Effect of extrusion on thermal, textural and rheological properties of legume based snack

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Revised: 16 June 2018 / Accepted: 20 June 2018 / Published online: 13 July 2018
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Abstract Attempts have been made to improve dough handling properties and quality of legume based snack by incorporating extruded black gram (EBG) flour as partial substitute for raw black gram (RBG) flour. In present work overall quality improvement was achieved by analyzing (a) thermal properties of RBG and EBG flour (b) rheological properties (shear stress, shear rate, storage modulus, loss modulus, deflection angle and complex viscosity) of legume based snack dough and (c) post frying characteristics (colour and texture) of legume based snack. Three different legume based snack samples with different flour formulations (RBG flour, RBG flour incorporated with 25% EBG flour and RBG flour incorporated with 50% EBG flour) were prepared, characterized and compared with standard market sample. Dough exhibited shear thinning behaviour and G' and G'' showed rising behaviour with angular frequency whereas, complex viscosity showed decreasing behaviour. Herschel–Bulkley model was best fitted. Significant changes were observed in values of onset, peak and endset gelatinization temperatures on extraction of black gram flour which improved dough handling properties during papad processing and enhanced organoleptic profile of end product.

Keywords Black gram flour · Extrusion · Dough rheology · Characterization of legume based snack

Introduction

Extrusion cooking plays a vital role in many processing industries as a continuous cooking, mixing, and forming process which is versatile, low cost, and very efficient technology (Gat and Ananthanarayan 2016). During extrusion processing raw materials has to undergo through many transformations such as starch gelatinization, protein denaturation, complex formation between amylose and lipids, and degradation reactions of vitamins, pigments, etc. (Ding et al. 2005). Moderate starch content in black gram flour favors an extrusion process to produce directly expanded extruded snacks. During extrusion processing of black gram, starch solubilization and gelatinization can be achieved more conveniently and economically without any discoloration. Some of the researchers have worked on use of extruded flour for the quality improvement of idli (Singh et al. 1995; Kaur et al. 2000). Similarly present study was also undertaken for quality improvement of legume based fried snack i.e. papad. In this paper quality improvement of papad was undertaken with use of extruded black gram flour as a partial substitute for raw (un-extruded) black gram flour.

Papad also known as “Appalam” is a legume based popular fried snack item in India. Preparation of papad mainly involves mixing appropriate mixture of black gram (*Phaseolus mungo*) flour salt and spice powders. Papad dough prepared by adding measured quantity of water into the appropriate mixture of black gram flour is rolled into a circular shape with uniform thickness and then drying to below moisture level 10%. Papads then normally

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consumed after roasting, microwaving or frying as an adjunct to the meal.

Knowledge of rheological behavior of papad dough is very crucial for new product development as well as for process scale up. Also in future rheological behaviour of papad dough will help in improving quality, sensory and process design of existing products of similar kind. Several studies have reported the viscoelastic properties of different flour batter (Sanz et al. 2005) and dough (Uthayakumar et al. 2002; Izydorczyk et al. 2001; Lazaridou et al. 2007). Rheological behaviour of black gram dispersions has been reported earlier by Castell-Perez and Mishra (1995), Reddy et al. (1989). To the best of our knowledge, there is no comprehensive information on rheological behavior of papad dough prepared from extruded black gram flour. A significant change in apparent viscosity of extruded black gram flour may takes place due to presence of higher moisture content and thermal processing during the extrusion process. Therefore, it was necessary to have a basic knowledge of the influence of extrusion conditions on the rheological behaviour of the dough formulated from the RBG–EBG flour blend.

Papad belna has been used as a metaphor for any difficult task since time immemorial as rolling a papad is not an easy task. Dough of raw black gram becomes very hard during processing due to cohesive nature of protein–carbohydrates matrix of black gram and requires lot of mechanical energy and manpower efforts to soften the dough. Hence alteration in dough rheology becomes a necessity in papad processing. Dough rheology of papad is an important attributes from both engineering and consumer viewpoints. Present research demonstrated that partial replacement of RBG with EBG can be used as a processing aid in papad manufacturing to alter the dough properties by improving dough rollability and enhances quality of end product upon frying/microwaving/roasting. Present research will economically beneficial to manufacturer as it lowers down the energy requirement needed for softening the papad dough and increase efficiency of papad rolling. Therefore objectives of present study were to estimate the effect of addition of extruded black gram flour on (a) thermal properties of RBG and EBG flour (b) rheological properties (shear stress, shear rate, storage modulus, loss modulus, deflection angle and complex viscosity) of papad dough and (c) post frying characteristics (colour and texture) of papad.

Materials and methods

Materials

Black gram dal (*VignaMungo* L.) was purchased and milled to prepare fine flour passing through 80 mesh sieve. Common salt (Annapurna), asafetida (Ramdev premium), papadkhar (Laxmi), market sample (Lijjat papad) and refined groundnut oil (Fortune) were used in the study.

Preparation of sample for extrusion

For making extrudates pre-conditioning of sample was undertaken in which, initial moisture content of black gram flour was estimated and a calculated amount of water was added to obtain moisture content of about 18%. After addition of calculated amount of water into sample, the sample was packed in airtight sealable polyethylene bags and stored at refrigerated condition for uniform distribution and equilibration of moisture throughout the sample.

Extrusion cooking and thermal analysis

Extrusion cooking was performed with the help of twin-screw extruder (KETSE 20/40 Brabender GmbH and Co. KG, Duisburg, Germany) as suggested by Gat and Ananthanarayan (2015a). Laboratory-scale-co-rotating extruder has 20:1 barrel length to diameter ratio and which is consisting four heating/cooling zones. Extruder was fitted with circular die of 4 mm diameter. During extrusion processing feed rate screw speed and die temperature were kept constant at 14 kg/h, 300 rpm and 180 °C respectively. After completion of extrusion process black gram extruded were cooled to room temperature (25 ± 3 °C). Ground extruded black gram flour was passed through 80 mesh sieve and then incorporated with raw un-extruded black gram flour at different desired proportions (25 and 50%) for preparation of papad. Thermal analysis of raw black gram (RBG) flour and extruded black gram (EBG) flour samples were evaluated with a differential scanning calorimeter (DSC-60, Shimadzu, India) as suggested by Gat and Ananthanarayan (2015b).

Textural properties of papad dough

Texture evaluation of papad dough was performed using a texture profile analysis (TPA) in penetration mode. Hardness, stickiness, cohesiveness and springiness of different papad dough formulations (RBG flour, RBG flour incorporated with 25% EBG flour and RBG incorporated with 50% EBG flour) were measured with the help of 'TA.XT2i

Texture Analyzer' (Stable Micro Systems, Surrey, England) as suggested by Bajaj and Singhal (2007).

Rheological properties of papad dough

Viscoelastic properties of three different papad dough formulations (RBG flour, RBG flour incorporated with 25% EBG flour and RBG incorporated with 50% EBG flour) were measured with the help of frequency sweep test by using a stress-controlled rheometer (MCR 101, Anton Paar, Austria), fitted with an aluminium parallel plate geometry (35 mm diameter and 1 mm gap) as suggested by Wu et al. (2010). Rheological data analysis was performed using Rheoplus/32V3.40 software supplied by the manufacturer. The steady-state shear experiments were carried out in the shear rate. All rheological investigations were performed in triplicates for each sample.

Preparation of papad

Papads were prepared with standardized recipe and procedure devised by Ananthanarayan et al. (2018) with few modifications. Three different types of papads were prepared by following the above mentioned procedure with slight modifications in formulations as, (1) control sample containing (raw black gram i.e. RBG) flour, (2) RBG incorporated with 25% EBG flour and (3) RBG incorporated with 50% EBG flour.

Frying of papad

All three different formulations of papads were fried in refined groundnut oil for a total period of 40 s at 175 °C and compared with market sample (Lijat papad). Until further analysis fried papad samples were packed in polyethylene bags and stored in air-tight containers.

Textural properties of fried papad

Texture of the fried papads was determined using a Stable Micro System TAXT2i texture analyzer (Serial No.4650, TEE version 2.64, UK). Ball probe was used for the measurement of texture of papad samples. Hardness (g) was expressed by the ratio: positive area of the texturogram/time. This parameter can be considered as the average force necessary to rupture the fried papad during the respective period of time. Ten measurements were performed for texture analysis of each sample and their average was taken as the mean value.

Colour measurement of fried papad

A HunterLab colourimeter (LabScan XE, Hunter associates laboratory, Reston, VA, USA) coupled with EasyMatch QC software was used for colour measurement (L^* , a^* , b^*) of fried papads as suggested by Gat and Ananthanarayan (2016).

Statistical analysis

Analysis of variance (ANOVA) test was carried out using commercial statistical package, SPSS ver. 11.5 (SPSS Inc., Chicago, IL, USA). All the analysis was recorded as mean $\pm$ SD of five replicates. Mean values were compared and significant differences were given using Duncan's LSD test ($P \leq 0.05$).

Results and discussion

Effect of extrusion on thermal properties of black gram flour

Differential scanning calorimetry has been used to quantify the thermal changes in un-extruded and extruded black gram flour (Fig. 1). Starch, when heated in the presence of excess water, undergoes gelatinization over a temperature range. Onset, peak and endset gelatinization temperatures of un-extruded black gram flour were 96.7, 108.1 and 134.8 °C respectively and changed to 60.7, 89.9 and 124.4 °C respectively on extrusion of black gram flour. The onset, peak and endset gelatinization temperatures values changed with extrusion due to partial gelatinisation of starch during extrusion processing. The difference in onset, peak and endset gelatinization temperatures in black gram starches may be attributed to the differences in amylose content and granular structure (Singh et al. 2004). Gelatinization enthalpy was higher for un-extruded black gram flour as compared to extruded black gram flour. The high gelatinization enthalpy of a starch suggests that the double helices (formed by the outer branches of adjacent amylopectin chains) that unravel and melt during gelatinization are strongly associated within the native granule (Hoover et al. 1997). On extrusion of black gram flour there was formation of amylose–lipid complex which lowered down gelatinization enthalpy of extrudate. These results of low gelatinization enthalpy value for starch may be due in part to the enthalpy of amylose–lipid complex formation during heating are in consistent with earlier study carried out by Juliano (1998).

Fig. 1 DSC thermogram indicating changes in thermal properties of un-extruded and extruded black gram flour

Effect of incorporation of extruded flour on textural properties of papad dough

Hardness of dough decreased significantly with addition of extruded flour ($P \leq 0.05$) (Table 1) due to reduction in the water holding capacity of dough after addition of extruded flour. In extrusion process the starch gets partially gelatinised which leads to lowering down the water holding capacity of dough. Dough of raw black gram has higher number of ungelatinized starch molecules which absorbs more water and resulted in hard dough. On the other hand stickiness of dough however increased significantly with addition of extruded black gram flour concentration due to reduced water holding capacity.

Dough of raw black gram becomes very hard during processing due to cohesive nature of protein–carbohydrates matrix of black gram. In EBG this matrix diluted due to the presence of partially gelatinized starch. Dough rollability and softness is an important attributes from both engineering and processing viewpoints. Softening of dough

with addition of EBG lowers down the energy requirement needed for softening the papad dough and increase efficiency of papad rolling.

Effect of incorporation of extruded flour on rheological properties of papad dough

The shear stress and shear rate relationship of dough is shown in Fig. 2 and which indicated that shear stress increases with increase in shear rate in all the samples revealing the non-Newtonian behaviour. Initially, shear stress increased very quickly up to 0.01 shear rate, after that stress was almost constant with respect to increase in shear rate. These results indicates that all dough formulations (raw black gram flour, RBG flour incorporated with 25% extruded flour and RBG incorporated with 50% extruded black gram flour) subjected to flow characterisation exhibited shear thinning behaviour. These results of shear thinning behaviour are in consistent with the earlier researchers for different products such as rice flour dough

Table 1 Effect of incorporation of extruded flour on dough characteristics

	Dough characteristics			Papad characteristics
	Hardness (g)	Adhesiveness (g)	Cohesiveness (g)	Hardness (g)
RBG:EBG (100:0)	2966.71 ± 287.41 ^a	109.41 ± 11.08 ^a	0.19 ± 0.00 ^d	473.43 ± 1.80 ^a
RBG:EBG (75:25)	2327.95 ± 224.82 ^b	170.07 ± 51.32 ^b	0.23 ± 0.01 ^c	395.25 ± 1.56 ^b
RBG:EBG (50:50)	1849.19 ± 186.05 ^c	172.57 ± 45.83 ^b	0.26 ± 0.00 ^b	317.76 ± 2.46 ^c
RBG:EBG (0:100)	1504.15 ± 80.31 ^d	241.11 ± 19.49 ^c	0.32 ± 0.02 ^a	267.43 ± 2.10 ^c
Market sample	–	–	–	301.62 ± 1.40 ^d

RBG raw black gram, EBG extruded black gram

All the values are mean ± SD of five replicates. Mean values with different superscripts on the same column differ significantly (Duncan's LSD test, $P < 0.05$)

Fig. 2 Influence of partial replacement of RBG with EBG on variation of shear stress with shear rate. Where, sample A (RBG:EBG, 100:0); sample B (RBG:EBG, 75:25) and sample C (RBG:EBG, 50:50)

(Gujral et al. 2003), wheat porridge (Gujral and Sodhi 2002) and pearl millet porridge (Yadav et al. 2012).

Oscillation measurements for data of frequency sweeps for dough at different formulations were plotted as G' and G'' in double logarithmic diagram, different lines with equal slope were obtained for different samples of dough (Eqs. 1–2). The oscillatory frequency was varied from 1 to 200 Hz. The storage modulus (G'), loss modulus (G'') and complex viscosity (η) were obtained, as function of frequency. The storage and loss modulus were modelled as a power function of oscillatory frequency used to explain viscoelastic behaviour of food samples.

$$G' = k' \cdot \omega \eta' \quad (1)$$

$$G'' = k'' \cdot \omega \eta'' \quad (2)$$

When yield stress of a food is measurable, it can be included in the power law model and the model is known as the Herschel–Bulkley model for the dough. Shear-stress and shear-rate data were fitted to the rheological Herschel–Bulkley model (Eq. 3). The flow behavior index and fluid consistency index for the best-fitted equation was estimated by employing a non-linear regression analysis of viscosity/shear-rate data.

$$\sigma - \sigma_{OH} = K_H \gamma^{nH} \quad (3)$$

where γ is shear rate (s^{-1}), σ is shear stress (Pa), nH is the flow behavior index, K_H is the consistency index, and σ_{OH} is yield stress.

The mechanical spectrum of dough was observed at 25 °C. The graph (parameter vs angular frequency) showed that storage modulus values (G') were always higher than those of loss modulus (G'') values in all the samples (Fig. 3) suggesting solid like elastic behaviour and was in coherence with results of Yadav et al. (2012). Initially, there was sharp increase in storage modulus which can be related to hydration and swelling of amorphous regions of

starch granules. After a particular point constant increase in storage modulus was observed.

As expected values of G' and G'' showed rising behaviour whereas, complex viscosity showed decreasing behaviour (Fig. 3) with angular frequency. Complex viscosity decreased with increasing shear rate revealing shear thinning behaviour. The value of n is less than 0.5 for Herschel–Bulkley model, which shows it is best fitted power law model. The increased shear rate deforms and rearranges starch particles resulting in lower flow resistance and consequently lower viscosity (Fig. 3). As the level of incorporation of extruded flour increases, complex viscosity values decreased. Complex viscosity decreased with increase in EBG flour concentration (0, 25, 50, 100%) making the dough more sticky and loose (Fig. 3). This non-Newtonian behaviour of dough can be well explained by power law. This behaviour is in coherence with finding of Maskat et al. (2013). Starchy foods during extrusion result in gelatinization, molecular fragmentation and destruction of the crystalline structure by shearing and thermal effects into low molecular weight dextrins (Sarifudin and Assiry 2014). Dextrins have higher solubility than native starch. This increased solubility is due to uncovering of hydrophilic groups by unfolding and loosening of biopolymer chains, greater availability and easier penetration of water molecules (Marzec and Lewicki 2006).

Effect of incorporation of extruded flour on textural properties of fried papad

Texture of papad was studied, once the trigger force was attained, the force increased until the papad fractured into pieces. This was observed as the maximum force (breaking strength) and can be referred to as the ‘hardness’ of the sample. The lesser hardness of the sample associated with greater crispness. Table 1 documents the effect of addition of EBG flour on the textural characteristics of papad. At frying temperature due to starch gelatinization and physical changes occurred in blackgram proteins leads to increase in crispness of papad (Senthil et al. 2006). Samples prepared with addition of EBG flour were crispier due to early and more gelatinisation of pregelatinized starch. It was observed that addition of EBG flour significantly alter the hardness of the papad ($P \leq 0.05$). Hardness of fried papad decreased with increased amount of EBG. Sample having 50% EBG resembles with the market sample in terms of crispness (hardness). Greater crispness (less hardness) in market sample might be due to presence of higher amount of papadkhar (sodium carbonate: sodium bicarbonate). A similar result of less hardness was observed by Senthil et al. (2006) where greater crispness may be due to the use of additives. During frying of market sample leavening agents (papadkhar) leached out into frying oil. Hence

Fig. 3 Influence of partial replacement of RBG with EBG on variation of **a** storage modulus (G'); **b** elastic modulus (G''); **c** complex viscosity (η) of dough with angular frequency (ω). Where, sample A (RBG:EBG, 100:0); Sample B (RBG:EBG, 75:25) and Sample C (RBG:EBG, 50:50)

quality of frying oil was degraded at faster rate which even affects the frying cycles. A similar result of degradation of quality of frying oil was observed by Patil et al. (2005). Present study reveals that crispness of papad can be achieved with addition of EBG and can avoid use of papadkhar concentration in papad.

Effect of incorporation of extruded flour on colour properties of fried papad

Colour of fried product is an important parameter and to be controlled during processing together with texture, moisture and oil contents. Colour of the fried product is a result of moisture loss, oil migration and Maillard reaction that depends on the amount of reducing sugar and amino acids

Table 2 Effect of incorporation of extruded flour on pre- and post-frying colour properties of papad

	L*		a*		b*	
	Before frying	After frying	Before frying	After frying	Before frying	After frying
RBG:EBG (100:0)	65.48 ± 0.06 ^d	63.72 ± 0.03 ^d	3.58 ± 0.05 ^c	5.03 ± 0.02 ^c	27.87 ± 0.02 ^b	28.23 ± 0.06 ^c
RBG:EBG (75:25)	67.34 ± 0.04 ^c	64.13 ± 0.02 ^c	3.75 ± 0.05 ^b	5.36 ± 0.07 ^b	27.34 ± 0.04 ^c	29.55 ± 0.05 ^b
RBG:EBG (50:50)	63.53 ± 0.03 ^d	62.02 ± 0.02 ^e	3.93 ± 0.06 ^a	5.77 ± 0.07 ^a	28.10 ± 0.05 ^a	29.91 ± 0.04 ^a
RBG:EBG (0:100)	71.03 ± 0.02 ^b	69.26 ± 0.03 ^b	3.65 ± 0.05 ^c	4.75 ± 0.05 ^d	26.87 ± 0.03 ^d	27.74 ± 0.04 ^e
Market sample	75.44 ± 0.04 ^a	73.75 ± 0.05 ^a	3.60 ± 0.02 ^c	4.83 ± 0.08 ^d	26.76 ± 0.06 ^e	27.87 ± 0.07 ^d

RBG raw black gram, EBG extruded black gram

All the values are mean ± SD of five replicates. Mean values with different superscripts on the same column differ significantly (Duncan's LSD test, $P < 0.05$)

of proteins at the surface, temperature and time of frying (Krokida et al. 2001). Experimental data of hunter colour parameters were shown in Table 2. Colour properties were determined with the help of lightness (L^*) and redness (a^*) and yellowness (b^*) values (Kaur et al. 2017). Slight variation in L^* values were observed among the raw and fried papads, whereas market sample showed very high L^* values (Table 2). All a^* values of raw papads were positive (3.58–3.93) indicating a fairly uniform tinge of red colour. Whereas after frying this fairly uniform tinge of red colour of all the fried papad samples increased. Raw as well as fried papad samples were more yellowish in colour as shown by comparatively higher b^* values, and sample having 50% EBG added in RBG had the highest b^* value (29.91). From Table 2 it was observed that b^* values of the fried papads were higher than those of raw papads, indicating more yellowish tinge in the fried papads.

Conclusion

Present research demonstrated that partial replacement of RBG with EBG alters the dough properties by improving dough rollability and enhances quality of end product upon frying. Values of storage modulus and loss modulus showed rising behaviour whereas, complex viscosity showed decreasing behaviour with angular frequency. Results of present study exhibits that addition of EBG lowered down the energy requirement needed for softening the papad dough and increased efficiency of papad rolling. Also it helped in giving the lighter products, with low red intensity. Besides increasing the brightness incorporation of EBG also impart crispness to the fried Papad and can lower down the use of papadkhar concentration.

Acknowledgements This work was supported by funding from University Grants Commission (UGC), India.

References

- Ananthanarayan L, Gat Y, Kumar V et al (2018) Extruded black gram flour: partial substitute for improving quality characteristics of Indian traditional snack. *J Ethn Foods* 5:54–59. <https://doi.org/10.1016/j.jef.2017.10.001>
- Bajaj I, Singhal R (2007) Gellan gum for reducing oil uptake in sev, a legume based product during deep-fat frying. *Food Chem* 104:1472–1477. <https://doi.org/10.1016/j.foodchem.2007.02.011>
- Castell-Perez M, Mishra A (1995) Flow behavior of regular and peanut-fortified idli batters. *J Texture Stud* 26:273–279. <https://doi.org/10.1111/j.1745-4603.1995.tb00965.x>
- Ding Q-B, Ainsworth P, Tucker G, Marson H (2005) The effect of extrusion conditions on the physicochemical properties and sensory characteristics of rice-based expanded snacks. *J Food Eng* 66:283–289. <https://doi.org/10.1016/j.jfoodeng.2004.03.019>
- Gat Y, Ananthanarayan L (2015a) Physicochemical, phytochemical and nutritional impact of fortified cereal-based extrudate snacks. *Nutrafoods* 14:141–149. <https://doi.org/10.1007/s13749-015-0036-7>
- Gat Y, Ananthanarayan L (2015b) Effect of extrusion process parameters and pregelatinized rice flour on physicochemical properties of ready-to-eat expanded snacks. *J Food Sci Technol* 52:2634–2645. <https://doi.org/10.1007/s13197-014-1378-7>
- Gat Y, Ananthanarayan L (2016) Use of paprika oily extract as pre-extrusion colouring of rice extrudates: impact of processing and storage on colour stability. *J Food Sci Technol* 53:2887–2894. <https://doi.org/10.1007/s13197-016-2271-3>
- Gujral HS, Sodhi NS (2002) Back extrusion properties of wheat porridge (Dalia). *J Food Eng* 52:53–56. [https://doi.org/10.1016/S0260-8774\(01\)00085-1](https://doi.org/10.1016/S0260-8774(01)00085-1)
- Gujral HS, Guardiola I, Carbonell JV, Rosell CM (2003) Effect of cyclodextrinase on dough rheology and bread quality from rice flour. *J Agric Food Chem* 51:3814–3818. <https://doi.org/10.1021/jf034112w>
- Hoover R, Li Y, Hynes G, Senanayake N (1997) Physicochemical characterization of mung bean starch. *Food Hydrocoll* 11:401–408. [https://doi.org/10.1016/S0268-005X\(97\)80037-9](https://doi.org/10.1016/S0268-005X(97)80037-9)
- Izydorczyk M, Hussain A, Macgregor A (2001) Effect of barley and barley components on rheological properties of wheat dough. *J Cereal Sci* 34:251–260. <https://doi.org/10.1006/jcrs.2000.0363>
- Juliano BO (1998) Varietal impact on rice quality. *Cereal Food World* 43:207–222
- Kaur K, Singh N, Singh H (2000) The effect of extruded flour and fermentation time on some quality parameters of idli. *J Food Qual* 23:15–25. <https://doi.org/10.1111/j.1745-4557.2000.tb00192.x>
- Kaur P, Sharma P, Kumar V et al (2017) Effect of addition of flaxseed flour on phytochemical, physicochemical, nutritional, and textural properties of cookies. *J Saudi Soc Agric Sci*. <https://doi.org/10.1016/j.jssas.2017.12.004>
- Krokida M, Oreopoulou V, Maroulis Z, Marinou-Kouris D (2001) Colour changes during deep fat frying. *J Food Eng* 48:219–225. [https://doi.org/10.1016/S0260-8774\(00\)00161-8](https://doi.org/10.1016/S0260-8774(00)00161-8)
- Lazaridou A, Duta D, Papageorgiou M et al (2007) Effects of hydrocolloids on dough rheology and bread quality parameters in gluten-free formulations. *J Food Eng* 79:1033–1047. <https://doi.org/10.1016/j.jfoodeng.2006.03.032>
- Marzec A, Lewicki PP (2006) Antiplasticization of cereal-based products by water. Part I. Extruded flat bread. *J Food Eng* 73:1–8. <https://doi.org/10.1016/j.jfoodeng.2004.12.002>
- Maskat MY, Rohaya MS, Maaruf AG (2013) Rheological properties of different degree of pregelatinized rice flour batter. *Sains Malays* 42:1707–1714
- Patil SJ, Singhal RS, Kulkarni PR (2005) Studies of a 2:1 sodium carbonate:sodium bicarbonate mixture as papadkhar substitute for papads. *Food Chem* 91:51–56. <https://doi.org/10.1016/j.foodchem.2004.06.006>
- Reddy GC, Susheelamma NS, Tharanathan RN (1989) Viscosity pattern of native and fermented black gram flour and starch dispersions. *Starch-Starke* 41:84–88. <https://doi.org/10.1002/star.19890410303>
- Sanz T, Salvador A, Vélez G et al (2005) Influence of ingredients on the thermo-rheological behaviour of batters containing methylcellulose. *Food Hydrocoll* 19:869–877. <https://doi.org/10.1016/j.foodhyd.2004.11.003>
- Sarifudin A, Assiry AM (2014) Some physicochemical properties of dextrin produced by extrusion process. *J Saudi Soc Agric Sci* 13:100–106. <https://doi.org/10.1016/j.jssas.2013.02.001>
- Senthil A, Ravi R, Kumar AKV (2006) Quality characteristics of blackgram papad. *Int J Food Sci Nutr* 57:29–37. <https://doi.org/10.1080/09637480500498676>

- Singh N, Bawa AS, Sekhon KS (1995) Quality improvement of idli using extruded rice flour. *J Food Qual* 18:193–202. <https://doi.org/10.1111/j.1745-4557.1995.tb00374.x>
- Singh N, Kaur M, Sandhu KS, Guraya HS (2004) Physicochemical, thermal, morphological and pasting properties of starches from some Indian black gram (*Phaseolus mungo* L.) cultivars. *Starch-Starke* 56:535–544. <https://doi.org/10.1002/star.200400290>
- Uthayakumaran S, Beasley HL, Stoddard FL et al (2002) Synergistic and additive effects of three high molecular weight glutenin subunit loci. I. Effects on wheat dough rheology. *Cereal Chem J* 79:294–300. <https://doi.org/10.1094/cchem.2002.79.2.294>
- Wu M, Li D, Wang L-J et al (2010) Rheological properties of extruded dispersions of flaxseed-maize blend. *J Food Eng* 98:480–491. <https://doi.org/10.1016/j.jfoodeng.2010.01.031>
- Yadav DN, Kaur J, Anand T, Singh AK (2012) Storage stability and pasting properties of hydrothermally treated pearl millet flour. *Int J Food Sci Technol* 47:2532–2537. <https://doi.org/10.1111/j.1365-2621.2012.03131.x>