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Hydration properties and viscosity of sorghum (*Sorghum bicolor* L.) as affected by extrusion processing

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Abstract

The present study evaluates the effect of extrusion processing on functionality of sorghum flour in terms of water absorption index (WAI), water solubility index (WSI), peak viscosity (PV) and final viscosity (FV). Extrusion treatments at varying feed moisture (FM), temperature (T) and screw speed (SS) were applied on preconditioned sorghum flour to vary the severity of processing. Irrespective of variable processing conditions; extrusion significantly ($p<0.05$) improved the hydration properties of sorghum. Overall, there was about 2.15-3.61 and 1.1-1.8 fold increase in WAI and WSI respectively; over the native flour. Extrusion imparted high paste stability to sorghum; resulted in significant ($p<0.05$) reduction of PV (42-77%) and FV (81-88%). Extrusion at 'mild' conditions (high FM, low T, and low SS) showed higher improvement in hydration properties; whereas high paste stability observed at 'severe' conditions (low FM, high T and high SS). Extruded sorghum flour with improved functionality could be a promising healthy proposition for developing gluten free ready-to-eat products.

Keywords: Sorghum, extrusion, water absorption index, water solubility index, peak viscosity, final viscosity

1. Introduction

All Asian countries including India have unenviable reputation as being the epicentre for lifestyle diseases, which has strong relation with dietary habits. Food industry is continuously looking for dietary interventions like functional foods to effectively deliver nutrition and health to the consumers. There have been consistent efforts to increase functionality of cereals based foods by enriching them with higher dietary fibre, non-gluten proteins, phenolics and mineral content. In this regard, use of millets, whole grains, legumes, bran and phytochemical extracts in ready-to-eat extruded snacks as well as bakery products has heightened (Filli *et al*., 2013a; Gbenyi *et al*., 2105; Gull *et al*., 2015; Irakli *et al*., 2015; Makila *et al*., 2014; Ronda *et al*., 2015; Schoenlechner *et al*., 2013) [1-7].

Among millets, sorghum (*Sorghum bicolor* L.) is nutritionally dense gluten free grain with high amount of dietary fibre, protein, iron, calcium and numerous other minerals and phytochemicals. It is known to possess antioxidant activity, anti-celiac, anti-carcinogenic, anti-diabetic and cholesterol reducing properties (Dykes and Rooney, 2006) [8]. Unique nutritional profile and phytochemical-associated health benefits of sorghum seems to offer enormous potential for development of functional foods.

However, unprocessed/raw flours especially millet flours like sorghum has certain shortcomings such as low water absorption, low solubility and high dough viscosity (Angioloni and Collar, 2012) [9]. On account of poor functionality, these flours are unsuitable for use in new product development. Processing of these flours is integral to improve the functionality and thus quality of end product (Martinez *et al*., 2015) [10]. Extrusion is cooking process in which food is subjected to high temperature and high shear at relatively low levels of moisture content; accentuating the changes in their functional properties (Hagenimana *et al*., 2006) [11]. Extrusion can modify the hydration properties and viscosity of the food melt and consequently can be used for the production of pregelatinized flours. However, the extent of modifications/changes is governed by severity of the process variables involved such as feed rate, feed moisture, screw speed and barrel temperature (Martinez *et al*., 2014) [12].

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Plethora of research has been published on effect of extrusion on hydration and viscometric properties of major cereals like rice, corn and some millets. However, the volume of literature available on functionality of extruded sorghum is grossly inadequate. Against this background, the present study was undertaken with the objective to study the effect of different extrusion treatments on hydration properties and viscosity of sorghum flour.

2. Materials and methods

2.1 Flour preparation

The Sorghum (variety M35-1) grains (moisture: 9.13%, ash: 1.42%, protein: 10.86%; crude fat: 4.93%; crude fibre: 2.02%, carbohydrate: 71.64%, total starch: 46.21% and amylose content: 19.54) grains were procured from local commercial suppliers. The grains were ground separately in hammer mill and sieved through BS 30 mesh sieve to obtained particle size less than 500 µm. Prior to extrusion, flour was pre-conditioned to pre-determined moisture content by spraying with a calculated amount of distilled water with continuous mixing. The desired amount of water to be added was calculated using following formula (Chakraverty, 1988) [13].

$$W_m = W_1 \left[\frac{\Delta M}{100 - M_2} \right]$$

Where, W_m = Moisture to be added (g), W_1 = Initial weight of the flour at M_1 (g), $\Delta M = M_2 - M_1$ (for $M_2 > M_1$) or $\Delta M = M_1 - M_2$ (for $M_1 > M_2$), M_1 = Initial moisture content (wb) and M_2 = Final or desired moisture content (wb).

The flour was kept overnight in polyethylene pouches in order to equilibrate moisture at room temperature.

2.2 Extrusion

Extrusion processing of sorghum flour was done using Brabender Lab-Compounder KETSE 40/20 twin screw extruder (Germany) with length to diameter (L/D) ratio of 40:1. Moistened corn flour was subjected to eight different extrusion treatments: T1 (LM/LT/LS), T2 (LM/LT/HS), T3 (LM/HT/LS), T4 (LM/HT/HS), T5 (HM/LT/LS), T6 (LM/LT/HS), T7 (HM/HT/LS) and T8 (HM/HT/HS). Details of each treatment are given in Table 1. During processing, flour with two moisture levels (10 and 20% wb) was fed to the extruder at two screw speed levels (200 and 400 rpm) and extruded through3 mm circular die without jamming extruder. For all treatments, the temperatures of first four zones (Z1: feed zone; Z2, Z3, Z4: barrel zones) were fixed to 30 ˚C, 50 ˚C, 90 ˚C and 100 ˚C respectively; whereas temperature of both Z5 (barrel zone) and Z6 (heating ring zone) were varied (120 and 180 ˚C). The feeder speed was kept constant at 20 rpm (23.45 kg/hr) throughout the experiment. The extrudates expelled were dried at 60°C to 5-6% moisture (wb), ground and sieved (BS 30 mesh). Extruded sorghum flours were then analysed for their hydration properties and viscosity. Unextruded sorghum flour was served as control.

Table 1: Different extrusion treatments

Treatments	Moisture content (%wb)	Screw speed (rpm)	Temperature (ºC)
T1 (LM/LT/LS)	10	200	120
T2 (LM/LT/HS)	10	400	120
T3 (LM/HT/LS)	10	200	180
T4 (LM/HT/HS)	10	400	180
T5 (HM/LT/LS)	20	200	120
T6 (HM/LT/HS)	20	400	120
T7 (HM/HT/LS)	20	200	180
T8 (HM/HT/HS)	20	400	180

L: low; H: high; M: moisture; T: temperature; S: screw speed.

2.3 Analysis

2.3.1 Physicochemical composition of sorghum flour

Proximate composition of sorghum flour was determined using AACC International methods (AACC, 2000) [14]: 44-15A (moisture), 08-01 (ash), 46-08 (protein), 30-10 (crude fat), 32-10 (crude fibre). Carbohydrate was calculated by difference.

Total starch (TS) was determined enzymatically according to the modified method of Goni *et al.* (1997) [15] using glucose oxidase-peroxidase Kit (Megazyme K-GLUC, Ireland) for measuring glucose concentrations.

Amylose content of sorghum flour was determined by colorimetric measurement of the blue amylose-iodine complex (Juliano, 1971) [16].

2.3.2 Hydration properties (WAI and WSI) of sorghum flour

Hydration properties of native and extruded sorghum flour were determined by the method of Gujral and Singh (2002) [17].

2.3.3 Viscosity of sorghum flour

The viscosity (peak viscosity and final viscosity) of native and extruded sorghum flour were performed in triplicate according to AACC international method: 76-21.01 (AACC, 2000) [14] (3.5 g flour, 14 g moisture basis) with slight modification using Rapid Visco Analyser (RVA) (MCR 52, Anton paar, Austria). The peak viscosity and final viscosity were identified from the pasting curve using Thermocline Version 2.2 software (Newport Scientific, Warriewood, NSW and Australia).

2.4 Statistical analysis

Analysis of Variance (ANOVA) was performed to identify significant differences among the effects of various extrusion treatments, using SAS (9.4) software. Further, data were subjected to Tukey's HSD test at a significance level of $p<0.05$ for pair-wise comparison of treatment effects for each parameter.

3. Results and discussion

3.1 Effect of different extrusion treatments on hydration properties

Hydration properties such as water absorption index (WAI) and water solubility index (WSI) can be used in particular, to estimate the functional characteristics of foods and predict the behaviour of materials on further processing. Hydration properties of sorghum flour as affected by different extrusion treatments are presented in Table 2.

WAI measures the amount of water absorbed or binded by starch and can be used as an index of gelatinization (Dogan and Karwe, 2003) [18]. Native/unextruded sorghum flour showed WAI value of 2.75 (Table 2). Irrespective of variable extrusion conditions, here was significant (p<0.05) increase in WAI of extruded sorghum flour. WAI of extruded flours ranged from 5.91 to 9.92; depicting about 2.15 to 3.61 fold increase over native flour. The maximum and minimum increase was observed at treatment T5 (HM/LT/LS) and treatment T4 (LM/HT/HS) respectively over control sample. All extrusion variables (feed moisture, temperature and screw speed) were found to have significant (p<0.05) effects. Irrespective of screw speed, high moisture caused rise in WAI at both levels of temperature. However, rise was more pronounced at low temperature than high temperature; depicting adverse effect of temperature on WAI. The screw speed had reciprocal effect; increase was more pronounced at low screw speed than high screw speed.

Table 2: Effect of different extrusion treatments on hydration properties of corn flour.

Treatments	WAI (g/g)	WSI (%)
Control	2.75^{g}	8.69^{b}
T1(LM/LT/LS)	7.95^{c}	10.46^{ab}
T2 (LM/LT/HS)	6.19^{fe}	13.77^{ab}
T3 (LM/HT/LS)	6.47^{fe}	12.97^{ab}
T4 (LM/HT/HS)	5.91^{f}	15.62^{a}
T5 (HM/LT/LS)	9.92^{a}	9.55^{b}
T6 (HM/LT/HS)	8.87^{b}	9.85^{b}
T7 (HM/HT/LS)	7.21^{d}	10.57^{ab}
T8 (HM/HT/HS)	6.75^{de}	11.60^{ab}
Standard error	0.139	1.143

Means with different superscript letter within same column are significantly different (p<0.05)

WSI measures the amount of small molecules solubilised in water; hence can be used as an indicator of starch breakdown/dextrinization and starch conversion (Rweyemamu *et al*., 2015) [22]. WSI value of native flour was found as 8.69%. Significant (p<0.05) increase in WSI of sorghum processed under variable extrusion parameters was observed; values ranged from 9.55 to 15.62%, depicting about 1.1 to 1.8 fold increase over native sorghum. The maximum increase was registered in treatment T4 (LM/HT/HS) over T5 (HM/LT/LS), being indicative of severity of the treatment. All extrusion variables had significant (p<0.05) impact on WSI.Low feed moisture, high temperature and high screw speed increased WSI significantly. Low moisture increased WSI at both levels of screw speed. The magnitude of increase was more at high screw speed than low screw speed; illustrating positive effect of screw speed on WSI. Similar trend was observed under high temperature extrusion treatments; although the effect was more pronounced.

In general, the WAI and WSI values of flours are influenced mainly by size and structure of starch granules (Nura *et al*., 2011) [19]. High WAI and WSI of extruded sorghum is expected as gelatinized starch had a higher ability to absorb water than did the native starch granules at room temperature (Jongsutjarittam and Charoenrein, 2014) [20]. High feed moisture during extrusion of sorghum aid starch gelatinization with concomitant swelling and reduced starch breakdown associated with plasticizing effect of excess moisture; consequently favouring absorption than solubility (Bhise *et al*., 2013; Rweyemamu *et al*., 2015) [21, 22]. Our results are in accordance with previous reports (Camacho-Hernandez *et al*., 2014; Keawpeng *et al*. 2014) [23, 24]. Increase in temperature and screw speed at constant feed moisture was observed to cause a significant (p<0.05) decrease in WAI and increase in WSI. High shear and high temperature conditions caused extensive polymer damage, dextrinization, starch melting and protein denaturation that prevailed over the gelatinization phenomenon; thereby decreasing the ability of starch molecules to bind water and increasing the solubility by producing more soluble molecules (Siddiq, 2013; Rodriguez-Miranda *et al.*, 2011) [25, 26]. Our results are in agreement with previous work (Bhise *et al*., 2013; Filli *et al*., 2013b) [21, 27].

Improved water absorption of extruded sorghum flour could potentially be useful in food products, such as frozen bakery products, sausage, mayonnaise, soups; where flour with high water absorption ability is required. High solubility is of interest for children's foods and beverages, where low viscosity and stickiness is desirable in end-products.

3.2 Effect of different extrusion treatments on viscosity

Viscosity provide imminent information about the cooking behaviour of starches during heating and cooling cycles, thus access the potential industrial application in products dependent on the viscosity and thickening behaviour of starch (Ahmed *et al.*, 2016) [28]. Viscosity of native and extruded sorghum flours were measured by Rapid Visco Analyser and the results are presented in Table 3.

3.2.1 Peak viscosity

Peak viscosity (PV) reflects degree of gelatinization and tendency of starch granules to swell freely before physical breakdown. Results showed that extrusion of sorghum caused significant (p<0.05) decrease in PV values. PV value of control flour was 1715 cP, whereas that of extruded flours ranged from 398.4 to 993.2 cP (Table 3); reflecting reduction of about 42-77%. The magnitude of decrease was highest for treatment T4 (LM/HT/HS) and lowest for treatment T5 (HM/LT/LS). In general, decrease in PV was more pronounced at low moisture and high temperature and screw speed extrusion conditions.

Table 3: Effect of different extrusion treatments on viscosity of corn flour.

Treatments	Peak viscosity(cP)	Final viscosity (cP)
Control	1725^{a}	3931^{a}
T1 (LM/LT/LS)	551.3^{cd}	604.1^{d}
T2 (LM/LT/HS)	440.6^{ef}	694.8^{bc}
T3 (LM/HT/LS)	459.1^{efd}	716.2^{bc}
T4 (LM/HT/HS)	398.4^{f}	474^{e}
T5 (HM/LT/LS)	993.2^{b}	741.4^{b}
T6 (HM/LT/HS)	584.3^{c}	674.2^{dbc}
T7 (HM/HT/LS)	543.1^{ecd}	662.8^{dc}
T8 (HM/HT/HS)	518.2^{ecd}	612.1^{d}
Standard error	21.89	15.629

Means with different superscript letter within same column are significantly different (p<0.05)

Low PV values of the extruded flours in comparison to native flour is a consequence of the starch disruption, denaturation of the protein and the starch-protein interactions that produce more fragile structure with lower capacity for interaction with water and hence low PV (Hernandez-Nava *et al*., 2011) [29].

High feed moisture has plasticization effect, act as a lubricant, leading to residual un-gelatinized starch granules rendering starch polymeric chains more flexible and thus facilitating the rearrangement of amylose/amylopectin unit chains and resulted in increased viscosity profiles (Watcharatewinkul *et al*., 2009) [30]; whereas low moisture had reciprocal effect.

With respect to the effect of temperature and screw speed, an increase in both variables causes greater friction and energy dissipation, inducing dextrinization or degradation of starch and an increased formation of water-soluble molecules (Hagenimana *et al*. 2006; Repo-Carrasco-Valencia *et al*. 2009a) [11, 31]. Our results are in accordance with results of Guha *et al*, (1998) [32]. The authors observed similar decrease in PV values of extruded rice with increasing barrel temperature and screw speed. Sarawong *et al*. (2014) [33] also reported increased pasting profile of banana flour at high moisture and low screw speed.

3.2.2 Final Viscosity

Final viscosity (FV) is a measure of gelling tendency and refers to the ability of the material to form a viscous paste or gel after cooking and cooling (Jan *et al*., 2016) [28]. According to RVA results (Table 3), FV values varied significantly (p<0.05) among native and extruded sorghum flours and followed similar trend to that of PV. FV values reduced drastically from 3931 cP in control to 474-741.4 cPin extruded flours. This shows reduction in FV to the tune of 81 to 88%. Among extrusion treatments, T4 (LM/HT/HS) registered lowest FV values, depicting severe degradation/fragmentation of amylose chains with loss in ability to form a viscous paste. This was expected as this treatment was identified as 'severe' treatment. Low level of moisture, especially at high temperature exerts significant decreasing effect on FV irrespective of screw speed. Similar decreasing trend was observed at low temperature, although the magnitudes being slightly lower. Decrease in FV was more pronounced at high level of screw speed.

In general, high FV value indicates high retrogradation, thus low stability of starch paste (Sun and Xiong, 2014) [34]. Extruded sorghum flours presented lower FV values than native flour, which adequately explains their reduced retrogradation tendency and increased paste stability. This is basically accredited to starch-granule modifications and absence of residual gelatinization enthalpy, following extrusion (Hagenimana *et al*., 2006) [11]. High feed moisture during extrusion especially at low temperature and low screw speed; may act as lubricant, allowing less starch degradation, higher gelatinization and reorganization of molecules, leading to high FV. In contrast, extensive shearing under low moisture, high temperature and high screw speed tends to increase dextrinization/degradation of starch, lower gelatinization, thus decreased FV (Repo-Carrasco-Valencia *et al*., 2009b) [35]. Our results are in agreement with other studies (Bhattacharya *et al*., 1999; Kim *et al*., 2006; Sompong *et al*., 2011) [36, 37, 38].

Reduced retrogradation tendency associated with low final viscosity of extruded sorghum can be exploited food products like bread which undergoes staling easily and in soups and sauces which undergo loss of viscosity and precipitation as a result of retrogradation.

4. Conclusions

Extruded sorghum flours presented high WAI, WSI and low peak and final viscosity over native flour. Improved hydration properties and paste stability of extruded sorghum reflected high degree of gelatinization coupled with starch degradation due to net effect of heat-moisture-mechanical energy applied during extrusion process. Based on the extent of changes in hydration properties and viscosities, treatment T5 (HM/LT/LS) and T4 (LM/HT/HS) were designated as most "mild" and "severe" extrusion treatment respectively. Results demonstrated that hydration properties and viscosity of native sorghum can be effectively modified by tailoring extrusion conditions. Improved functionality of extruded sorghum allows its use as a gluten free functional ingredient in various ready-to-eat food products.

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