles, breakfast cereals, extruder-puffed rice snacks, shredded rice cereals and multi-grain cereals (Luh and Bhumiratana 1980; Wandee et al. 2014). These are ready-to-eat or ready-to-prepare products in which the rice starch provides the texture-modifying properties while rice imparts its characteristic flavour.

Rice is free from gluten protein and is the least allergenic cereal (Rolfes et al. 2012) but the absence of gluten offers a dough which possesses a poor cohesiveness and flattening/stretching ability compared to that of wheat. This drawback may be eliminated by using an appropriate additive like a hydrocolloid to develop gluten-free foods. Rice bread has been formulated for people suffering from the celiac disease where a hydrocolloid like hydroxypropyl methylcellulose has been used in the formulation (Bean and Nishita 1985). Rice flour is also used for preparing the flat unleavened bread (*roti*) which is conventionally prepared from wheat flour (Juliano and Sakurai 1985). Other rice flour based baked products are the Japanese rice cakes or rice crackers that include *senbei* and *arare*. The preparations of rice *sev*, vermicelli and noodles are also possible (Wandee et al. 2014, Sangpring et al. 2015).

A number of convenience foods, usually the traditional foods, are fried to offer an attractive crisp texture, and are often prepared from a mixture of rice and pulse flour (Bhattacharya and Narasimha 2008); a dough from the flours of rice and blackgram is formed with salt and shortening followed by extrusion in a low-pressure forming extruder to obtain continuous strands, which are latter fried in hot oil. However, the details of the role of raw materials and the effect of the processing conditions on such dough based fried products are scarce. Subba and Katawal (2013)

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have found that the particle size of the flour affects the physical properties and sensory attributes of the rice flour batter-based fried products. The extrusion formed 'half-products' do not show significant expansion when come out of extrusion die. These products are later subjected to frying or hot-air puffing; these additional processes allow expansion, removal of moisture and attainment of the desired texture of the finished product (Moghaddam et al. 2015).

Hydrocolloids have been reported to modify the functional properties of foods. The recent reviews by Pedreschi and Enrione (2015), and Varela and Fiszman (2011) have concluded that an appropriate hydrocolloid in a suitable condition can be used to develop lower-oil containing products. The addition of carboxymethylcellulose controls the uptake of oil in various deep-fat fried products such as French-fry (Garmakhany et al. 2014), *samosa* casing (Sakhale et al. 2011) and shrimp (Izadi et al. 2015). However, a few of the hydrocolloids (like gum Arabic) offers low viscosities at a relatively high concentration, but most of them exhibit high viscosities at a concentration even below 1% (Walstra 2003). The other advantages of gum Arabic are cost-effectiveness, wide uses in various products, and are permitted to be used even at a high concentration (Bhattacharya 2012; Shanthilal and Bhattacharya 2015). The use of gum Arabic appears to be a promising additive for the development of gluten-free and low-gluten dough formulations (Bhattacharya et al. 2003; Guarda et al. 2004; Anton and Artfield 2008). The absence of gluten in rice-based formulations makes the dough substantially less stretchable and low in internal binding as compared to that of wheat (O'Shea et al. 2014). Invariably, the rice flour doughs do not possess good handling properties like that of the wheat doughs. A good handling property is mandatory to shape, flatten, roll and sheet the dough so that different products like flakes, chips, multi-layered and filled products can be prepared. It is thus a severe limitation for the large scale preparation of rice flour dough based products. Hence, the incorporation of an additive like a hydrocolloid may be a suitable and pragmatic technological approach to achieve the required handling properties for product making (de la Hera et al. 2013). However, studies emphasizing the changes in the attributes of the rice based finished products and the understanding of the inter-relation among the frying variables and the properties of the products in the presence of a hydrocolloid at higher concentrations are not available, and thus offer a good scope for a detailed investigation with an overall intention of developing a gluten-free acceptable fried snack with reduced oil content.

The objectives of the present study are to determine the effect of (a) the rice flour and gum Arabic contents on the attributes of the fried product, and (b) inter-relationships

among the independent variables and the attributes of the product using rice flour dough as the model system, and product optimisation.

Materials and methods

Materials

Polished raw rice and gum Arabic were described elsewhere (Shanthilal and Bhattacharya 2015). The mean particle size of rice flour was determined by employing a particle size and shape analyser (Model # Bluewave S3500, Microtrac, FL, USA); the average particle size reported as D_{50} , was $157.6 \pm 0.6 \mu\text{m}$. Refined sunflower oil was purchased from a local supermarket of Mysore, India.

Rice flour dough and strands

Appropriate masses of gum Arabic powder and water were mixed thoroughly for 3 h and the dispersions containing 0, 1, 3 and 5% gum (dry solid basis, w/w) were prepared at the room temperature of 25 °C. The dispersion was later added to the rice flour while mixing in a laboratory model Hobart mixer, operated at a low speed for 15 min to obtain homogeneous doughs. The contents of rice flour were 50, 52, 54 and 56% (dry solid basis, w/w). The moisture content of these doughs, as determined by the air oven method of AOAC (1980), was 50, 48, 46 and 44%, respectively. The gum contents were 0, 1, 3 and 5% meaning a total of 16 samples. The process of the preparation of dough was repeated twice. These formulations were selected based on preliminary studies to obtain strands that could be easily extrusion-formed through a die (3 mm in diameter) of a laboratory model pasta press (Bhattacharya and Narasimha 2008), but not losing integrity on frying. A dough having a rice flour content of more than 56% was too difficult to extrude. On the other hand, a dough having less than 50% flour was a too soft material to extrude as it was close to a batter-like sample; the moisture content of these two samples were 44 and 50%, respectively.

Preparation of fried snack

The dough strands were allowed to fall directly into hot oil, maintained at a temperature of $180 \pm 3 \text{ }^{\circ}\text{C}$ with a gentle circulation of oil by mechanical means. The oil-to-sample ratio was 10:1. Based on initial frying trials, the frying time was decided at 2 min for dough strands having 54 and 56% rice flour, while it was 3 min for strands having 50 and 52% rice flour to obtain a fried product with adequate crispness but not undercooked or overcooked. The

moisture content of the dough strands before frying was between 44 and 50%. After cooling, the samples were packaged in flexible pouches, and texture testing was conducted within 2 h of frying. The number of samples tested each time was ten. The oil content of the fried samples was determined using the AOAC (1980) method on triplicate samples.

Instrumental texture

Ten rod-shaped fried products, as shown in Appendix (Fig. 5), were subjected to texture testing by employing a texture testing machine (model # TA Plus, AMETEK Lloyd Instruments, Hampshire, England) along with a Warner–Bratzler shear attachment. The crosshead speed was 1 mm s^{-1} , and failure characteristics were determined such as failure force (force at which the sample was sheared into two pieces), failure stress (failure force divided by the initial cross-sectional area of sample), failure strain (deformation of sample at failure divided by the diameter of sample) and the failure energy (area under the force-deformation curve till failure).

Microstructure

The fried samples were subjected to repeated extraction with hexane. They were then mounted on aluminium stubs with conductive adhesive tapes followed by coating with gold employing a sputter coater and examined under a scanning electron microscope (model # 435VP; Leo Electron Microscopy Ltd, Cambridge, UK) at an accelerating voltage of 20 kV. The cross-section of the samples were viewed at magnifications of $\times 100$ and $\times 500$, and the representative photomicrographs were captured. The thickness of the cell walls was determined by using an imaging software (IMA-GEJ 1.45s, National Institutes of Health, Maryland, USA).

Sensory assessment

A trained panel consisting of 10 trained judges evaluated the coded fried products in terms of sensory attributes such as hardness, appearance, taste, crispness and overall acceptability (Ravi et al. 2007) employing a 9-point hedonic scale. The definition for sensory hardness was the force required to compress the sample with molars while crispness was related to the brittle nature of the sample (or ease of breaking it) which could snap easily by emitting a typical sound upon deformation.

Statistical analysis

The methodology of principal component analysis (PCA) was applied to inter-relate data on instrumental and sensory

assessment results. The independent variables (rice flour and gum contents) were linked by PCA method using the statistical software Statistica'99 (StatSoft, Tulsa, OH, USA) (Lawless and Heymann 1998).

The different response functions, obtained as instrumental and sensory data, were represented by 3-D surface plots as a function of rice flour and gum contents. The method of least squares was used to fit the data by employing a second-degree polynomial and Statistica'99 software (StatSoft, Tulsa, OK, USA).

The desirability index (D) was calculated to select an appropriate condition for product formulation as shown earlier (Kapri and Bhattacharya 2008). It was calculated by assigning a score between 0 and 1, where 0 indicated the poorest desirability and 1 indicated the maximum possible desirability under examination; the software Statistica'99 was employed to obtain the desirability function. In the present study, the calculation of desirability index was conducted to optimise the fried product having the minimum oil content and a maximum score of overall sensory acceptability within the range of the experimental variables of rice flour and gum contents.

Results and discussion

Fried strands

The rice flour dough strands, prepared with different levels of rice flour solids and gum Arabic, were fried to obtain crisp strands (Appendix Fig. 5). The diameters of the strands (between 3.70 and 4.26 mm), prepared with gum, appear to be higher compared to samples prepared without gum (significant at $p \leq 0.05$); the moisture contents of the fried snacks are below 2.5% (individual values of diameter and moisture contents are not reported here).

Oil content

Figure 1 shows the oil content (19.9–26.8%, w/w) of the fried products as a function of rice flour and gum contents; the lowest oil content (significant at $p \leq 0.05$) is associated with 56% rice flour for a dough containing 5% gum Arabic meaning a maximum of 25.8% reduction is possible. The effect of rice flour on the oil content of the fried product is complex in nature and shows a curvilinear trend. It depends on the level of gum used; in the absence of gum or at a low level of 1%, an increase in the content of rice flour usually increases the oil content while a reverse trend happens when a higher level of gum, such as 5%, is used. It may be recalled here that the required frying time was 2 min for doughs having 54 and 56% rice flour content (moisture contents 46 and 44%, respectively), while it was 3 min for

Fig. 1 Oil content and overall sensory acceptability of fried rice dough strands as a function of rice flour and gum Arabic contents

50 and 52% rice flour (moisture contents 50 and 48%, respectively) containing samples; the frying time has been adjusted to achieve a product with appropriate sensory attributes. It is particularly true when the rice flour level is low (meaning more moisture containing dough), the sample requires a higher time of frying. On the other hand, at a high level of rice flour, an increase in gum content markedly decreases the oil content in the fried snack. It is possible that the levels of rice flour are inter-related to the oil content. Further, there is a possible competition for

water by both rice flour and gum which again depends on the moisture available in the system. Thus, a dough system with a low level of rice flour behaves in a different way to those having a higher content of rice flour. A high level of gum can retain more moisture in the dough matrix as the prominent functional property of a hydrocolloid is to absorb and/or retain water. In a high rice flour containing system, the available water is low and thus requires a lesser time of frying. If gum is added to this system, gum tries to absorb more water allowing less water available for rice flour to absorb.

An increase in moisture content in corn dough has been reported to increase the oil content in the fried dough products (Bhattacharya et al. 2003). However, these authors have indicated that a gum level beyond 1% does not serve any additional benefit on the reduction of oil content of the fried snack which is not true for the present study. It may be possible that different cereal flours behave in a different manner. Corn flour dough contains a small amount of gluten while rice dough does not possess it, and thus, the effect of gum Arabic on fried products is expected to be different. Subba and Katawal (2013) have reported that the uptake of oil is inversely related to the particle size of the rice flour during frying of the rice flour batter-based products, while hardness and fracturability are directly related.

Objective textural indices

The sample texture (shearing) curve (Appendix Fig. 6) shows an initial small zone when the shearing blade touches the outer surface of the sample so that a minor reorientation of the sample happens. In the next, a sharp increase in force occurs during the initial stage of compression-cum-shearing. The slope then increases further till it reaches the maximum force where it gets sheared into two pieces; this value has been taken as the failure force. After failure, the force decreases drastically but occasionally shows one or two minor fractures due to the broken pieces occupying the slot of the Warner–Bratzler (WB) shear attachment.

The different instrumental textural parameters related to the phenomenon of failure, as a function of rice flour and gum contents, are shown in Fig. 2. The wide variations in failure force (13.8–25.3 N) and failure strain (11.0–28.6%) indicate an ample difference in the texture of the fried sample. It thus indicates the formation of snacks which vary from a soft-to-bite brittle product to a hard-to-eat less brittle sample.

The failure force during shearing is an indication of the extent of force required by the frontal teeth to cut the sample into two parts, or molar teeth to break into a few pieces by compression. A low value of 13.8 N means a

Fig. 2 Effect of different rice flour and gum Arabic contents on various textural attributes of the fried rice dough strands such as **a** failure force, **b** failure stress, **c** failure strain, and **d** failure energy

moderately soft snack while a high value of 25.3 N meaning a relatively hard-to-bite snack. An increase in the level of rice flour, in the absence of gum, offers a sample with a lower failure force (significant at $p \leq 0.01$). The failure strain depicts the extent of deformation a sample undergoes prior to failure. In the present study, the deformation of fried strands is a combination of shearing and compression phenomena as the inverted V-shaped WB

shear attachment has a thickness of about 2 mm. An increase in the level of rice flour increases the failure force to behave like a harder sample. An increase in gum level up to about 3% level decreases failure strain but increases it with a further addition of gum.

The ranges for failure stress and failure energy are 1.1–2.3 MPa and 4.3–14.4 mJ, respectively (Fig. 2). The failure stress means the extent of stress required to shear

Table 1 Sensory attributes of the fried rice dough strands prepared with different rice flour and gum contents

Rice flour (% w/w)	Gum Arabic (% w/w)	Hardness (–)	Appearance (–)	Taste (–)	Crispiness (–)	Overall acceptability (–)
56	0	6.9±1.1	6.9±0.8	6.3±1.8	6.6±0.8	6.6±1.6
56	1	6.9±1.2	7.2±1.3	6.6±1.2	7.3±0.5	7.3±0.8
56	3	5.9±0.9	7.1±1.2	6.6±1.2	6.9±0.9	6.9±1.1
56	5	6.6±0.5	7.1±0.8	6.6±0.9	6.7±1.0	6.7±0.9
54	0	7.4±0.9	7.1±1.5	6.7±0.7	6.6±0.9	6.6±0.7
54	1	6.8±0.8	6.9±0.9	6.4±1.2	7.1±0.4	7.0±0.9
54	3	6.4±0.5	6.8±1.3	6.8±0.7	6.9±1.2	6.9±1.4
54	5	6.4±0.7	6.6±0.9	6.9±1.3	6.9±1.1	6.9±1.4
52	0	7.7±1.0	6.9±1.6	6.0±1.7	6.1±0.7	6.1±0.8
52	1	6.9±1.2	6.2±1.5	6.6±1.6	6.9±0.7	6.9±1.3
52	3	7.1±1.4	6.4±1.3	6.7±0.7	7.0±1.6	7.0±1.1
52	5	6.2±0.7	5.6±1.1	6.3±1.6	6.1±1.5	6.1±1.5
50	0	6.9±1.4	6.4±1.5	6.3±1.4	6.1±1.2	6.1±0.8
50	1	7.0±0.9	6.0±1.3	6.4±1.1	6.4±0.7	6.3±1.2
50	3	7.2±1.0	5.9±0.9	6.3±1.0	6.7±1.1	6.7±1.3
50	5	6.3±0.7	4.1±1.1	6.3±1.2	5.2±1.4	5.2±1.7

the sample; it follows a similar trend like failure force as the diameters of the samples are marginally different. Failure energy indicates the magnitude of energy required to show the failure phenomenon. The lowest failure energy is associated with the sample prepared with the formulation of 50% flour-5% gum while the highest energy is associated with 56% flour-5% gum combination (significant at $p \leq 0.05$).

Sensory assessment

The different sensory attributes like hardness, appearance, taste, crispness and overall acceptability of the products prepared with different rice flour and gum contents are shown in Table 1. The overall acceptability values are between 5.2 and 7.3; the lowest value of 5.2 is for the snack prepared with rice flour and gum contents of 50 and 5%, respectively while the highest value of 7.3 is associated with 56 and 1% combination (significant at $p \leq 0.05$). The low values of overall acceptability are associated with the dough samples prepared with 50% rice flour. The overall acceptability (Fig. 1) shows that an increase in rice flour or gum content initially increases the overall acceptability but decreases when both are high.

An important feature of any snack is crispness which makes the product attractive to the consumers due to easy fracture and failure characteristics. The crispness of the samples is ≥ 7.0 meaning that all of them are well acceptable which may be attributed to adequate frying time to offer low moisture containing (<3%) product. It is possible that a high moisture containing dough absorbs

more oil while a high level of gum offers an undesirable gummy taste, and thus the overall acceptability decreases.

Microstructure

The photomicrographs of the fried strands show a porous structure containing air cells and vacuoles (Fig. 3, and Appendix Fig. 7). The cell walls are thick enough to be even more than 100 μm in thickness. Generally, an increase in the concentration of rice flour makes the product more compact. It is possible that a high moisture containing dough (which contains lower rice flour) strands offer a high extent of steam flash-off to create vacuoles; the sudden contact of thin dough strands with hot oil results in an instantaneous loss of moisture from the outer surface, and then oil starts entering the product along with simultaneous heat transfer. In the present situation when the sample diameter is low and a high moisture containing dough strand is fried, the temperature of the core increases rapidly. However, the steam formed at the centre is not expected to be completely released due to the occurrence of case hardening at the outer surface. This finally results in an expansion of the product leading to the formation of large pores or a vacuole at the central part of the strand. This phenomenon is also assisted by gelatinisation wherein the starch granules swell in the starch-rich cereal flour product.

The microstructures of the fried snacks in the presence of gum Arabic are shown in Fig. 3. The absence of gum makes the fried snack more compact (Fig. 3a) compared to gum containing samples (Fig. 3b–d). The noticeable difference is that the gum containing samples

Fig. 3 Microstructure of fried rice dough strands prepared with 52% rice flour, and gum Arabic at **a** 0%, **b** 1%, **c** 3%, and **d** 5% levels. *Left column* low magnification of 100 $\times$, *right column* corresponding higher magnification (500 $\times$)

possess a big vacuole at the central portion as the gums always have a tendency to retain water, and thus create a vacuole when steam is released but the outer case hardening does not allow the formed steam to come out easily.

Bhattacharya and Narasimha (2008) have investigated the microstructure of the fried strands obtained from rice-blackgram doughs, prepared from powdery mixes of the ingredients. The doughs appear to be fused together by an adhesive-like material. It is possibly made up of the

Fig. 4 Three dimensional score plot for a three component principal component analysis (PCA) of independent variables (rice flour and gum Arabic contents) and response parameters obtained from texture analysis, sensory studies and oil estimation. *RF* rice flour, *GA* gum Arabic, *FF* failure force, *FS* failure stress, *FSn* failure strain, *FE* failure energy, *OSA* overall sensory acceptability, and *OC* oil content

leached-out soluble materials comprising soluble proteins and carbohydrates that ooze out as a result of hydration of the flour particle while preparing the dough. These researchers have mentioned that when rice-blackgram dough pieces come in contact with hot oil during the process of frying, the moisture on the surface is lost instantaneously followed by case hardening. The transfer of heat from the oil to the core increases the vapour pressure which may even lead to bursting as the case hardening phenomenon can obstruct the superheated vapour escaping easily. The vapour pressure of the product thus acts as a negative factor that finally inhibits the entrance of oil such that the fried product contains less oil compared to control sample. However, such bursting phenomenon has not been noticed with the present investigation dealing with rice flour strands. The fried dough pieces, prepared from rice-

blackgram flour mixes, have been reported to be irregular, uneven and porous which are also true for the present investigation. These structural features are expected to provide softness and crispness in the fried snacks.

Inter-relationships

Figure 4 shows the inter-relationships between/among the independent variables (contents of rice flour and gum Arabic) and the measured parameters (oil content, overall sensory acceptability, failure force, failure energy, failure stress and failure strain) employing the method of principal component analysis (PCA). The principal components PC1, PC2 and PC3 account for 39.3, 26.8 and 12.8%, respectively of the total variation indicating that a total of 78.9% variation is accounted by these three PCs. The independent variables like rice flour and gum contents are placed in different quadrants, and thus, behave in a different manner. The textural parameters like failure force, failure energy and failure stress act in a similar manner as they are in the neighbourhood. However, the remaining textural parameter (failure strain) is placed away from those three textural parameters meaning that failure strain is an outlier here. The nearest neighbour of overall sensory acceptability is the content of rice flour. It indicates that a high content of rice flour in the dough prior to frying increases the sensory acceptance of the fried snack.

Optimisation

The fried strands, prepared with different proportions of rice flour and gum Arabic, have been optimised employing the technique of desirability index. The calculation is based on obtaining a product having the minimum oil content but possessing a maximum overall sensory acceptability within the range of the experimental independent variables. The calculated high desirability index (Table 2) indicates that a high value of about 0.9 can be achieved with a high level of rice flour (56%, w/w) while gum Arabic content is between 3.50 and 3.75%. The predicted oil content and overall sensory acceptability are 21% and 7.2, respectively.

Table 2 Desirability index of fried snack prepared with different contents of rice flour and gum Arabic

Level of rice flour (%, w/w)	Level of gum Arabic (%, w/w)	Predicted overall sensory acceptability (—)	Predicted oil content (%, w/w)	Desirability index (—)
56	3.50	7.23	20.98	0.901
56	3.75	7.17	20.87	0.897

Conclusion

The present study is to determine the effect of the rice flour and gum Arabic contents on the attributes of the fried product, prepared by using rice flour dough as the model system. The oil content in the product varies from 19.9 to 26.8% (w/w), and up to 25.8% reduction in oil is possible if gum Arabic is used. The sensory crispness of the samples is more than seven meaning that all of them are well acceptable. The electron photomicrographs of the snacks exhibit a porous structure containing air cells and vacuoles. The cell walls are thick enough to be even more than 100 μm in thickness. An increase in the concentration of rice flour in the dough makes the fried product compact. The instrumental textural parameter like failure energy is the lowest when the sample is prepared with a formulation containing 50% flour and 5% gum while the highest failure energy value is associated with the sample with a 56 + 5% combination. The high desirability index of about 0.9 can be obtained with a high level of rice flour (56%) while gum Arabic content is between 3.50 and 3.75%.

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Compliance with ethical standards

Conflict of interest The authors declare that there is no conflict of interest.

Appendix

See Figs. 5, 6 and 7.

Fig. 6 Sample plot during shearing of fried rice dough strands prepared with 56% rice flour in the absence of gum Arabic

Fig. 5 Photographs of fried rice dough strands prepared from doughs containing 50% rice flour and gum Arabic at levels of **a** 0%, **b** 1%, **c** 3%, and **d** 5%

Fig. 7 Microstructure of fried rice dough strands prepared with **a** 56%, **b** 54%, **c** 52% and **d** 50% rice flour without gum Arabic. *Left column* low magnification of 100 $\times$, *right column* corresponding higher magnification (500 $\times$)

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