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Research Article

Sorghum- and Chickpea-Based Ready-to-Eat Extrudate Flakes: Quality Attributes and *In Vitro* Digestibility

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The study is aimed at the development of whole sorghum-based ready-to-eat extruded snacks using chickpea at different barrel temperature (BT) (130, 145, and 170°C) and feed moisture (FM) (14, 16, and 18%) conditions, and quality changes on the functionality aspects of prepared snacks were evaluated. Data revealed that with increment in barrel temperature and feed moisture, the antioxidant properties, viz., ferric reducing antioxidant potential (FRAP) and 2,2-diphenyl-1-picrylhydrazyl (DPPH) inhibition, total phenolic content (TPC), and hardness of the flakes amplified; however, elevated barrel temperature and decreased feed moisture enhanced the expansion ratio, water solubility index, and overall acceptability of lakes. The results of the (L^*, a^*, and b^*) color values indicated that the rates of Maillard's reaction were higher when the BT and FM processes were intensified. Enhanced extrusion conditions (BT and FM) lead to higher levels of resistant starch and improved in vitro protein digestibility. The estimated glycemic index of the flakes ranges from 52 to 54, thus showing low estimated glycemic index (E-GI) of flakes. Slowly digestible starch and Exp-GI reveal a positive correlation among themselves. Results from the present study showed that highly acceptable flakes with commercialization properties can be successfully formulated using extrusion processing.

1. Introduction

The rise in the occurrence of lifestyle-related illnesses like diabetes, cardiovascular diseases (CVD), and obesity has resulted in a greater need for nutritious food products than ever before [1]. Convenience and nutritional value of a food product are two main points that are considered most important while developing a new food product; third being the price of the food product as it should be affordable for lower poverty line section of society as well. Breakfast cereals are highly popular due to their convenience in consumption, their nutritious value, and, of course, their crispiness. A combination of easily available, cheap, and nutrient-full raw material with a technology (green) could be utilized to achieve a healthy food product.

Presently, sorghum has attained increased consumer interest because of dietary modifications such as gluten-free options, high-bioactive compound, and high fiber. Sorghum is an important crop that thrives in the drought-prone regions of Africa and India [2]. Many researchers have leveraged sorghum as a whole grain or as an ingredient to enhance its value [3, 4]. Furthermore, sorghum is highly regarded for its abundant phytochemical composition, which includes phenols, tannins, anthocyanins, hydroxybenzoic acids, hydroxycinnamic acids, and various other flavonoids [5]. These phenolic compounds do present a significant impact on human health; these are also responsible for its antioxidant activity [6]. However, the protein quantity and quality are the factors that limit its applications in human food products. This problem could be tackled to achieve products with higher protein content along with a good protein digestibility. Blending of whole sorghum with legumes using an efficient technology could do the trick. In a recent study by Kaur et al. [7], it was demonstrated that incorporating mungbean flour into whole sorghum flour resulted in enhanced functional and nutritional characteristics of extruded snacks. There are numerous high-protein food ingredients, including whey protein and other nutricereals, which can be added to boost the protein content of sorghum-based products [8].

Chickpea is the popular source of vegan diet owing to its higher dietary proteins (17–22%), crude fiber, and carbohydrate (50%) while having low lipid content (6.48%) [9]. India is the top producer of chickpea with a production of about 11 million metric tons (FAOSTAT). Consumption of chickpea is reported to have beneficial effects on lowering glucose levels, cardiovascular diseases, cancer, hypertension, and cholesterol [10] and is thus recommended for the development of nutrient-dense diets to promote general well-being and overall health [11]. The combination of chickpea and sorghum could result in the food product with the properties and goodness of both the crops. Moreover, the crops complement each other with respect to their amino acid composition. However, in spite of all the plus points, the utilization of sorghum is still confined to the traditional consumers, the population living in villages, mostly the lower-economic people, generally due to the nonavailability of ready-to-eat (RTE) forms and convenience food products.

Extrusion technology is known to be the most useful technique to deal with consumer's demand owing to its various advantages such as innovation and versatility in food production, higher food quality, and low manufacturing costs [12, 13]. The cooking of food material in the high-temperature short time (HTST) process via extrusion technology involves the use of mechanical shear and elevated temperatures (Bobade et al. 2022; [14]). Extrusion, as a method, has shown the ability to enhance the release and availability of bioactive compounds by disrupting their connections with the cellular structure and liberating those [15]. This results in the molecular transformation and chemical reactions in order to modify the functional properties, nutrient, and phytochemical composition of food [16]. Moreover, the formulation of an affordable, healthy extruded snack will offer a great solution in combating the issue of malnutrition [17], and thus the addition of whole chickpea flour will complement the inherent properties of sorghum and enhance its utilization. The present study is intended to (1) establish the BT and FM-mediated effect on the physicochemical, nutritional, and functional properties of flakes prepared using whole sorghum-chickpea and (2) conclude the optimal combination of BT-FM for the development of flakes with an improved quality attribute.

2. Materials and Methods

2.1. Material. For experimental work, white sorghum (2077 B Line) and *kabuli* chickpea (PBG 7) having 9.69 and 24.59% protein, 1.23 and 4.36% fat, 1.82 and 2.58% ash, and 3.35 and 1.89%, respectively, were procured from the Directorate of Seed, Punjab Agricultural University. Grains were ground in Torrento flour mill (Tech Electric Enterprise, Ahmedabad, India) with stator setting at no. 2 to obtain the whole flour with average particle size of 250 μ. The preliminary trials have shown that 80 : 20 (sorghum:-chickpea) was found to be best composition to achieve improved nutritional and functional properties as well as sensorial attributes. Therefore, the same ratio is used in the present study. Till further analysis, the flour was stored (air-tight packing).

2.2. Extrusion. For the extrusion process, a twin-screw extruder from Clextral (Firminy, France), specifically Model BC 21, was utilized. The extruder features a barrel diameter of 25 mm and a length-to-diameter ratio of 16 : 1. It is equipped with corotating and intermeshing screws. The feed was subjected to extrusion processing at a constant feed rate of 10 kg/hr and screw speed of 500 rpm via feed hopper. The temperature of feed hopper was sustained at 35-40°C, while it was kept fixed at 70°C for second zone and 100°C for third zone of the extruder barrel; however, the temperature in the last zone of barrel varied from 130 to 170°C for experiment. The moisture content of the barrel was adjusted in the range of 14-18% during different extrusion conditions. Figure 1 shows the flakes prepared at different extrusion conditions. The opening of the die had a diameter of 3 mm. A8.5 kW power motor with a speed variable of 0-682 rpm (rotation per minute) was used [7, 18].

2.3. Specific Mechanical Energy (SME). The specific mechanical energy (SME) was determined by applying the formula that involves calculating the torque indicated in the extruder controls [7].

$$\text{SME (Wh/kg)} = \frac{\text{Actual screw speed (rpm)}}{\text{Rated screw speed (rpm)}} \times \frac{\text{\%motor torque}}{100} \times \frac{\text{motor power rating}}{\text{mass flow rate (kg/h)}} \times 1000. \tag{1}$$

2.4. Expansion Ratio (ER). Flakes were studied for ER by following the method promulgated by Bobade et al. [12] using the following formula. Diameter of die was 3 mm.

$$\text{ER} = \frac{\text{Diameter of the extrudate (mm)}}{\text{Diameter of die (mm)}}. \tag{2}$$

2.5. Bulk Density (BD). BD of the flakes produced through different extrusion conditions extruded was calculated by rapeseed displacement method given by Bobade et al. [13] which is expressed as a mean of five random samples.

$$\text{Bulk density (BD) (g/mL)} = \frac{\text{mass(g)}}{\text{volume(mL)}} \tag{3}$$

2.6. Functional Properties. Water absorption and water solubility index (WAI and WSI) were estimated using methods depicted by Anderson et al. [19]. Distilled water (30 mL)

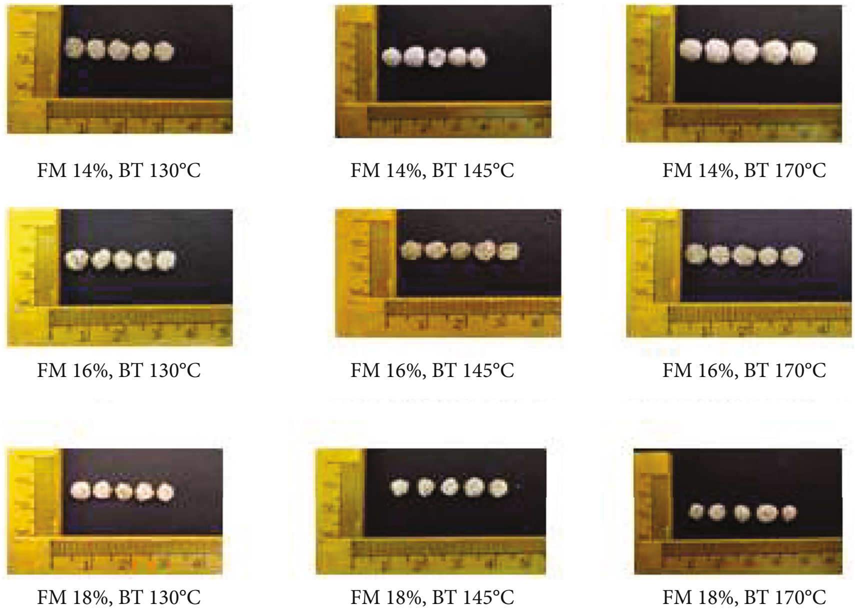

Figure 1: Images of sorghum-chickpea flakes formulated at different extrusion conditions.

was poured to a tarred centrifuge tube, to which 2.5 g of ground sample was added at 30°C. Contents were mixed by stirring for 30 min, followed by centrifugation (3000 × g) for 10 min. Supernatant was added to a pre-weighed dish. WSI was calculated from content of desiccated solids obtained by removing the supernatant.

$$\mathrm{WAI}\ (\mathrm{g/g}) = \frac{\text{Weight of gel}}{\text{Weight of dry solids}},$$

$$\mathrm{WSI}\ (\%) = \frac{\text{Weight of dry matter in supernatant}}{\text{Weight of dry solids}} \times 100, \tag{4}$$

2.7. Hardness. Ten random extruded flakes were selected and their hardness was determined using TA-XT2i, texture analyzer (Stable Micro System, Surrey, UK) as per methodology of Kaur et al. [18].

2.8. Color Characteristics. The color characteristics of flakes in terms of L, a^*, b^* were recorded using Hunter colorimeter (Konia Minolta CR-410 T) having Pulsed xenon lamp as light source. The colorimeter was standardized against standard color plates black and white [12, 13].

2.9. Antioxidant Activity and Total Phenolic Content (TPC). The procedure as described by Kataria et al. [20] was followed to check the antioxidant activity of flakes in terms of % DPPH inhibition and ferric reducing antioxidant potential (FRAP). TPC was determined by the Folin-Ciocalteu spectrophotometric method, and results were expressed as mg GAE/g [7, 18].

2.10. In Vitro Protein Digestibility (IVPD). IVPD of extruded flakes is assessed utilizing standard protocol [21]. The multienzyme system comprises of trypsin (1.6 mg, 24.320 units), chymotrypsin (3.1 mg, 155 units), and peptidase (1.3 mg, 0.133 units/mL). The weighed grounded flakes were dispersed in 10 mL of distilled water at a pH of 8.0 and a temperature of 37°C. Subsequently, the mixture was incubated using a water bath. Afterward, the mixed enzyme system was added to the dispersion, and any changes in pH were observed and recorded down after 10 min IVPD is calculated by $Y = 210.46 - 18.10X$ (change in pH after 10 min).

2.11. In Vitro Starch Digestibility (IVSD) and Estimated Glycemic Index (E-GI). The various fractions of starch digestibility such as rapidly digestible starch (RDS), slowly digestible starch (SDS), and resistant starch (RS) content were determined to assess the IVSD along with E-GI of the extruded flakes using the method outlined by Amin et al. [22], in which glucose release after hydrolysis of starch by pancreatic alpha-amylase and amyloglucosidase was measured over period of 180 min. The starch hydrolyzing in first 20 min is termed as RDS, starch which is hydrolyzing within 20-120 min is SDS and starch which remains undigested after 120 min is RS.

Hydrolysis index (HI): HI was evaluated through a digestibility curve (0 min-180 min), using white bread as reference material.

$$\mathrm{HI} = \frac{\text{area under digestibility curve of sample } (0-180\ \text{min})}{\text{rea under the digestibility curve of white bread}},$$

$$\mathrm{EGI} = 39.71 + 0.549\mathrm{HI}. \tag{5}$$

2.12. Sensory Properties. Sensory characteristics of the extruded flakes such as appearance, texture, flavor, and overall acceptability) were analyzed via 80 semitrained judges/panelists (20-50 years old, male and female) [23] who were the staff and graduate students at our institute. For determining the acceptability level of flakes, a hedonic scale (nine-point) was used, which goes from dislike extremely (1) through neither liked nor disliked (5) to liked extremely (9).

2.13. Statistical Analysis. All the observation were mean three of the experiment readings ($n = 3$). The data obtained was subjected to analysis of variance (ANOVA), and Duncan's multiple range tests was utilized for comparison of means using SPSS software.

3. Results and Discussion

3.1. Specific Mechanical Energy (SME). The extruder is exceedingly responsible for converting of starch to different forms by transmitted mechanical energy to the material. Increased gelatinization of starch combined with higher extrudate expansion is clearly attributed to the SME. Hence, a higher SME is favored for achieving expanded products [11]. The SME of extrudates developed at varying levels of BT and FM varied significantly from 161.0 to 214 Wh/kg. Data depicts that at 14% FM and 130°C BT, the SME was 214 Wh/kg, which reduced to 178 Wh/kg with exceeding BT. Likewise, Wang et al. [24] have reported a similar relationship between SME and BT in case of extrudates formulated from chickpea, by the reason of reduction in melt viscosity, leading to a decreased SME. Enhanced BT is related to flow modifications, thus lowering the transfer of mechanical energy during extrusion [11]. Similar results have been documented in earlier published report of Pardhi et al. [25] where the raise in BT results an inverse impact on SME. Enhanced SME was observed in flakes prepared from FM (16% at 130°C (196 Wh/kg)), whereas at 18% FM at 130°C, the SME is 181 Wh/kg. The findings have indicated that SME diminishes with increasing FM (Table 1). Energy dissipation is affected by FM, thereby reducing the number of viable sites which impose plasticizing phenomenon. Elevating MC triggers a lubricating effect, thus diminishing particle friction at movement from barrel to screw. The dual effect of a higher MC and BT also lowers down the motor torque as promulgated by Sharma et al. [10], and further, as melt viscosity decreases with increasing FM [26].

3.2. Functional Properties. Water absorption index (WAI) is the measure of amount of water absorbed by starch as well as other polysaccharides such as fibers and proteins and is an important factor when it comes to extruded products as it indicates degree of starch gelatinization and computes the extent of water absorption by starch [27]. WAI increased from 3.21 to 3.76 g/g at 14% FM as BT augmenting from 130 to 170°C (Table 1). WAI is positively affected by increasing BT, in effect of enhanced dextrinization [28]. The findings obtained in the present investigation are in agreement with observations reported by Singh et al. [29] and Mugabi et al. [30]. WAI incremented from 2.76 to 3.48 g/g at 16% FM, while at 18% FM, the WAI increased from 3.07 to 3.72 g/g. Studies of Pathania et al. [31] reported a decreased starch viscosity resulting from a higher FM, thus ensuring a heat uniformity as well as improved gelatinization. A similar observation of enhancing FM on WAI was described in earlier published report [32], which was found to be due to the reduction in starch degradation incrementing the water absorption. Table 2 represents the correlation among studied parameters. WAI is positively correlated with taste OA ($r = 0.80$), while it is negatively correlated with BD ($r = -0.87$).

Water solubility index (WSI) is a result of dextrinization of starch molecules occurred due to their soluble nature [33]. Moreover, it has also been suggested that WSI is not only due to starch content but also because of other water-soluble components [34]. WSI increased with the enhancement in BT from 130 to 170°C at 14% FM, and WSI of extruded snacks increased from 22.0 to 23.10% (170°C) (Table 1). High BT could significantly affect the observations associated with increased solubility of starch. Similarity in variations related to WSI in reaction to increasing BT were presented by Seth et al. [35] in their study on corn-rice-based snacks with yam and Singh et al.[29] for potato powder-based extrudates. A raise in WSI, at a higher BT and lower FM could be accredited to the increased starch degradation producing extended starch aggregates with soluble lower chain [19]. Data shows that WSI decreased in response to decreasing FM. At 170°C, WSI decreased from 23.10 to 18.95% when FM increased from 14 to 18%. This trend could be explained by increased disruption of starch caused by shear effect at lower MC, resulting in much more solubility of starch granules in aqueous phase [30]. Similar fluctuations in WSI in effect to decrease in FM were already documented by Tadesse et al. [36] in which they shown that WSI has reduced from 8.07 to 7.95% due to rising FM from 15 to 21%. WSI exhibits a significant positive correlation with IVPD ($r = 0.91$) and ER ($r = 0.79$), while it is negatively correlated with RS ($r = -0.93$).

3.3. Expansion Ratio (ER). Extruded snacks exhibit certain level of expansion ratio, which is an important physical property of extruded products and is basically a degree of expansion as the contents exit the extruder and it is inversely proportional to bulk density [37]. The results from the current study revealed that with enhanced BT, ER of the flakes improved. At 14% FM and BT of 130°C, ER value was 1.67; however at 170°C, the value jumped to 2.04. Koksel et al. [38] reported that high BT results in rising potential energy in order to mop-up the superheated steam coming from studied extrudates, thus causing a higher linear change in viscosity near die region, resulting in an extruded product with more expansion. Ali et al. [32] promulgated that an amplified BT results into a modulated water superheating, which thus favors the creation of bubble that depresses the melt viscosity. At 14% FM, the ER modulates from 1.67 to 2.04, and similarly, ER ranges from 1.60 to 1.92 at 16% FM and 1.55 to 1.71 at 18% FM. FM effect the ER which is expected to be in inverse manner, as an elevated MC that tend to diminish melt elasticity ultimately rising the fluidity [39]. Kaur et al. [40, 41] justified that the suppression of FM assists drag forces which in turn boost the pressure in the die which in turn gives a product an extruded snack

Table 1: Effect of feed moisture and barrel temperature on physical characteristics and hardness of Sorghum-Chickpea-based flakes.

Feed moisture (%)	Barrel temperature (°C)	SME	WAI (g/g)	WSI (%)	Expansion ratio	Bulk density (g/l)	Hardness (N)
14	130	$214.00 \pm 2.00^{b,c}$	3.21 ± 0.31^{c}	22.00 ± 0.35^{a}	1.67 ± 0.01^{e}	482.00 ± 4.66^{d}	98.97 ± 0.18^{c}
	145	$198.00 \pm 3.00^{c,d,e}$	3.46 ± 0.06^{a}	22.25 ± 0.18^{d}	1.77 ± 0.06^{a}	335.00 ± 7.77^{f}	90.87 ± 0.24^{f}
	170	$178.00 \pm 0.2^{d,e}$	$3.76 \pm 0.01^{a,b,c}$	23.10 ± 0.32^{b}	2.04 ± 0.04^{b}	205.00 ± 3.10^{e}	79.44 ± 0.12^{i}
16	130	196.00 ± 2.4^{a}	$2.76 \pm 0.07^{a,b}$	18.30 ± 0.13^{e}	1.60 ± 0.03^{d}	442.00 ± 9.32^{c}	102.10 ± 0.68^{b}
	145	$178.00 \pm 1.5^{b,c}$	2.87 ± 0.12^{c}	19.65 ± 0.09^{d}	1.72 ± 0.061^{e}	424.00 ± 10.88^{a}	96.23 ± 0.26^{e}
	170	168.00 ± 1.0^{e}	$3.48 \pm 0.03^{a,b}$	21.20 ± 0.34^{c}	1.92 ± 0.11^{c}	288.00 ± 1.55^{f}	80.12 ± 0.35^{h}
18	130	$181.00 \pm 2.0^{a,b}$	$3.07 \pm 0.17^{a,b}$	15.15 ± 0.12^{f}	1.55 ± 0.08^{d}	436.00 ± 3.10^{e}	111.12 ± 0.31^{a}
	145	$175.00 \pm 3.0^{b,c}$	$3.27 \pm 0.48^{a,b,c}$	15.92 ± 0.20^{e}	1.58 ± 0.01^{f}	358.00 ± 9.32^{b}	96.91 ± 0.17^{d}
	170	$161.00 \pm 2.8^{c,d}$	$3.72 \pm 0.09^{a,b,c}$	18.95 ± 0.18^{d}	1.71 ± 0.02^{l}	247.00 ± 9.32^{d}	84.62 ± 0.06^{g}

Values having different superscript a, b, c…i were significantly ($p < 0.05$) different from each other at different barrel temperature and feed moisture. SME: specific mechanical energy; WAI: water absorption index; WSI: water solubility index.

with more expansion.ER showed positive correlation with OA ($r = 0.94$) ER and IVPD ($r = 0.87$), and a negative correlation was seen with hardness ($r = -0.87$).

3.4. Bulk Density (BD). Low value for BD of extruded snacks is a required parameter for extruded products which produce a light and crunchy product. Results show that with amplifying BT from 130 to 170°C, the BD of extruded flakes reduced significantly from 442 g/l to 288 g/l. High BT enhances the dough temperature higher than its boiling point, resulting in pressure alterations, resulting a flash off in moisture. This will allow the production of bubbles, which in turn formulate low-BD extrudates [37]. Similar findings regarding association of BT and BD have been mentioned in previous publications [10, 32]. As the moisture of feed increased, the BD of extruded flakes at 14% FM ranged from 205 to 482 g/l when BT progressed from130-170°C, which further ranges from 288 to 442 g/l at 16% FM and 247 to 436 g/l at 18% FM (Table 1). This kind of effect is certain, as Singh et al. [29] in their study reported that enhanced FM leads to an enhanced lubrication, lowering the SME which ultimately degrades starch, increasing the extrudate density. Sharma et al. [10] showed similar relationship between FM and BD and promulgated that the combination of a high BT along with low FM value aids vapor pressure gradient leading to an increased pressure within the barrel, giving a puffed product. Moreover, BD exhibits positive correlation with hardness ($r = 0.87$) was positive, followed by BD and b^* value ($r = 0.81$, $\rho = 0.01$); however, the output between BD and taste ($r = -0.89$, $\rho = 0.001$) and BD and OA ($r = -0.84$, $\rho = 0.005$) was negative (Table 2).

3.5. Hardness. Hardness of an extruded product is related to the expansion as well as the cell arrangement. The results have shown that BT is inversely linked to the hardness of sorghum-chickpea flakes. The hardness of flakes ranges from 79.44 N to 99.97 N as BT goes from 170°C to 130°C at 14% FM (Table 1). Similar effects on the hardness of extrudates were reported by Mugabi et al. [30]. While the results showed that snack hardness amplifies with enhanced FM, Singh et al. [29] reported parallel variations in hardness of potato-based snacks in response to FM, pointing out the plasticizing effect of water on starchy materials which lowers the viscosity along with scattered mechanical energy within extruder, producing a denser appearance of products. Hardness of extruded flakes showed negative correlation with OA ($r = -0.91$) (Table 2).

3.6. Color Characteristics. Color of the products was considered a vital physical feature, so it was evaluated for studied flakes, and the output values are represented in Table 3. Values of L^* have shown a decreasing trend with effect to an increasing BT (130-170°C); however, it increased (57.06-68.30) with enhanced FM (14 to 18%). Corresponding values of flakes in terms of their color parameters ranged from 0.14 to 2.82 for a^* value, from 12.59 to 16.17 for b^* value, from 1.44 to 1.56 for hue angle, and from 12.59 to 16.30 for chrome. The lowest L^*, a^*, and b^* values were seen for flakes developed at 18% FM, 170°C BT, whereas the highest L^* value is observed at 14% FM, 130°C BT. The color changes in the extrudates owing to extrusion treatment represents the intense treatment in combination with the occurring chemical changes. There are number of factors during

Table 2: Correlations among different factors of sorghum-chickpea-based flakes.

	SME	WAI	WSI	ER	BD	Hd	L*	a*	b*	Hue	Chrome	DPPH	FRAP	TPC	IVPD	RDS	SDS	RS	ExpGI	App	Taste	Texture	Color	OA
SME	1																							
WAI	-.40	1																						
WSI	.29	.46	1																					
ER	-.24	.66	.79*	1																				
BD	.65	-.87**	-.36	-.74*	1																			
Hd	.45	-.79*	-.67*	-.87*	.87*	1																		
*L**	.43	-.81**	-.05	-.27	.62	.40	1																	
*a**	.76*	-.49	.00	-.24	.63	.64	.35	1																
*b**	.89**	-.67	-.01	-.46	.81**	.71*	.54	.88**	1															
Hue	-.29	-.10	-.12	.15	-.03	-.14	.21	-.11	-.23	1														
Chrome	.82**	-.23	.56	.20	.31	.11	.40	.69	.70*	-.32	1													
DPPH	-.87**	.43	-.48	-.05	-.53	-.24	-.60	-.75	-.82**	.05	-.90**	1												
FRAP	-.89**	.39	-.33	.02	-.52	-.39	-.45	-.90**	-.86**	.17	-.92**	.92**	1											
TPC	-.88**	.35	-.41	-.03	-.46	-.32	-.47	-.84**	-.83**	.27	-.95**	.92**	.98**	1										
IVPD	.10	.61	.91**	.87**	-.59	-.75*	-.26	-.06	-.17	-.23	.51	-.28	-.24	-.31	1									
RDS	-.89**	.23	-.53	-.14	-.41	-.21	-.36	-.81**	-.77*	.21	-.94**	.93**	.96**	.97**	-.40	1								
SDS	.94**	-.22	.55	.05	.48	.21	.34	.72	.77*	-.27	.89**	-.91**	-.90**	-.91**	.36	-.96**	1							
RS	-.36	-.56	-.93**	-.72	.37	.57	.28	-.13	-.05	.31	-.62	.44	.41	.46	-.93**	.59	-.59	1						
ExpGI	.84**	-.12	.65	.12	.31	.05	.26	.54	.69	-.47	.89**	-.84**	-.79**	-.83**	.51	-.86**	.91**	-.69*	1					
App	-.15	.42	.69*	.88**	-.50	-.65	.00	-.07	-.33	.25	.22	-.16	-.09	-.16	.67*	-.24	.14	-.56	.07	1				
Taste	-.52	.82**	.54	.82**	-.89**	-.90**	-.63	-.53	-.68	.04	-.13	.33	.38	.34	.74*	.25	-.29	-.56	-.09	.51	1			
Textur	-.34	.79*	.68*	.89**	-.84**	-.89**	-.56	-.40	-.56	-.05	.08	.16	.19	.14	.86**	.05	-.09	-.71*	.08	.59	.97**	1		
Color	.00	.76*	.82**	.85**	-.72*	-.80**	-.40	-.18	-.31	-.20	.37	-.11	-.11	-.18	.95**	-.26	.22	-.87** -.74*	.36	.62	.78*	.89**	1	
OA	-.32	.80**	.72*	.94*	-.84**	-.91**	-.51	-.36	-.56	.00	.10	.11	.15	.10	.88**	-.00	-.05	-.74*	.08	.70*	.94**	.98**	.91**	1

**Correlation is significant at the 0.01 level (2-tailed). *Correlation is significant at the 0.05 level (2-tailed).

Table 3: Effect of feed moisture and barrel temperature on color characteristics of sorghum-chickpea-based flakes.

Feed moisture (%)	Barrel temperature (°C)	L^*	a^*	b^*	Hue angle	Chrome
14	130	61.63 ± 0.23^{d}	2.43 ± 0.10^{a}	16.17 ± 0.17^{f}	1.45 ± 0.00^{f}	16.30 ± 0.07^{f}
	145	58.99 ± 0.10^{e}	2.33 ± 0.06^{a}	15.94 ± 0.10^{b}	$1.45 \pm 0.00^{f,g}$	$16.10 \pm 0.21^{a,b}$
	170	58.23 ± 0.12^{c}	1.75 ± 0.09^{a}	13.61 ± 0.37^{a}	1.45 ± 0.01^{g}	16.06 ± 0.06^{b}
16	130	68.30 ± 0.20^{b}	2.10 ± 0.00^{f}	15.88 ± 0.04^{b}	1.48 ± 0.00^{d}	15.73 ± 0.04^{d}
	145	63.40 ± 0.13^{h}	1.64 ± 0.04^{d}	14.96 ± 0.04^{c}	1.46 ± 0.00^{e}	15.05 ± 0.10^{c}
	170	61.03 ± 0.32^{e}	1.09 ± 0.15^{b}	13.22 ± 0.04^{b}	1.56 ± 0.00^{a}	13.72 ± 0.07^{a}
18	130	59.71 ± 0.07^{g}	2.82 ± 0.01^{d}	15.48 ± 0.07^{d}	1.48 ± 0.00^{b}	14.03 ± 0.10^{e}
	145	58.19 ± 0.27^{a}	1.16 ± 0.09^{e}	13.98 ± 0.03^{e}	1.48 ± 0.00^{c}	13.86 ± 0.03^{b}
	170	57.06 ± 0.72^{f}	0.14 ± 0.03^{c}	12.59 ± 0.03^{c}	1.44 ± 0.01^{h}	12.59 ± 0.10^{c}

Values having different superscript a, b, c…i were significantly ($p < 0.05$) different from each other at different barrel temperature and feed moisture.

extrusion process that cause alterations in the color characteristics of a product such as Maillard reactions, hydrolysis, caramelization, and nonenzymatic browning [42]. All the color coordinates studied such as L^*, a^*, and b^* values were showed positively correlated among themselves. Table 2 represents the correlations values among studied parameters. Correlation observed for a^* with b^* ($r = 0.88$) was positive, however, it was observed as negative for a^* and FRAP ($r = -0.90$).

3.7. Antioxidant Properties. Antioxidant properties estimate the free radical scavenging potential of extracts. Both FRAP and DPPH assays were applied to explore the antioxidant properties of extracts prepared from extruded flakes (Table 4). Both methods have implied that the antioxidant properties improve in effect to rising FM along with BT. DPPH assay denotes an increase from 10.34 to 28.54 μmol TE/g dw, whereas FRAP values uplift from 6.89 to 9.42 μmol TE/g dw. High BT may lead to antioxidative Maillard browning in products which ultimately enhances antioxidant properties. Sharma et al. [43] and Espinoza-Moreno et al. [44] promulgated that various factors which affect the production of these products, including reactant concentration, BT, time, and water activity. Moreover, extrusion process permits the liberation of compounds having antioxidant properties that are deep-rooted in grains cell wall, causing an inactivation of those enzymes which are responsible for the phenolic oxidation. Bran portion contributes 15-18 times more to TPC as compared to endosperm portion [45]; this might be the reason for enhancement in antioxidant properties of samples studied during the present work. Like the observations of present experimental work, earlier Bekele et al. [46] has also indicated the rise in DPPH levels in case of chickpea-sorghum snacks (a different composition) with elevating BT. FRAP and DPPH activities also augment with increased FM. Variations in antioxidant properties in effect of FM in case of Fenugreek:oat:greenpea-based snacks, testifying an increased destruction of antioxidant compounds at lower FM caused by shearing effect [47].

3.8. Total Phenolic Content (TPC). Extruded flakes exhibit good amount of TPC value, and it increased with raising BT; the amount incremented from 3799.76 mg FE/100 g dw (130°C) to 4025 mg FE/100 g dw (170°C) at 14% FM (Table 4). Earlier published reports support the concept that as compared to other thermal treatments, short-span processing of samples through extrusion is beneficial as it will help to maintain phenolic compounds [48, 49]. The findings in the present study are in agreement to reported observations by Wafula et al. [50], which showed that cooking by extrusion has shown a modulating effect on quality attributes and nutrients of grains (rice and sorghum) and bamboo composites. Similarly, Bekele et al. [46] has also reported comparable results for chickpea-sorghum blends (50 : 50). A significant increase of 25-146.96% in TPC was observed for different blends. It has been recommended that extrusion technology can possibly lead to de-polymerization of phenolic compounds, thus improving its extractability. It has been mentioned that TPC rises from 4657.50 to 5005.18 mg FE/100 g dw with response to increasing FM from 16 to 18% at 170°C. The observations are in line with those documented by Kumar et al. [51] for extrudates based on honey-barley. Sarawong et al. [52] reported that extrusion technology can amplify the concentration of phenolics especially bound forms whereas suppressing the free forms of phenolics.

3.9. In Vitro Protein Digestibility (IVPD). IVPD values of extruded flakes showed an increase with enhancement in BT (Figure 2). High IVPD value (77.45%) was indicated by flakes prepared at 14% FM and 170°C of BT. Bekele et al. [46] also reported the similar trend. There are various reasons that might be responsible for this observable fact, such as breaching in the protein structure due to variable noncovalent interaction along with the inactivation of protease inhibiting and antinutritional factors; augmenting protein digestibility caused by higher BT which may be one of the reasons for decrease in antinutrients; process-mediated changes in the enzymatic activity of endogenous hydrolytic enzyme; or changing the storage protein structure matrix [53]. Whereas an inverse relation was observed between IVPD and FM, where with the enhancement in FM from 14 to 16%, IVPD decreased from 70.33 to 66.46%. This might be justified by the lower shear rate along-with amplifying FM. Outcomes (related to IVPD) of current research

Table 4: Effect of feed moisture and barrel temperature on chemical properties of sorghum-chickpea-based flakes.

Feed moisture (%)	Barrel temperature (°C)	DPPH (μ mol TE/g dw)	FRAP (μ mol TE/g dw)	TPC (mg FE/100 g dw)
14	130	10.34 ± 1.53^{d}	6.89 ± 0.29^{e}	3799.76 ± 0.171^{i}
	145	12.07 ± 2.22^{d}	$7.93 \pm 1.72^{d,e}$	3928.11 ± 1.58^{h}
	170	17.81 ± 3.37^{c}	9.42 ± 0.35^{c}	4025 ± 0.12^{g}
16	130	12.37 ± 1.44^{d}	8.40 ± 0.07^{d}	3914.21 ± 7.94^{f}
	145	16.44 ± 3.14^{c}	11.20 ± 0.24^{c}	4302.98 ± 1.57^{d}
	170	$18.92 \pm 1.72^{b,c}$	13.12 ± 0.10^{b}	4657.50 ± 17.90^{c}
18	130	$20.08 \pm 1.36^{b,c}$	9.99 ± 0.18^{c}	4260.43 ± 1.57^{e}
	145	$24.15 \pm 1.55^{a,b}$	13.27 ± 0.32^{b}	4711.56 ± 11.58^{b}
	170	28.54 ± 0.52^{a}	17.18 ± 0.06^{a}	5005.18 ± 4.85^{a}

Values having different superscript a, b, c…i were significantly ($p < 0.05$) different from each other at different barrel temperature and feed moisture. DPPH: 2,2-diphenyl-2-picryl hydrazyl hydrate; FRAP: ferric reducing antioxidant power; TPC: total phenolic content.

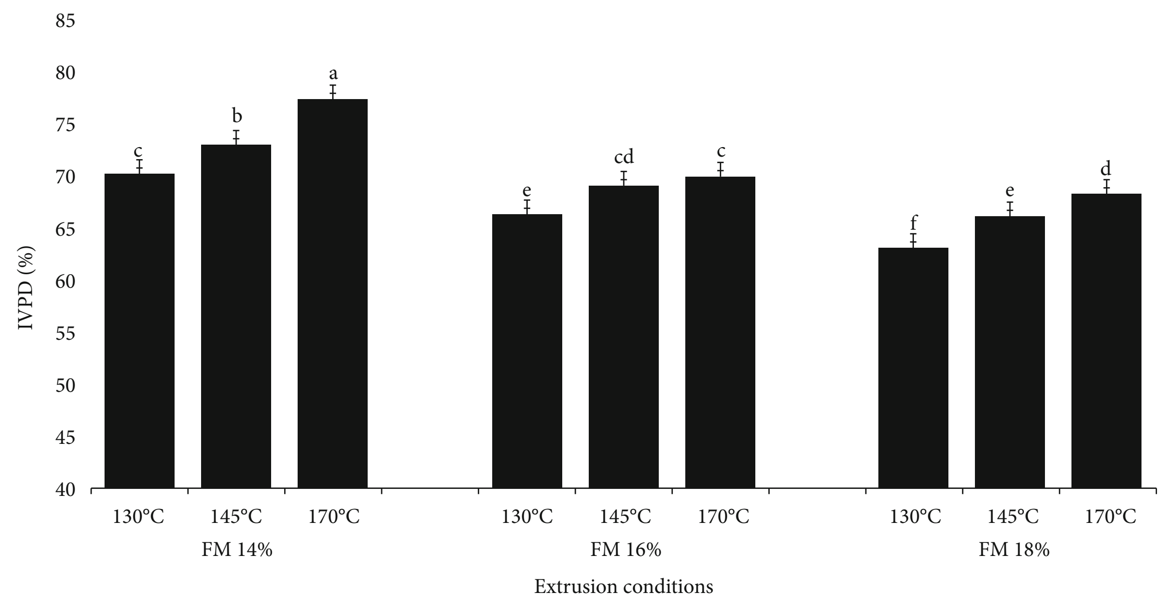

Figure 2: Effect of extrusion conditions on in vitro protein digestibility of the sorghum-chickpea flakes.

Table 5: Effect of feed moisture and barrel temperature on starch digestibility profile of sorghum-chickpea-based flakes.

Feed moisture (%)	Barrel temperature (°C)	RDS	SDS	RS (g/100gm)
14	130	19.04 ± 0.10^{c}	17.61 ± 3.28^{a}	64.10 ± 3.28^{a}
	145	$19.65 \pm 0.24^{b,c}$	16.46 ± 2.06^{a}	63.81 ± 2.72^{a}
	170	$19.99 \pm 0.17^{b,c}$	15.73 ± 1.60^{a}	63.29 ± 1.74^{a}
16	130	$20.13 \pm 0.38^{b,c}$	15.87 ± 0.17^{a}	66.90 ± 0.56^{a}
	145	20.82 ± 0.68^{b}	15.35 ± 1.74^{a}	66.02 ± 2.98^{a}
	170	$21.21 \pm 1.57^{a,b}$	14.86 ± 0.69^{a}	65.56 ± 1.58^{a}
18	130	$20.70 \pm 0.49^{a,b}$	15.11 ± 0.17^{a}	67.34 ± 1.27^{a}
	145	$21.82 \pm 0.63^{a,b}$	14.43 ± 2.08^{a}	66.88 ± 0.90^{a}
	170	22.44 ± 0.29^{a}	13.97 ± 1.41^{a}	66.08 ± 2.46^{a}

Values having different superscript a, b, c…i were significantly ($p < 0.05$) different from each other at different barrel temperature and feed moisture. RDS: rapidly digestible starch; SDS: slowly digestible starch; RS: resistant starch.

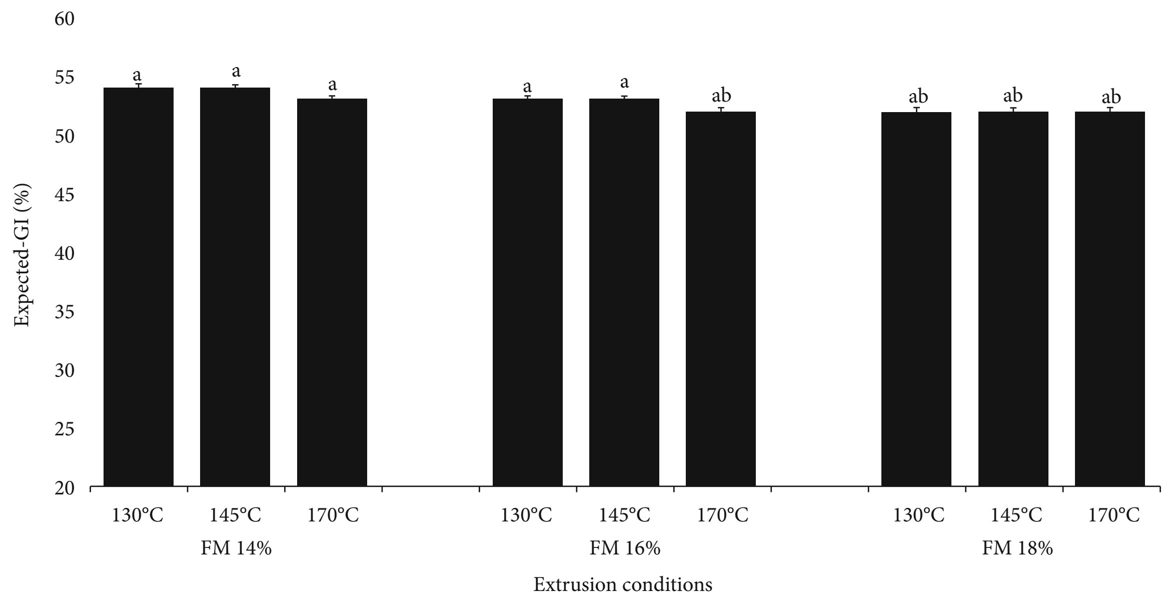

Figure 3: Effect of extrusion conditions on expected glycemic index (Exp-GI) of the sorghum-chickpea flakes.

Table 6: Effect of feed moisture and barrel temperature on sensory characteristics of sorghum-chickpea-based flakes.

Feed moisture (%)	Barrel temperature (°C)	Appearance	Taste	Texture	Color	Overall acceptability
	130	$7.10 \pm 0.00^{a,b}$	6.50 ± 0.31^{c}	$6.60 \pm 0.15^{c,d}$	7.00 ± 0.46^{aA}	$6.80 \pm 0.31^{b,c}$
14	145	$6.90 \pm 0.15^{a,b}$	$8.00 \pm 0.15^{a,b}$	7.50 ± 0.31^{b}	$7.50 \pm 0.00^{a,b}$	$7.40 \pm 0.31^{a,b}$
	170	7.80 ± 0.47^{a}	8.80 ± 0.16^{a}	8.40 ± 0.31^{a}	8.30 ± 0.31^{a}	8.30 ± 0.25^{a}
	130	$7.00 \pm 0.15^{a,b}$	6.00 ± 0.31^{c}	6.00 ± 0.32^{d}	$6.50 \pm 0.31^{e,d}$	6.30 ± 0.31^{e}
16	145	$7.10 \pm 0.31^{a,b}$	7.40 ± 0.47^{b}	$7.00 \pm 0.00^{b,c}$	$6.50 \pm 0.39^{c,d}$	$7.00 \pm 0.00^{b,c}$
	170	7.60 ± 0.46^{a}	8.20 ± 0.16^{a}	7.50 ± 0.31^{b}	$7.10 \pm 0.15^{b,c}$	7.60 ± 0.15^{b}
	130	$6.90 \pm 0.00^{a,b}$	6.30 ± 0.00^{c}	6.00 ± 0.46^{d}	6.00 ± 0.15^{d}	6.30 ± 0.47^{c}
18	145	6.50 ± 0.16^{b}	7.50 ± 0.16^{b}	$7.00 \pm 0.15^{b,c}$	$6.70 \pm 0.31^{b,c}$	6.90 ± 0.15^{bc}
	170	$7.00 \pm 0.16^{a,b}$	$7.90 \pm 0.00^{a,b}$	7.20 ± 0.16^{b}	$7.00 \pm 0.16^{b,c}$	$7.20 \pm 0.16^{b,c}$

Values having different superscript a, b, c…i were significantly ($p < 0.05$) different from each other at different barrel temperature and feed moisture.

were in line with those reported in earlier published studies by Bai et al. [54] and Wang et al. [24].

3.10. In Vitro Starch Digestibility (IVSD). As per classification, the digestible starch can be RDS, SDS, and RS. The amount of RDS showed minor enhancement (19.04-19.99) with the rising BT from 130 to 170°C at 14% FM, while it increased with increasing feed FM. (Table 5). The present results obtained in the present study are in close proximity with studies of Liu et al. [55] for finger millet. The reason for the same might be the enhanced amount of disrupted starch at higher BT, causing a decreased crystallinity of starch and thus increasing susceptibility of starch to enzymatic action. The results indicate that RDS augments with increasing FM as well, from 21.21% (170°C) to 22.44% (170°C) at 16 and 18% FM. Modulation in RDS in response to rise in FM was supported by earlier published report [56] on extrudates based on sorghum-barley blend. Gonzalez et al. [57] observed that SDS fraction is solely linked to starch structure. Level of SDS may impose diminution (17.61 to 15.73%) w.r.t. increasing BT (130-170°C) at 14% FM. Koa et al. [56] demonstrated that high BT could improve thermal melt process which ultimately favors starch gelatinization. Decreasing trend in SDS values from 15.73 to 14.86% in response to raising FM from 14 to 16% at BT of 170°C was observed. Feed moisture has a tendency to support numerous transformations in the medium such as alterations in melt properties which undergo numerous transformations. Koa et al. [56] promulgated SDS decrease, however, only after a critical BT (30°C). SDS is important form of digestible starch when it comes to health because it is related to slow release of blood glucose and could be utilized in health-based food formulations.

Content of RS was found to be diminished with elevating BT, from 130 to 170°C. Extrusion treatment results in reduction of starch crystallinity which increases the availability of enzyme and eventually decreases the RS content. Moreover, a higher temperature causes significant structural changes in starch. Sarawong et al. [52] reported enhancement in content of RS was with an increment in FM along with diminished speed of screw. Like observations of present study where RS content was augmented with enhanced FM which ultimately elevates the amount of retrograded starch and simultaneously the content of RS. This statement is also supported by findings of Koa et al. [56]. It has been reported that the melt properties transform to glassy state to rubbery at high FM, leading up to higher number of molecular alterations, producing higher retrograded starch [58]. Table 2 depicts the level of correlation among the studied parameters. Correlation between SDS showed positive correlation with E-GI ($r = 0.91$) and a negative correlation RDS ($r = -0.96$).

3.11. Estimated Glycemic Index (E-GI). Multiple factors are responsible for the glycemic index of food products especially ratio of amylose-amylopectin, type of methods of food processing, composition of food, ripening degree, size of particle, and resistant starch. The findings indicate that samples prepared with a feed moisture level of 18% exhibit a lower E-GI of 52 (Figure 3). This reduction in GI may be attributed to the higher content of resistant starch (66.08-67.34 g/100 g), which leads to a slower release and metabolism of glucose, resulting in a slower increase in blood sugar levels which supports the above-said concept. The observations in Figure 3 indicate that the GI of the food products has not been significantly affected by decreased BTs; however, at 16% FM and 130°C BT, GI is 53, which decreased to 52 at 170°C. Klein et al. [59] observed that heat-moisture treatment resulted in a high stability in structure as this treatment helps in rearranging the amylose chains in an ordered manner, leading to higher RS which gives a low GI. With rise in FM, the GI of the product has shown a decreasing trend. Reshi et al. [60] reported a lower GI (40.37) of barley-based extruded snacks as compared to that of barley flour (45), owing to the higher RS of barley extrudates.

3.12. Sensory Characteristics. Sensorial attributes of flakes were estimated in terms of its five characteristics (taste, texture, color, appearance, and overall acceptability), and data for the same is given in Table 6. It was seen that snack items formulated at high BT (170°C) were more desirable with OA scores of 8.3 at 14% FM, 7.6 at 16% FM, and 7.2 at 18%FM, which indicates that FM inversely effect OA (Table 6). Samples formulated at different BT have shown a significant difference in OA. Flakes developed at higher BT and the lower FM has shown a higher expansion with a crisped mouth feel which is desirable feature for extruded product. Overall sorghum-chickpea (80 : 20) blend-based products have a good acceptability value with desirable attributes when produced at higher BT and moderate FM.

4. Conclusions

The research demonstrated that by adjusting the barrel temperatures and feed moisture levels, while keeping the screw speed constant, it is possible to affect the nutritional and functional characteristics of sorghum- and chickpea- (80 : 20) based ready-to-eat flakes. The findings indicated that utilizing a higher barrel temperature (170°C) and lower feed moisture (14%) yields the most favorable combination for producing highly desirable flakes with enhanced attributes, including increased expansion, higher amino acid content (AA), higher total phenolic content (TPC), good in vitro protein digestibility (IVPD), higher resistant starch (RS), and lower glycemic index due to lower expected glycemic impact (Exp-GI).

Data Availability

The data used to support the findings of this study are included within the article.

Additional Points

Practical Application. The flakes produced using inexpensive and conventional raw materials have shown a higher antioxidant activity, higher total phenolic content, a good in vitro protein digestibility, higher content of resistant starch and lower glycemic index. Thus, these sorghum-chickpea combination flakes could be a healthier option for every segment of population for an in between the meal munching, as compared to the overly processed fat-based foods available in the markets nowadays.

Conflicts of Interest

The authors declared no potential conflict of interest with respect to the research, authorship, and/or publication of this article.

Authors' Contributions

JK did the investigation and writing, which includes the original draft preparation. BS was responsible to conceptualization, resources, and writing which includes the original draft preparation. SBD did the reviewing, and editing. AS was in charge to validation, reviewing, and editing. SSP performed the validation, reviewing, and editing.

References

[1] D. Ridder, F. Kroese, C. Evers, M. Adriaanse, and M. Gillebaart, "Healthy diet: health impact, prevalence, correlates and interventions," *Psychology & Health*, vol. 32, no. 8, pp. 907–941, 2017.

[2] J. Kaur, B. Singh, A. Singh, and S. Sharma, "Geometric, physical and functional properties of selected pulses and millets for the formulation of complementary food products," *International Journal of Chemical Studies*, vol. 8, no. 4, pp. 2854–2858, 2020.

[3] J. Kaur, B. Singh, A. Singh, and S. Sharma, "Characterization of extruded products from millets-legumes in combinations," *Pharma Innovation Journal*, vol. 9, no. 4, pp. 369–374, 2020.

[4] A. Kumar, I. Mani, A. Pramod et al., "Effect of extrusion technique on antinutritional factors of sorghum- soya blends," *Indian Journal of Agririculture Sciences*, vol. 88, no. 3, pp. 81–89, 2018.

[5] A. Singh, S. Sharma, B. Singh, and G. Kaur, "In vitro nutrient digestibility and antioxidative properties of flour prepared from sorghum germinated at different conditions," *Journal of Food Science & Technology*, vol. 56, no. 6, pp. 3077–3089, 2019.

[6] L. Dykes, G. C. Peterson, W. L. Rooney, and L. W. Rooney, "Flavonoid composition of lemon-yellow sorghum genotypes," *Food Chemistry*, vol. 128, no. 1, pp. 173–179, 2011.

[7] J. Kaur, B. Singh, and A. Singh, "Sorghum–mung bean combination snacks: Effect of extrusion temperature and moisture on chemical, functional, and nutritional characteristics," *Legume Science*, vol. 5, no. 3, article e186, 2023.

[8] N. L. Devi, S. Shobha, X. Tang, S. A. Shaur, H. Dogan, and S. Alavi, "Development of protein-rich sorghum- based expanded snacks using extrusion technology," *International-Journal of Food Properties*, vol. 16, no. 2, pp. 263–276, 2013.

[9] A. A. Saleh and A. E. Tarek, "Nutritional composition of chickpea (Cicer arietinum L.) as affected by microwave cooking and other traditional cooking methods," *Journal of Food Composition and Analysis*, vol. 19, no. 8, pp. 806–812, 2006.

[10] C. Sharma, B. Singh, and S. Z. Hussain, "Investigation of process and product parameters for physicochemical properties of rice and mung bean (Vigna radiata) flour based extruded snacks," *Journal of Food Science and Technology*, vol. 54, no. 6, pp. 1711–1720, 2017.

[11] X. Meng, D. Threinen, M. Hansen, and D. Driedger, "Effects of extrusion conditions on system parameters and physical properties of a chickpea flour-based snack," *Food Research International*, vol. 43, no. 2, pp. 650–658, 2010.

[12] H. Bobade, A. Singh, S. Sharma, A. Gupta, and B. Singh, "Effect of extrusion conditions and honey on functionality and bioactive composition of whole wheat flour-based expanded snacks," *Journal of Food Processing and Preservation*, vol. 46, no. 1, Article ID e16132, 2022.

[13] H. Bobade, A. Singh, S. Sharma, A. Gupta, and B. Singh, "Effect of extrusion processing on techno-functional, textural and bioactive properties of whole-grain corn flour-based breakfast cereals sweetened with honey," *Journal of Texture Studies*, vol. 53, no. 5, pp. 672–683, 2022.

[14] D. Bhati, B. Singh, A. Singh, S. Sharma, and R. Pandiselvam, "Assessment of physicochemical, rheological, and thermal properties of Indian rice cultivars: implications on the extrusion characteristics," *Journal of Texture Studies*, vol. 53, no. 6, pp. 854–869, 2022.

[15] R. A. Ortiz-Cruz, B. Ramirez-Wong, A. I. Ledesma-Osuna et al., "Effect of extrusion processing conditions on the phenolic compound content and antioxidant capacity of sorghum (Sorghum bicolor (L.)Moench) bran," *Plant Foods for Human Nutrition*, vol. 75, pp. 252–257, 2020.

[16] P. Morales, L. Cebadera-Miranda, R. M. Camara et al., "Lentil flour formulations to develop new snack-type products by extrusion processing: phytochemicals and antioxidant capacity," *Journal of Functional Foods*, vol. 19, pp. 537–544, 2015.

[17] F. H. Shah, M. K. Sharif, S. Bashir, and F. Ahsan, "Role of healthy extruded snacks to mitigate malnutrition," *Food Reviews International*, vol. 35, no. 4, pp. 299–323, 2019.

[18] J. Kaur, B. Singh, A. Singh, S. Sharma, and M. K. Kidwai, "Effect of extrusion processing on techno-functional properties, textural properties, antioxidant activities, in vitro nutrient digestibility and glycemic index of sorghum–chickpea-based extruded snacks," *Journal of Texture Studies*, 2023.

[19] R. A. Anderson, H. F. Conway, V. F. Pfeifer, and E. L. Griffin, "Gelatinization of corn grits by roll-and extrusion-cooking," *Cereal Science Today*, vol. 14, pp. 4–12, 1969.

[20] A. Kataria, S. Sharma, and B. N. Dar, "Changes in phenolic compounds, antioxidant potential and antinutritional factors of Teff (Eragrostis tef) during different thermal processing methods," *International Journal of Food Science & Technology*, vol. 57, no. 11, pp. 6893–6902, 2022.

[21] H. W. Hsu, D. Vavak, L. D. Satterlee, and G. A. Miller, "A multienzyme technique for estimating protein digestibility," *Journal of Food Science*, vol. 42, no. 5, pp. 1269–1273, 1977.

[22] T. Amin, H. R. Naik, S. Z. Hussain, M. A. Mir, and A. Jabeen, "In vitrodigestion, physicochemical and morphological properties of low glycemic index rice flour prepared through enzymatic hydrolysis," *International Journal of Food Properties*, vol. 21, no. 1, pp. 2632–2645, 2018.

[23] E. Larmond, *Methods for Sensory Evaluation of Foods*, Canada Department of Agriculture, Ottawa, 1970.

[24] S. Wang, M. G. Nosworthy, J. D. House, Y. Ai, S. Hood-Niefer, and M. T. Nickerson, "Effect of barrel temperature and feed moisture on the physical properties of chickpea-sorghum and chickpea-maize extrudates, and the functionality and nutritional value of their resultant flours—Part II," *Cereal Chemistry*, vol. 96, no. 4, pp. 621–633, 2019.

[25] S. D. Pardhi, B. Singh, G. A. Nayik, and B. N. Dar, "Evaluation of functional properties of extruded snacks developed from brown rice grits by using response surface methodology," *Journal of the Saudi Society of Agricultural Sciences*, vol. 18, no. 1, pp. 7–16, 2019.

[26] S. Wang, *Effect of Extrusion BT and Moisture on Physical, Functional and Nutritional Properties of Kabuli Chickpea, Sorghum, Maize and their Blends, [M.S. thesis]*, University of Saskatchewan, Saskatoon, 2018.

[27] S. Yagci and F. Gogus, "Response surface methodology for evaluation of physical and functional properties of extruded snack foods developed from food-by-products," *Journal of Food Engineering*, vol. 86, no. 1, pp. 122–132, 2008.

[28] N. Kumar, B. C. Sarkar, and H. K. Sharma, "Development and characterization of extruded product of carrot pomace, rice flour and pulse powder," *African Journal of Food Science*, vol. 4, no. 11, pp. 703–717, 2010.

[29] B. Singh, H. Rachna, S. Z. Hussain, and S. Sharma, "Response surface analysis and process optimization of twin screw extrusion cooking of potato-based snacks," *Journal of Food Processing and Preservation*, vol. 39, no. 3, p. 281, 2015.

[30] R. Mugabi, S. Byakika, and I. M. Mukisa, "Effects of feed moisture content, soybean ratio and barrel temperature on physical and functional properties of extruded maize-soybean flour blends," *Tanzania Journal of Science*, vol. 48, no. 2, pp. 447–459, 2022.

[31] S. Pathania, B. Singh, and S. Sharma, "Development of low cost multipurpose instant mix by extrusion process using response surface methodology," *International Journal of Scientific Research*, vol. 2, pp. 317–320, 2013.

[32] A. Ali, B. Singh, and S. Sharma, "Deveopment of high-quality weaning food based on maize and chickpea by twin-screw extrusion process for ow-income populations," *Journal of Food Process Engineering*, vol. 40, no. 3, 2016.

[33] H. Anastase, D. Xiaolin, and F. Tao, "Evaluation of rice flour modified by extrusion cooking," *Journal of Cereal Science*, vol. 43, no. 1, pp. 38–46, 2006.

[34] K. B. Filli, I. Nkama, U. M. Abubakar, and V. A. Jideani, "Influence of extrusion variables on some functional properties of extruded millet-soybean for the manufacture of 'fura': a Nigerian traditional food," *African Journal of Food Science*, vol. 4, no. 6, pp. 342–352, 2010.

[35] D. Seth, L. S. Badwalk, and V. Ganapathy, "Effect of feed composition, moisture content and extrusion temperature on extrudate characteristics of yam-corn-rice based snack food," *Journal of Food Science & Technology*, vol. 52, no. 3, pp. 1830–1838, 2015.

[36] S. A. Tadesse, G. Bultosa, and S. Abera, "Functional and physical properties of sorghum-based extruded product supplemented with soy meal flour," *Cogent Food & Agriculture*, vol. 5, no. 1, article 1707608, 2019.

[37] A. Altan, L. M. Kathryn, and M. Medeni, "Evaluation of snack foods from barley-tomato pomace blends by extrusion processing," *Journal of Food Engineering*, vol. 84, no. 2, pp. 231–242, 2008.

[38] H. Koksel, G. H. Ryu, A. Basman, H. Demiralp, and K. W. N. Perry, "Effects of extrusion variables on the properties of waxy Hulless barley extrudates," *Nahrung*, vol. 48, no. 1, pp. 19–24, 2004.

[39] J. Ye, X. Hu, S. Luo et al., "Properties of starch after extrusion: a review," *Starch-Starke*, vol. 70, no. 11-12, article 1700110, 2017.

[40] J. Kaur, K. Kaur, B. Singh, A. Singh, and S. Sharma, "Insights into the latest advances in low glycemic foods, their mechanism of action and health benefits," *Journal of Food Measurement and Characterization*, vol. 16, no. 1, pp. 533–546, 2022.

[41] N. Kaur, B. Singh, S. Sharma, and R. Kumar, "Study of relationships between independent extrusion variables and dependent product properties during quality protein maize extrusion," *Applied Food Research*, vol. 2, no. 1, article 100048, 2022.

[42] R. Geetha, H. N. Mishra, and P. P. Srivastav, "Twin screw extrusion of kodo millet-chickpea blend: process parameter optimization, physico-chemical and functional properties," *Journal of Food Science &Technology*, vol. 51, no. 11, pp. 3144–3153, 2014.

[43] P. Sharma, H. S. Gujral, and B. Singh, "Antioxidant activity of barley as affected by extrusion cooking," *Food Chemistry*, vol. 131, no. 4, pp. 1406–1413, 2012.

[44] R. J. Espinoza-Moreno, C. Reyes-Moreno, J. Milán-Carrillo, J. A. López-Valenzuela, O. Paredes-López, and R. Gutiérrez-Dorado, "Healthy ready-to-eat expanded snack with high nutritional and antioxidant value produced from whole amarantin transgenic maize and black common bean," *Plant Foods for HumanNutrition*, vol. 71, no. 2, pp. 218–224, 2016.

[45] K. K. Adom and R. H. Liu, "Antioxidant activity of grains," *Journal of Agricultural and Food Chemistry*, vol. 50, no. 21, pp. 6182–6187, 2002.

[46] E. K. Bekele, M. G. Nosworthy, R. T. Tyler, and C. J. Henry, "Antioxidant capacity and total phenolics content of direct-expanded chickpea–sorghum snacks," *Journal of Food Processing & Preservation*, vol. 45, no. 5, 2021.

[47] S. A. Wani and P. Kumar, "Influence on the antioxidant, structural and pasting properties of snacks with fenugreek, oats and green pea," *Journal of the Saudi Society of Agricultural Sciences*, vol. 18, no. 4, pp. 389–395, 2019.

[48] E. Sarka, M. Slukova, and P. Smrckova, "New food compositions to increase the content of phenolic compounds in extrudates," *Czech Journal of Food Sciences*, vol. 38, no. 6, pp. 347–358, 2020.

[49] E. Xu, Z. Wu, A. Jiao, J. Long, J. Liab, and Z. Jin, "Dynamics of rapid starch gelatinization and total phenolic thermomechanical destruction moderated via rice bio-extrusion with alpha-amylase activation," *RSC Advances*, vol. 7, no. 32, pp. 19464–19478, 2017.

[50] N. W. Wafula, M. Omwamba, and S. M. Mahungu, "Feed rate, water addition rate and mixture composition nexus role on alterations of nutritional properties in extrusion of composites containing rice (Oryza sativa), sorghum (Sorghum bicolor) and bamboo (Yushaniaalpina) shoots," *Journal of Food Processing & Preservation*, vol. 45, no. 1, article e15063, 2020.

[51] K. Kumar, N. Jindal, S. Sharma, and V. Nanda, "Physicochemical and antioxidant properties of extrudates developed from honey and barley," *International Journal of Food Science & Technology*, vol. 48, no. 8, pp. 1750–1761, 2013.

[52] C. Sarawong, R. Schoenlechner, K. Sekiguchi, E. Berghofer, and P. K. W. Ng, "Effect of extrusion cooking on the physicochemical properties, resistant starch, phenolic content and antioxidant capacities of green banana flour," *Food Chemistry*, vol. 143, pp. 33–39, 2014.

[53] A. Ghumman, A. Kaur, N. Singh, and B. Singh, "Effect of feed moisture and extrusion temperature on protein digestibility and extrusion behaviour of lentil and horsegram," *Food Science and Technology*, vol. 70, pp. 349–357, 2016.

[54] T. Bai, M. G. Nosworthy, J. D. House, and M. T. Nickerson, "Effect of tempering moisture and infrared heating temperature on the nutritional properties of desi chickpea and hull-less barley flours, and their blends," *Food Research International*, vol. 108, pp. 430–439, 2018.

[55] P. Liu, J. Chang, M. Li et al., "Effects of extrusion conditions on physicochemical properties of finger millet (Gramineae Setaria)," *Journal of Agricultural Science*, vol. 12, no. 9, pp. 149–158, 2020.

[56] S. S. Koa, X. Jin, J. Zhang, and P. A. Sopade, "Extrusion of a model sorghum-barley blend: starch digestibility and associated properties," *Journal of Cereal Science*, vol. 75, pp. 314–323, 2017.

[57] M. Gonzalez, J. Alvarez-Ramirez, E. J. Vernon-Carter, I. Reyes, and L. Alvarez-Poblano, "Effect of the drying BT on color, antioxidant activity and in vitro digestibility of green pea (Pisum sativum L.) flour," *Starch-Stärke*, vol. 72, no. 9-10, article 1900228, 2020.

[58] K. Mahasukhonthachat, P. A. Sopade, and M. J. Gidley, "Kinetics of starch digestion and functional properties of twin-screw extruded sorghum," *Journal of Cereal Science*, vol. 51, no. 3, pp. 392–401, 2010.

[59] B. Klein, V. Z. Pinto, N. L. Vanier et al., "Effect of single and dual heat-moisture treatments on properties of rice, cassava, and pinhao starches," *Carbohydrate Polymers*, vol. 98, no. 2, pp. 1578–1584, 2013.

[60] M. Reshi, F. Shafiq, S. Z. Hussain, B. Naseer, and T. Amin, "Physicochemical properties of iron-fortified, low glycemic index (GI) barley based extruded ready-to-eat snacks developed using twin-screw extruder," *Journal of Food Processing and Preservation*, vol. 44, no. 8, Article ID e14606, 2020.