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Research Article

Functional Properties of Extruded Corn Flour

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ABSTRACT

Effect of extrusion cooking on hydration properties (water absorption index (WAI), water solubility index (WSI)), and viscosity (peak viscosity (PV), final viscosity (FV)) of corn flour was studied. The preconditioned corn flour was processed using different extrusion cooking conditions at the variable moisture content (MC), temperature (T), and screw speed (SS). Statistical analysis showed that irrespective of variable processing parameters the hydration properties were improved after extrusion cooking. WAI and WSI were increased by 70% to 268% and 5 to 198%, respectively over unextruded flour. The viscosity of extruded corn flour showed a significant ($p < 0.05$) decrease, indicating high paste stability of corn flour after extrusion cooking. Overall, there was 72 to 86% decrease in PV and 89 to 95% decrease in FV. The mild processing conditions (high MC, low SS, and low T) imparted better hydration properties, whereas severe processing conditions (low MC, high SS, and high T) imparted better paste stability to corn flour. Extruded corn flour with modified functional properties has the potential to be exploited in the development of various gluten-free ready-to-eat products, composite flours, bakery products, etc.

RESEARCH ARTICLE

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INTRODUCTION

Corn, also known as maize (*Zea mays* L.) is called as 'Queen of Cereals'. At the global level, it is the second important cereal crop with a production of 1 040 million MT in 2016-17 (FICCI Maize vision-2022, 2018). Corn is not only an important staple cereal for food security but also a potential whole cereal for nutritional foods. Corn is a gluten free grain with unique profiles of nutrients and bioactive compounds. It contains about 62% starch, 4% fat, and 8.7% protein. It is an essential source of micronutrients, dietary fiber, and bioactive such as carotenoids, phytosterols, phenolics, flavonoids, anthocyanins, and (Hassan *et al.*, 2019). The consumption of corn and other whole grain products has been linked to the lowering risk of cardiovascular disease, type-2 diabetes, obesity, cancer etc. (Siyuan *et al.*, 2018). According to Shah *et al.* (2016), the resistant starch from corn is known for prevention against cecal cancer, atherosclerosis, and obesity-related complications.

Recently, the bioactive compounds derived from corn and other whole grains have gained the attention of the food industry for the development of functional foods. It is increasingly being processed into a variety of food products such as corn starch, cornmeal, grits, composite flours, tortillas, ready-to-eat snacks, and breakfast cereals, etc. Corn flour also has vast potential in the bakery industry for the development of gluten-free baked products like composite bread (Sun *et al.*, 2019). However, the poor functionality of raw corn flour with regard to water absorption capacity, water solubility, and dough viscosity renders it unsuitable for bakery products. Being gluten-free, the incorporation of unprocessed corn flour in bread can deteriorate the technological and textural properties of bread. It lowers the gluten content, disrupts the gluten network of composite dough, and retains a low amount of gas, resulting in rapid staling and poor crumb texture (Jafari *et al.*, 2018). Gluten, hydrocolloids, modified starches and enzymes in the form of additives have been used to make up for the poor functionality of composite flours (Martinez *et al.*, 2013; Schoenlechner *et al.*, 2013).

Thermal treatment is another way to enhance the functional properties of corn flour and thereby the quality of the final product. Extrusion cooking is an important hydrothermal treatment, in which material with relatively low moisture content is processed at high temperature and high shearing rate. Extrusion modifies the functional properties of flours by the way of starch gelatinization, fiber dissolution, and protein aggregation (Hagenimana *et al.*, 2006). Extruded flours can replace hydrocolloids being used to mimic the viscoelasticity properties of wheat in low gluten or gluten-free food products. The earlier studies showed that the incorporation of extruded flours of sorghum (Jafari *et al.*, 2018), finger millet (Patil *et al.*, 2016) and wheat flour (Martinez *et al.*, 2014) had positive effects on crumb texture, dough rheology, and organoleptic properties of breads. Extruded corn flour can also be a gluten-free healthy ingredient for bakery industries. Thus, this experiment was undertaken to envisage the consequence of extrusion cooking on the functional properties of corn flour so that its potential applications in food formulations can be explored.

MATERIALS AND METHODS

Preconditioning of Corn Flour

Corn grains of Pusa Composite-3variety were purchased from local commercial suppliers (New Delhi, India) and were subjected for milling in the hammer mill and screened subsequently (BS 30 mesh) to obtain uniform flour. Before subjecting to extrusion cooking, the flour was conditioned to attain desired moisture content by adding a known quantity of distilled water. The flour was stirred continuously while adding water to ensure uniform hydration. The flour was then transferred to zip-lock polyethylene pouches and kept overnight for equilibration of moisture. The quantity of added water was determined as per the methodology reported by Chakraverty, (1988).

Extrusion Cooking of Corn Flour

Extrusion cooking was performed using a twin 40/20 screw extruder (M/s Brabender Lab-Compounder KETSE, Germany). The preconditioned flour was extruded at eight cooking conditions having three variable parameters: moisture content (10 and 20% wb), screw speed (200 and 400 rpm), and die temperature (120 and 180°C) as given in Table 1. The feeding and barrel zone temperatures were fixed as 80°C and 100°C, respectively, and the feeder speed was fixed as 20 rpm during all experiments. The extruded corn was dried, milled, and screened to obtain fine flour (BS 30 mesh) which was stored at the dry and cool place before analysis. Unextruded corn flour was taken as a control sample.

Table 1. Details of extrusion cooking parameters

Treatments	Feeder speed (rpm)	Moisture content (% wb)	Screw speed (rpm)	Temperature (°C)
T1	20	10	200	120
T2	20	10	400	120
T3	20	10	200	180
T4	20	10	400	180
T5	20	20	200	120
T6	20	20	400	120
T7	20	20	200	180
T8	20	20	400	180

Analysis of Corn Flour

Physicochemical analysis

Proximate analysis of corn was done using a standard procedure (AACC, 2000). Total starch (TS) was estimated by measuring glucose level (Goni *et al.*, 1997) and the amylose content of flour was determined by the colorimetric method (Juliano 1971).

Hydration properties

Hydration properties of extruded and unextruded corn flour were determined by the method suggested by Gujral and Singh (2002). WAI corresponds to the quantity of water immobilized or absorbed by the starch, also reflects the degree of starch gelatinization (Rweyemamu *et al.*, 2015), WSI is the leaching of molecular compounds out of the starch also denotes the level of conversion and degradation of molecules (Siddiq *et al.*, 2013).

Viscosity of corn flour

The pasting properties with respect to extruded and unextruded corn flour were measured by Rapid Visco Analyser (M/s MCR 52, Anton paar, Austria) using AACC standard method: 76-21.01 (AACC, 2000). Thermocline Version 2.2 software (M/s Newport Scientific, Warriewood, NSW, and Australia) was used to obtain pasting curve, from which the values of PV and FV were identified.

Statistical Analysis

The significant differences between the effects of various treatments were analysed by Analysis of Variance (ANOVA) using SAS (9.4) software. Tukey's HSD test was performed for pair-wise comparison of effects of each treatment at 5% significance level.

RESULTS and DISCUSSION

Physicochemical Characterization

The physicochemical composition of corn was performed and the respective values of moisture (8.60%), carbohydrate (72.07%), fat (4.95%), protein (11.06%), crude fibre (1.97%), ash (1.35%), total starch (45.81%) and amylose content (19.45%) were reported.

Hydration Properties of Extruded Corn Flour

Extrusion cooking involves several phenomena such as starch gelatinization and degradation, fiber solubilization, protein denaturation, enzyme inactivation etc. These reactions modify the functionality of flours by changing their hydration properties and pasting properties (Martinez *et al.*, 2014). Hydration properties display its behavior during processing and are presented in Table 2.

Extrusion cooking significantly ($p<0.05$) increased the WAI of corn flour. Unextruded (control) corn flour had a WAI value of 2.45 g g^{-1}. WAI of extruded corn flours varied from 4.16 to 9.02 g g^{-1}, showing about 69.8% to 268.2% rise over the control sample. The highest and lowest increment was noted for T5 and T4 treatment, respectively. Results indicated that the higher improvement in WAI was observed at mild processing conditions i.e. high moisture content, low screw speed, and low temperature. WSI of control corn flour was found to be 10.46%. Like WAI, significant ($p<0.05$) increase in WSI values (10.99 to 31.18%) was observed for corn flours extruded under variable extrusion conditions; depicting about 5 to 198% rise over control sample. The highest and lowest increase was registered in T4 and T5 treatment, respectively. Results depicted high severity of extrusion process at moisture (low), screw speed (high) and temperature (high), causing higher degradation and conversion of molecules.

An increase in WAI and WSI of extruded corn flour was anticipated on account of gelatinization of starch and degradation of other molecules after extrusion. Gelatinized starch possess high water absorption potential than raw starch at room temperature (Jongsutjarittam and Charoenrein, 2014). Increase in water absorption capacity was due to the uncovering and loosening of molecular chains, resulting in higher availability of hydrophilic structures and easier penetration of water molecules (Marzec and Lewicki, 2006). The degradation and dextrinization of material during extrusion results in low molecular weight compounds, on account of which the water solubilityincreases. (Mesquita *et al.*, 2013). However, the limit of increase varies with the molecular bonding between degraded starch, proteins, and lipids (Patil and Kaur, 2018).

Table 2: Hydration properties of corn flour.

Treatments	WAI (g g^{-1})	WSI (%)
Control	2.45^{f}	10.46^{d}
T1	6.46^{bc}	12.01^{d}
T2	4.41^{e}	29.17^{a}
T3	4.94^{de}	27.06^{ab}
T4	4.16^{e}	31.18^{a}
T5	9.02^{a}	10.99^{d}
T6	7.18^{b}	11.68^{d}
T7	5.83^{cd}	12.73^{cd}
T8	5.05^{de}	20.24^{bc}
Standard error	0.247	1.594

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

Viscosity of Extruded Corn Flour

The viscosity curves, also known as pasting profile are the efficient assay for rapid determination of cooking attributes of flours (Jan *et al.*, 2016). Viscosity primarily depends on the swelling potential and rigidity of the starch granules, and the leaching of amylose in the solution (Kaushal *et al.*, 2012). The viscous behavior is generally decided by the starch, protein, and the ratio of amylose and amylopectin present in the flours. (Sun *et al.*, 2015).

Peak viscosity (PV) is the highest viscosity attained while pasting/heating due to the net effect of starch swelling and disruption of the granules (Balet *et al.*, 2019). PV indicates the degree of gelatinization and water-holding potential of the starch granules before physical breakdown (Cozzolino, 2016). Final viscosity (FV) is a thickening or gelling capacity of the material, also denotes the viscous paste forming ability of the material after cooking and cooling (Jan *et al.*, 2016). The extent of modification of starch molecules during the processing of flours can be estimated by its viscosity values. These changes are pronounced in extrusion processing, due to the high shearing rate. (Desouza *et al.*, 2011). PV and FV values of unextruded and extruded corn flours are presented in Table 3.

Table 3. Viscosity of corn flour as affected by extrusion cooking

Treatments	Peak viscosity (cP)	Final viscosity (cP)
Control	1237.0^{a}	3260.0^{a}
T1	321.6^{bc}	342.0^{b}
T2	192.0^{d}	192.6^{f}
T3	269.3^{c}	257.5^{e}
T4	178.7^{d}	172.7^{f}
T5	347.8^{b}	357.2^{b}
T6	338.5^{bc}	327.0^{dbc}
T7	311.6^{bc}	305.4^{dec}
T8	281.4^{bc}	288.4^{de}
Standard error	14.990	9.787

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

Extruded corn flour exhibited significantly ($p < 0.05$) low PV values than unextruded corn flour, values ranged from 178.7 to 338.5 cP (Table 3). The PV value of control corn flour was 1237 cP. Overall, there was about 72.6 to 85.6% decrease in PV of corn flour after extrusion cooking. The highest and lowest decrease was found for treatment T4 and T5, respectively. A similar trend was observed for FV values of corn flour. Extruded corn flour showed low FV values (172.7 to 357.2 cP) than unextruded flour (3260 cP), depicting about 89 to 94.7% decrease.

Results confirmed that decrease in moisture and increase in screw speed, as well as temperature during extrusion, caused a marked decrease in viscosity values. This has a direct relation with the severity of extrusion conditions. In case of low severe processing conditions, a part of starch molecules may retain their structure while in a fully swollen state, which in turn increases the paste viscosity (Siddiq *et al*., 2013). Reduction in viscosity values of extruded flours is because of the higher starch gelatinization and degradation on account of the combined effect of moisture, heat, and mechanical shearing generated during extrusion cooking (Repo-Carrasco-Valencia *et al*., 2009). These results were corroborated with the findings of Guha *et al.* (1998) in extruded rice and Sarawong *et al.* (2014) in extruded banana flour. Siddiq *et al.* (2013) also observed reduced pasting profile thus low peak and final viscosities of extruded bean flours. Overall, extrusion altered the viscoelasticity of corn flour; forming relatively stable pastes having low final viscosity and retrogradation tendency (Patil and Kaur, 2018).

CONCLUSION

Extrusion cooking significantly improved the functionality of corn flour in terms of water absorption capacity, water solubility, and dough viscosity, thus can be effectively used to make up for the poor functionality of raw corn flour. Extruded corn flour exhibited better hydration properties in terms of high water absorption and high water solubility than that of unextruded corn flour. Extruded resulted in corn flour showed a unique pasting profile with low peak and final viscosities and low retrogradation tendency. Results demonstrated that the changes in hydration and pasting properties of corn can be controlled by regulating the extrusion parameters. The modified functionality of corn flour may be effectively exploited in food formulations such as instant corn starches, composite flours, baby foods, gluten-free bakery products, ready-to-eat snacks, etc.

DECLARATION OF COMPETING INTEREST

The authors must declare that they have no conflict of interest.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Sharmila Patil: Conceptualization, methodology, investigation, writing-original draft, review and editing.

Charanjit Kaur: Project administration, funding acquisition, writing-original draft, formal analysis, discussed the results and contributed to the final manuscript.

Manoj Kumar Puniya: Data curation, validation, review and editing, discussed the results and contributed to the final manuscript.

Archana Mahapatra: Data curation, review and editing, visualization, discussed the results and contributed to the final manuscript.

Jyoti Dhakane: Data validation, review and editing, discussed the results and contributed to the final manuscript.

Kirti Jalgaonkar: Writing-review & editing, formal analysis, software.
Manoj Kumar Mahawar: Writing-review & editing, formal analysis, software.

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