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Research Article

Preparation of Low Glycemic Rice and Comparison of Its Physicochemical Properties, Cooking Characteristics, Starch Digestibility and Microstructure with Raw Rice (*Swarna Cv*)

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Abstract: Rice broken and low glycemic ingredients such as millet and pseudocereal were used to formulate the multigrain flour using Linear Programming (LP) in MATLAB to prepare Low Glycemic Rice (LGR). The constraints considered in LP were: glycemic index (GI < 55), protein (≥ 10 g/100 g), iron (≥ 6 mg/100 g) and carbohydrate (≤ 70 g/100 g). A laboratory-scale co-rotating twin-screw extruder was used to produce the LGR. Proximate composition, mineral content, physicochemical properties, cooking characteristics, starch digestibility, pasting properties and microstructure of LGR were analyzed and compared with raw rice (*Swarna Cv*.). The LGR was characterized as a highly nutritious low glycemic food (GI value of 55.03) with high protein (12.88%), fiber (2.22%), fat (2.28%), ash (1.38%), and iron content (16.11 mg/100 g) as compared to the raw rice. The cooking losses (14.23%), water solubility index (7.21%) and total colour difference (25.14) of LGR were significantly higher, whereas cooking time (8.25 minutes) was significantly lower, which may be due to several cracks and voids as observed in SEM analysis. Moreover, the LGR showed significantly different pasting properties compared to raw rice.

Keywords: low glycemic rice, millet, extrusion, cooking characteristics, nutritional properties, physicochemical properties

1. Introduction

Non-Communicable Diseases (NCDs) such as diabetes, obesity, heart problems, hyperlipidaemia, and other Cardiovascular Diseases (CVDs) are on the rise in both developed and developing countries, particularly among younger people [1, 2]. To reduce the risk of these health issues over the past 25 years, dietary advice is primarily focusing on carbohydrates rather than saturated fatty acids, with very little consideration on the Glycemic Load (GL) of carbohydrates, while carbohydrates having high Glycemic Index (GI) has been known to be a major cause of these health problems. The GL of a particular food is a number that estimates how much blood glucose level of a person will rise after its consumption. One unit of GL approximates the effect of consuming one gram of glucose. Over that period, rates of NCDs such as type-2 diabetes and obesity have shoot up [3]. Diabetes is the third-largest non-communicable disease, and about 415 million people have been affected by diabetes worldwide. India has been listed as the "Diabetic Capital of the World" by World Health Organization (WHO) and estimated that about 134.5 million Indian people will

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have diabetes by 2030 [4]. A high dietary glycemic load (predominantly from rice) has been associated with increased risk of type-2 diabetes in Chinese and Japanese and Indian populations [5]. The prevalence of overweight and obesity is extremely high in adults, and there is a rapid increase in children. Since 1980, the risk of overweight and obesity has doubled worldwide. In 2014, about 1.9 billion adults (18 years and above) and 41 billion children under 5 years of age were overweight [6]. Therefore, the present investigation was undertaken to optimize the extrusion process parameters for manufacturing the instant LGR using multigrain flour from broken rice, foxtail millet, barnyard millet, and quinoa. Low Glycemic Rice (LGR) containing low glycemic ingredients such as foxtail millet, barnyard millet, and pseudocereal such as quinoa could be a strategic solution to the risk of these health problems. Moreover, millets and quinoa can provide additional health benefits because of their high nutritional value.

Foxtail millet is an important crop containing a significant amount of protein, dietary fiber, phytochemicals, and minerals [7]. It is a good source of crude fiber, which helps in the digestion process by inducing bowel movement and laxative effect. Additionally, foxtail millet has several health benefits, including prevention of cancer, hyperglycaemic, and hyperlipidemic effects [8]. Barnyard millet has several health benefits like preventing cancer developing cells and type-2 diabetes by reducing the blood glucose level due to its low GI [9]. It is a fair source of highly digestible protein and a magnificent source of dietary fiber with a significant quantity of soluble and insoluble fractions. The slowly digestible carbohydrate content of barnyard millet makes it a natural designer food that could become ideal for diabetic patients [10]. Quinoa is classified as low GI food, reducing the risk of type-2 diabetes and obesity [11]. It is one of the most important pseudocereal seeds, which contains nutritionally well-balanced essential amino acids [11, 12]. It is gluten-free and known to have high contents of fiber, essential fatty acids, protein with high biological values, minerals and vitamins. It also contains a significant amount of phytochemicals such as saponins, phytoecdysteroids, and phytosterols beneficial for health [12]. It has a relatively low level of trypsin inhibitor, which improves the bioavailability of the protein. Rice broken is the main by-product of the rice milling industries, which can be utilized for manufacturing the extruded rice kernels. The bland taste, flavour, colour, and better functional properties of rice make it a desirable raw material for manufacturing several kinds of innovative and value-added extruded food products [13].

Extrusion is a versatile and low-cost product manufacturing technology that includes operations such as mixing, kneading, shearing, cooking, shaping, and forming. It has a number of benefits, including flexibility, multifunction, low cost, high productivity, zero process effluents, and environmental friendliness [14]. Moreover, extrusion enables improved functional properties and sensory attributes of the extruded products [15]. Ding et al. [15] have reported that a remarkable improvement was observed in the sensory attributes (hardness, crispiness, and overall acceptability) after extrusion of rice-based snacks. Feed rate, feed moisture and barrel temperature had significant effect with feed moisture having the greatest effect on the sensory characteristics of the rice-based extrudates.

Several studies have been reported on the development of extruded rice kernels from rice broken such as fortified rice kernels [13, 16, 17], artificial instant rice [18, 19] and texturized rice [20]. However, millet and pseudocereal such as quinoa have not been explored yet for developing the extruded rice kernels. Moreover, only a few attempts have been made for reduction of GI of rice. Therefore, an attempt has been made to develop an LGR using rice broken, foxtail millet, barnyard millet and quinoa and compare it with raw rice (*Swarna Cv.*) using proximate composition, mineral content, physicochemical properties, cooking characteristics, starch digestibility, pasting properties and microstructure.

2. Materials and methods

2.1 *Raw materials*

The availability, low GI, and high nutritional values of foxtail millet (*Setaria italic*), barnyard millet (*Echinochloa esculenta*), and quinoa (*Chenopodium quinoa Willd*) were factors in their selection. Swarna rice also called Mansuri rice, is one of the healthiest staple Indian rice varieties and carries a very low risk of diabetes, and also has a low GI (http://www.asiaglobalcommodities.com/product/35/india-swarna-rice.html). A local rice mill in Kharagpur, West Bengal, India, provided the broken rice (*Swarna Cv.*). Jayalakshmi Arya Farm Products, Bengaluru, India, supplied the millets used in the study. Quinoa was supplied by Urban Style in Hyderabad, India. All raw materials were cleaned, milled and sieved before analysis.

2.2 *Proximate composition and mineral analysis of raw materials*

Moisture, ash, fat, fiber and protein contents of all ingredients were determined in triplicate by the Standard method AOAC [21] to assess carbohydrate by difference (equation 1). Mineral contents were analyzed in triplicates using atomic absorption spectrometer (Model: AAnalyst 700, Perkin Elmer, USA) [22].

$$\text{Carbohydrate}(g/100g) = 100 - [\text{Moisture}(g/100g) + \text{Protein}(g/100g) + \text{Fat}(g/100g) + \text{fiber}(g/100g) + \text{Ash}(g/100g)] \quad (1)$$

2.3 *Formulation of multigrain flour*

Multigrain flour was formulated using Linear Programming (LP) in MATLAB (MATLAB & Simulink-Mathworks online 2019a), where the objective function was the minimization of cost subject to the constraints Glycemic Index (GI), carbohydrate, protein and iron content (Table 1). The linear programming has also been used by Balasubramanian et al. [23] and Semasaka et al. [24]. The objective function and constraints were defined as shown below:

$$\text{Objective function, Cost}(Z) = Min(c_1x_1 + c_2x_2 + c_3x_3 + c_4x_4) \quad (2)$$

Subject to constraints,

$$Glycemic\ index: \frac{X_1C_1GI_1 + X_2C_2GI_2 + X_3C_3GI_3 + X_4C_4GI_4}{X_1C_1 + X_2C_2 + X_3C_3 + X_4C_4} \le GI \quad (3)$$

$$Carbohydrate: C_1x_1 + C_2x_2 + C_3x_3 + C_4x_4 \le C \quad (4)$$

$$Iron: Fe_1x_1 + Fe_2x_2 + Fe_3x_3 + Fe_4x_4 \ge Fe \quad (5)$$

$$Protein: p_1x_1 + p_2x_2 + p_3x_3 + p_4x_4 \ge p \quad (6)$$

$$Material\ balance: x_1 + x_2 + x_3 + x_4 = 100\ \text{(Total weight of formulation)} \quad (7)$$

$$Limits\ of\ variables: x_1, x_2, x_3, x_4 \ge 10 \quad (8)$$

Where, $x_1, x_2...$ = Amount of ingredients (g); $c_1, c_2...$ = Cost of ingredients (Rs/g)
$C_1, C_2...$ = Carbohydrate content of ingredients (g/g)
$p_1, p_2...$ = Protein content of ingredients (g/g)
$GI_1, GI_2...$ = Glycemic indices of ingredients
$Fe_1, Fe_2...$ = Iron content of ingredients (mg/g)
$C, p, Fe, GI...$ = Carbohydrate, protein, iron content and glycemic index of the formulation.

For validating the results, the experimental values of constraints viz., glycemic index, protein, iron and carbohydrate were compared with the theoretical values as obtained from LP. Relative percentage (%) errors were determined to estimate the deviation of experimental results from the theoretical results. The relative errors for all the constraints were within 5% except for the protein, indicating no significant differences between the theoretical and the experimental results (Table 1).

Table 1. Nutritional value of ingredients and formulation using Linear Programming (LP)

Variable (g/100 of formulation)	Ingredients	Nutritional values and cost (per 100 g)				
		Protein (g)	Carbohydrate (g)	Iron (mg)	GI	*Cost (Rs)
x_1	Rice broken	7.82 ± 0.12	78.42 ± 0.32	3.93 ± 0.03	70	1.6
x_2	Barnyard millet	10.85 ± 0.87	64.61 ± 0.99	40.81 ± 0.81	33	6.5
x_3	Foxtail millet	12.73 ± 0.49	66.87 ± 0.07	16.72 ± 0.56	41	6.8
x_4	Quinoa	16.64 ± 0.40	59.57 ± 2.20	27.78 ± 1.35	53	8.0

Objective function: Min Cost (Z) = $0.016x_1 + 0.065x_2 + 0.068x_3 + 0.08x_4$

Constraints	Equation	Theoretical results from LP	Experimental results	% Error
GI ≤ 55	$11.4x_1 - 7.7x_2 - 13.86x_3 - 1.084x_4 \leq 0$	54.59	55.03 ± 1.36** ≤ 55 (True)	0.806
Protein ≥ 10 g/100 g	$0.0782x_1 + 0.1085x_2 + 0.1273x_3 + 0.1664x_4 \geq 10$	11.14	12.88 ± 0.32 ≥ 10 (True)	15.619
Iron ≥ 6m g/100 g	$0.0393x_1 + 0.4081x_2 + 0.1672x_2 + 0.2778x_4 \geq 6$	15.76	16.11 ± 2.02 ≥ 6 (True)	2.221
Carbohydrate ≤ 70 g/100 g	$0.7842x_1 + 0.6461x_2 + 0.6687x_3 + 0.5957x_4 \leq 70$	70.25	70.69 ± 1.33 ≥ 70 (True)	0.626
Material balance	$x_1 + x_2 + x_3 + x_4 = 100$	$x_1 = 43.00$		
Upper and lower bound	$x_1, x_2, x_3, x_4 \geq 100$	$x_2 = 10.35$		
		$x_3 = 28.18$		
		$x_4 = 18.47$		
		Cost (Z): Rs 4.85/100 g		

*Cost of the ingredients is as per 2019 (India Mart); **Results expressed as Mean ± SD

2.4 *Preparation of Low Glycemic Rice (LGR)*

Using a sieve shaker (Retsch GmbH, Germany), the ingredients viz., rice broken (43.00 g), barnyard millet (10.35 g), foxtail millet (28.18 g), and quinoa (18.47 g) were milled and sieved below 250 micron particle size. To prepare multigrain flour, the ingredients were properly mixed using a planetary mixer (Reico Equipment & Instrument, Kolkata) at a rotation speed of 400 rpm for 30 minutes in the proportion obtained from the LP (Table 1). The required amount of distilled water was added to obtain the Feed Moisture (FM) of 30% (wb), and then the moistened flour was kept at 4 °C overnight for equilibration of the moisture. The wet sample was fed into a pilot-scale twin co-rotating extruder (Brabender GmbH & Co-KG, Germany) which was run under the condition as follows: Feeder Speed (FS): 8 rpm; Screw Speed (SS): 30 rpm; Die Head Temperature (DHT): 120 °C and Cutter Speed (CS): 280 rpm. The extruded rice was dried to a moisture content of around 10% (wb) in a re-circulation tray dryer (Basic Technology Private Limited, Kolkata) at 40 °C [25]. The extrusion process parameters viz., FS (8 rpm), SS (30 rpm), DHT (120 °C), and CS (280 rpm) were decided from several preliminary trials where these parameters were varied several times to get the desirable quality characteristic of the LGR. The raw and cooked LGR have been shown in Figure 1.

(a)

(b)

Figure 1. (a) Raw LGR (b) Cooked LGR

2.5 *Analysis of characteristic properties of LGR*

2.5.1 *In vitro starch digestibility and estimated Glycemic Index (eGI)*

The eGI of LGR was determined using the procedure given by Goñi et al. [26] with minor modifications. Approximately, 44 mg of rice grains were dropped in a 30 ml Erlenmeyer flask and cooked in an autoclave at 120 °C for 30 minutes with 4 ml of distilled water. After cooking, 10 ml of HCl-KCl buffer solution (pH 1.5) was added to the cooked rice samples, followed by 2 minutes homogenization using Ultra Turrax T 18 homogenizer (IKA India Private Limited, India). After that, 0.2 ml of pepsin enzyme solution, prepared by adding 22 mg of pepsin (Porcine Stomach Mucosa) in 10 ml of HCl-KCl buffer solution, was added to each of the homogenized samples followed by incubation at 40 °C for 60 minutes in a shaking water bath (Reico Equipment and Instruments Pvt. Ltd., India). After incubation, Tris-Maleate Buffer solution (pH 6.9) was added to make the sample volume up to 25 ml. For hydrolysis of starch present in the sample, 5 ml of α-amylase solution, prepared by adding 2.6 UI of α-amylase (ref. 101309219) in Tris-Maleate buffer solution, was added to each of the liquid samples. After that, samples were incubated at 37 °C in a shaking water bath. During the incubation, 0.1 ml of aliquot from each flask was taken every 30 minutes from 0 to 180 minutes and immediately placed in boiling water for 5 minutes to inactivate the -amylase. The samples were then incubated at 60 °C for 45 minutes in a shaking water bath with 3 ml of 0.4 M sodium acetate buffer solution (pH 4.75) and 60 µl of amyloglucosidase from *Aspergillus* niger (ref. 101087442) solutions for further hydrolysis of the digested starch to glucose (simple sugar). Finally, glucose concentration was determined using Arkray GOD-POD kinetic assay Kit (93DP100-74). Total starch content was obtained by multiplying the glucose concentration by 9.5, a conversion factor. Each sample was run in triplicate. The rate of starch hydrolysis was presented as a percentage of the total starch hydrolyzed at different time (30, 60, 90, 120, 150 and 180 minutes). A non-linear model (8) given by Goñi et al. [26] was used to study the kinetics of starch hydrolysis.

$$C = C_{\infty}(1 - e^{-kt}) \tag{9}$$

Where C is the percentage of starch hydrolyzed at time t, C_{∞} is the percentage of starch hydrolyzed after 180 minutes, k is kinetic constant, and t is the time (minutes). The parameters C_{∞} and k were estimated by fitting the starch hydrolysis data in the above non-linear model using the Solver tool in Microsoft Excel (Version 2010). The area under the hydrolysis curve (AUC) was calculated using equation (10).

$$AUC = C_{\infty}(t_f - t_0) - (C_{\infty} / k)\{1 - \exp[-k(t_f - t_0)]\} \tag{10}$$

Where t_f and t_0 are the final time (180 minutes) and initial time (0 minutes), respectively. Hydrolysis Index (HI) was obtained by dividing the AUC of each sample by the AUC of the reference food (white bread). The eGI was estimated using the model (11):

$$eGI = 39.71 + (0.549\ HI) \tag{11}$$

2.5.2 *Physicochemical properties*

Water Absorption Index (WAI), Water Solubility Index (WSI), and total colour difference (E) were used to determine physicochemical properties. The WAI and WSI were calculated in triplicate using the method described by Yadav et al. [13]. LGR colour values were measured using a colorimeter (CM-5, Konica Minolta, Japan) in terms of L^* (lightness), a^* (redness), and b^* (yellowness), h (hue) and c^* (chroma) as described by Dalbhagat & Mishra [27]. White and black standard plates were used to calibrate the instrument. The standard was raw rice (*Swarna Cv.*), and its colour values were measured in terms of L_0^* (lightness/darkness), a_0^* (redness/greenness), and b_0^* (yellowness/blueness). Equation (12) was used to calculate the total colour difference (E) between LGR and raw rice.

$$\Delta E = \sqrt{(L^* - L_0^*)^2 + (a^* - a_0^*)^2 + (b^* - b_0^*)^2} \tag{12}$$

2.5.3 *Cooking characteristics*

Cooking characteristics were determined in triplicates using the method described by Yadav et al. [13] in terms of Cooking Time (CT), Cooking Losses (CL), and Water Absorption Ratio (WAR) with minor modifications. The rice grain sample (2.5 g) was dropped in boiling water (25 ml). Few rice grains were taken out and pressed between two glass slides for checking if the white core (belly) is present within the rice kernels. When the white belly disappeared, the cooking process was completed. For calculating the WAR and CL, rice grains were cooked in the same way as cooked for calculating the CT. When the rice grains were cooked, the gruel containing the leached solids were transferred into glass petri plates and kept for drying at 105 °C in a hot air oven. Simultaneously, the weight of cooked rice grains was noted down. The weight of dry solids was recorded, and WAR and CL were calculated as:

$$WAR = \frac{\text{Weight of cooked rice (g)}}{\text{Weight of sample (g)}} \tag{13}$$

$$CL\ (\%) = \frac{\text{Weight of dry solid (g)}}{\text{Weight of sample (g)}} \times 100 \tag{14}$$

2.5.4 *Pasting properties*

Pasting properties were analyzed in terms of peak viscosity, pasting temperature, breakdown viscosity, setback viscosity and final viscosity in triplicates by the method described by Dalbhagat & Mishra [25] using a rheometer (Model: MCR-52, Anton Paar, Austria). The rice flour samples (approx. 2.5 g) were slurred with 22.5 ml of distilled water in an aluminium cylindrical canister. The canister was placed in instrument, and samples were first incubated at 50 °C for 1 minute and then heated to 95 °C at a rate of 12.0 °C/minute and maintained for 2.5 minute at 95 °C. Finally, the samples were cooled to 50 °C at 12.0 °C/minute and held for 2 minutes at 50 °C. The standard processing was set for 13 minutes. All pasting properties were determined from the pasting curve (Figure 2).

2.5.5 *Microstructure*

The microstructure of the LGR was examined for surface and the transverse section under a scanning electron microscope (ZEISS EVO 60, Germany). The samples for the transverse section were carefully cut with a razor blade and placed on pin stubs adhered with carbon tape and coated with gold-palladium layer. SEM images of samples were captured at magnification levels of 5000X and 10000X and a maximum acceleration voltage of 20 kV.

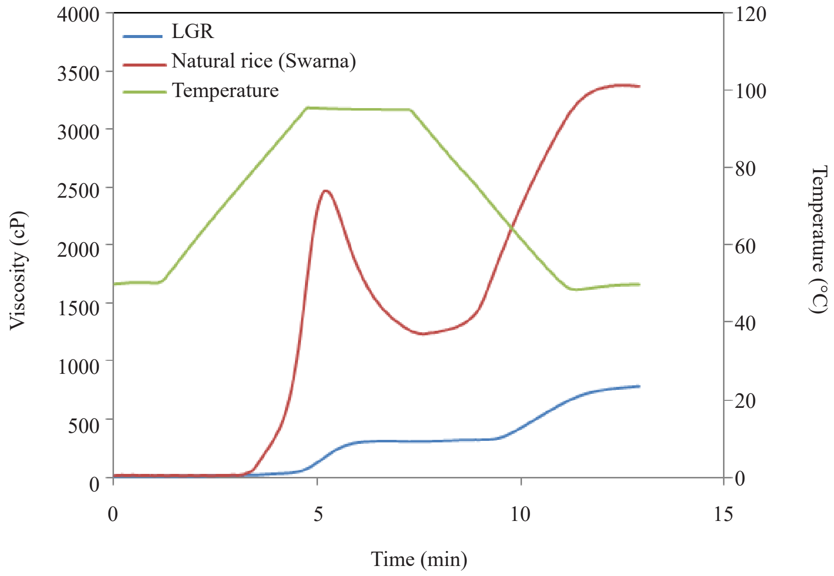


Figure 2. Pasting curves for LGR and raw rice (*Swarna Cv*)

2.6 *Statistical analysis*

Microsoft Excel (Version 2010) was used to perform one-tailed t-test following the procedure described by Grech [28] using the option "*t-test: Two-Sample Assuming Unequal Variances*" for the statistical analysis of comparison of mans of all replications. The significant level was established at $p \leq 0.05$.

3. Results and discussion

3.1 *Proximate composition and mineral analysis*

Proximate compositions and mineral contents in terms of iron (Fe), calcium (Ca), magnesium (Mg), sodium (Na) and manganese (Mn) of LGR along with the raw rice (*Swarna Cv.*) are shown in Table 2. The protein, fat, fiber and ash content of LGR were 12.88%, 2.28%, 2.22% and 1.38%, respectively, which were significantly higher ($p \leq 0.05$) than the raw rice, while carbohydrate was significantly lower ($p \leq 0.05$). The Fe, Mg and Na contents in LGR were significantly higher ($p \leq 0.05$) than the raw rice. However, there was no significant difference ($p \leq 0.05$) in Ca and Mn contents. The proximate composition and mineral analysis revealed that LGR had better nutritional value than raw rice. Moreover, lower carbohydrate content in LGR could reduce the Glycemic Load (GL) and could be helpful for diabetic and obese people. Brand-Miller et al. [3] have reported that lowering the GL of the food products by restricting the carbohydrate intake leads to rapid weight loss and improved high-density lipoprotein and triglyceride concentrations.

3.2 *In vitro starch digestibility and estimated Glycemic Index (eGI)*

The results of in *vitro* starch hydrolysis kinetics, including the estimated parameters, C_∞ and k in the starch hydrolysis model, the Hydrolysis Index (HI) and the eGI, are shown in Table 2. GI is the measure of blood glucose level rise when a carbohydrate-containing food is consumed. When a food product is consumed, the complex carbohydrates such as starch are metabolized and broken down to simple sugar, i.e. glucose. The rate of metabolization and the final equilibrium glucose concentration are measured by the parameters k and, respectively. The HI is a measure of the relative change in glucose concentration with respect to a reference food. The GI is a combination of all the starch hydrolysis kinetics parameters that indicate how the blood glucose level is affected when a carbohydrate-containing food is consumed. Foods with GI ≤ 55 are classified as low glycemic food. The GI value of LGR was found to be 55.03, which was very close to 55, and therefore it can be considered as low glycemic food. The reduced GI of the LGR could mainly be attributed to the addition of foxtail and barnyard millets and quinoa, which are low glycemic foods. Anju & Sarita [29] prepared a biscuit with low GI (50.8) from foxtail millet. Ugare et al. [10] reported the suitability of barnyard millet for consumption by diabetic people. Xu et al. [11] observed that the composite bread prepared from wheat and quinoa flour decreased in *vitro* starch digestibility with lower expected GI and higher levels of slowly digestible starch and resistant starch. Moreover, the decrease in GI of LGR could also be due to starch-lipid and starch-protein complexes formation, making the starch unavailable to the digestive enzymes and reducing the starch digestibility rate and hence lowers the GI [30].

Table 2. Nutritional value and in vitro starch digestibility kinetics parameters of LGR

Parameters	Proximate composition (%)		Minerals	Mineral content (mg per 100g)	
	LGR	Raw rice (*Swarna*)		LGR	Raw rice (*Swarna*)
Moisture (wb)	11.43 ± 0.02^{a}	11.98 ± 0.30^{a}	Fe	16.11 ± 2.02^{a}	3.96 ± 0.03^{b}
Ash	1.38 ± 0.06^{a}	0.45 ± 0.21^{b}	Ca	20.24 ± 0.94^{a}	17.93 ± 0.12^{a}
Fat	2.28 ± 0.04^{a}	0.27 ± 0.03^{b}	Mg	117.28 ± 0.16^{a}	35.82 ± 0.20^{b}
Fiber	2.22 ± 0.22^{a}	0.46 ± 0.02^{b}	Na	20.79 ± 0.16^{a}	12.87 ± 0.17^{b}
Protein	12.88 ± 0.32^{a}	7.82 ± 0.12^{b}	Mn	3.27 ± 0.07^{a}	3.15 ± 11^{a}
Carbohydrate	70.69 ± 1.33^{b}	79.19 ± 0.32^{a}			

Particulars	In *vitro* starch digestibility kinetics parameters			
	C_{∞}	k	HI	eGI
LGR	25.951 ± 3.085	0.021 ± 0.002	27.908 ± 2.475	55.032 ± 1.359
White bread (reference food)	81.01	0.036	100	100

Results are represented as Mean ± SD from triplicates (n = 3). Values in the same row with different letters are significantly different at $p \leq 0.05$

3.3 *Physicochemical properties and cooking characteristics*

Physicochemical properties in terms of WAI, WSI, and colour (L^*, a^*, b^*, c, h, and ΔE) and cooking characteristics in terms of CT, CL and WAR of the LGR and the raw rice are given in Table 3. The CT, CL and WAR of LGR were found to be 8.25 minutes, 14.23% and 2.87, respectively and WAI, WSI and ΔE were found to be 2.36 g/g, 7.21% and 25.14, respectively. The CT of LGR was found to be significantly lower ($p \leq 0.05$), whereas CL was significantly ($p \leq 0.05$) higher than the raw rice. However, there was no significant difference ($p \leq 0.05$) in WAR. The CT is the minimum time required to gelatinize the starch completely. Due to the increasing number of working population and changing lifestyle so rapidly, there is a huge demand for quick-cooking and convenient food worldwide. Instant rice is gaining popularity worldwide because of its low CT. The low CT (8.25 minutes) of LGR over raw rice (16.11 minutes) will definitely make the LGR more acceptable among the consumers. However, higher values of ΔE and CL of LGR may result in reduced acceptability among the consumers. The reduced CT of the LGR could probably be due to the pre-gelatinization of starch during extrusion. Moreover, the addition of millets and quinoa led to a dilution of starch, requiring less time for gelatinization. The extent of disintegration of the extruded product during cooking is measured in terms of CL. The CL and WAR indicate the starch network stability during the cooking [31]. The higher CL of LGR than the raw rice could be attributed to starch degradation under the severe condition of extrusion cooking [13].

WAI measures the water holding capacity of starch when it swells in excess water [14]. It is the measure of integrity of the starch network in aqueous dispersion as well as the behaviour of extruded products during subsequent processing [13, 14]. Because native starch is unlikely to absorb water at room temperature, WAI may also indicate the degree of starch gelatinization [15]. The WSI is a measure of the amount of soluble polysaccharides and is affected by the degree of dextrinization. In other words, WSI assesses the extent to which starch is converted into soluble polysaccharides, such as amylose, during the extrusion process [13, 14]. There was no significant difference ($p \leq 0.05$) in the WAI of LGR and that of the raw rice in the present study. The WSI of LGR was found to be significantly higher ($p \leq 0.05$) than the raw rice, which could be attributed to the structural degradation of starch during extrusion leading to an increase in water-soluble polysaccharides. Jongsutjarittam & Charoenrein [32] also found an increased WSI for extruded rice flour compared to the native rice flour.

Table 3. Cooking characteristics and physicochemical properties of LGR

Rice	Cooking characteristics			Physicochemical properties							
	CT (minutes)	WAR	CL (%)	WAI (g/g)	WSI (%)	L^*	a^*	b^*	c	h	ΔE
LGR	8.25 ± 0.62^b	2.87 ± 0.11^a	14.23 ± 2.39^a	2.36 ± 0.13^a	7.21 ± 0.28^a	52.93 ± 0.03^b	5.87 ± 0.01^b	17.06 ± 0.06^b	18.04 ± 0.06^b	71.00 ± 0.03^b	25.14 ± 0.08
Raw rice (*Swarna*)	16.11 ± 0.49^a	3.59 ± 0.14^a	2.70 ± 0.19^b	2.19 ± 0.02^a	1.24 ± 0.07^b	77.34 ± 0.07^a	1.86 ± 0.03^a	21.40 ± 0.09^a	21.43 ± 0.06^a	85.04 ± 0.06^a	00.00

Results are represented as Mean ± SD from triplicates ($n = 3$). Values in the same column with different letters are significantly different at $p \leq 0.05$; CT: Cooking Time; CL: Cooking Loss; WAR: Water Absorption Ratio; WAI: Water Absorption Index; WSI: Water Solubility Index; ΔE: Colour difference

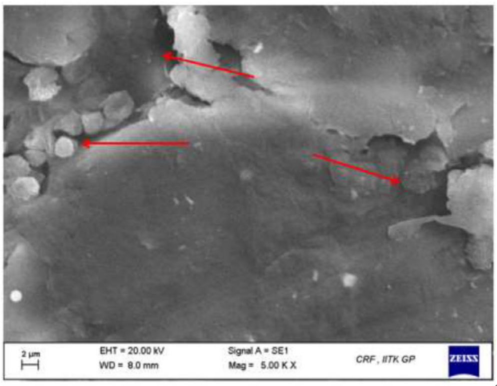
Colour is an important physical property that plays a crucial role in consumers' acceptability of the extruded products. It is heavily influenced by the feed compositions and the process conditions used for the manufacturing of products. There were significant differences ($p \leq 0.05$) in the colour values of LGR and the raw rice. The LGR showed significantly lower L^* and higher a^* ($p \leq 0.05$) value as compared to raw rice. The E between the LGR and the raw rice was found significantly higher ($p \leq 0.05$). E is the total colour difference between the raw rice (*Swarna Cv*) and the prepared LGR. It is a measurement of how much a displayed colour can differ from its input colour. A lower E means better colour accuracy. In the present study, displayed colour is the colour of LGR and input colour is the colour of raw rice (*Swarna Cv*). A higher value of E indicates that LGR has a lesser demand as far as consumers acceptability in concerned in terms of appearance. The decrease in lightness and increase in redness could be attributed to the increased protein content provided by millets and quinoa. The protein present in the feed material promotes the Maillard reaction resulting in browning of the extruded product. Bouasla et al. [33] found a decreased lightness and an increased redness when legume flour was blended in rice flour for the preparation of pasta. Furthermore, high extrusion temperature has a profound effect on the colour of the extruded product as high temperature accelerates the non-enzymatic browning reactions [13].

3.4 *Pasting properties*

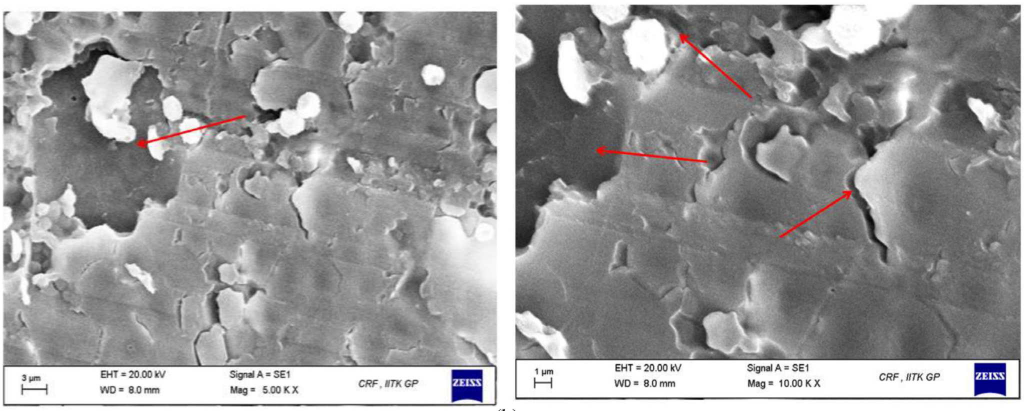
Figure 3 shows the pasting curves for LGR and the raw rice, which provides information about the starch gelatinization, structural breakdown, and retrogradation. Pasting properties of the extruded product indicate the degree of cooking of the feed material during extrusion processing [34]. During extrusion, starch undergoes several changes, including gelatinization, expansion, and degradation [35]. Significant differences were found in the pasting profiles of LGR and the raw rice, as shown in Table 4. Peak viscosity and peak temperature of the LGR were significantly lower ($p \leq 0.05$) than the raw rice. However, peak time was significantly higher ($p \leq 0.05$) than the raw rice. The lower peak viscosity of LGR is associated with the pre-gelatinization and degradation of starch during extrusion. Yadav et al. [36] have stated that gelatinization and structural degradation of starch during the extrusion process reduce the swelling capacity and thereby, result in lower viscosity. Similar results were reported by Dalbhagat & Mishra [25] for fortified rice kernels and Hagenimana et al. [37] for extruded rice flour. Another reason for the lower peak viscosity of LGR could be the presence of foxtail millet and barnyard millet. Kharat et al. [35] have reported that major millets contain type-B starch, which has a moderate swelling tendency and lower pasting peak and much lower thinning. The lower thinning of millets also reflected the breakdown viscosity of LGR, where the breakdown viscosity was significantly lower ($p \leq 0.05$) than the raw rice. The pasting temperature of LGR was significantly higher ($p \leq 0.05$) than the raw rice. Kaur & Singh [38] have stated that the increased pasting temperature of extruded product is associated with the amylose-lipid complexes formation during extrusion. Setback viscosity measures the degree of starch retrogradation when a hot paste of gelatinized starch is cooled. The increase in the viscosity is determined by the tendency of the starch to reassociate. Setback viscosity of LGR was significantly lower ($p \leq 0.05$) than the raw rice. The result obtained for setback viscosity was consistent with that reported by Hagenimana et al. [37] for extruded rice flour.

3.5 *Microstructure*

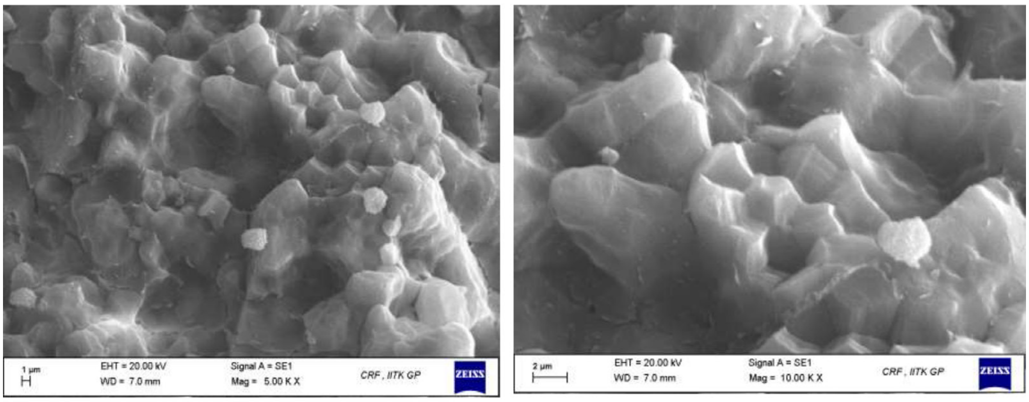
The Scanning Electron Microscopy (SEM) images show the microstructure of the surface and the cross-section of LGR and the raw rice (Figure 3) at 5000 X and 10000 X magnification levels. The images reveal (indicated by arrows) that there are several cracks and voids on the surface as well as within the LGR kernel (Figure 3a & 3b). However, these voids or cracks are almost negligible in the raw rice (Figure 3c & 3d). Moisture flashing during extrusion could have caused these cracks and voids in the LGR. During extrusion, a sudden flash of moisture causes expansion in the hot viscoelastic melt at the die opening, where bubbles grow and eventually rupture, resulting in a large number of voids [35, 36]. The significantly shorter cooking time of LGR also reflects the formation of cracks and voids during extrusion process. Rice grains with fewer voids and cracks, indicating a dense and compact intercellular structure, take longer time to absorb water, resulting in a longer cooking time [39]. Similar observations have been reported by Yadav et al. [13] for low glycemic instant rice, and Dalbhagat et al. [27] for iron-fortified rice kernels.



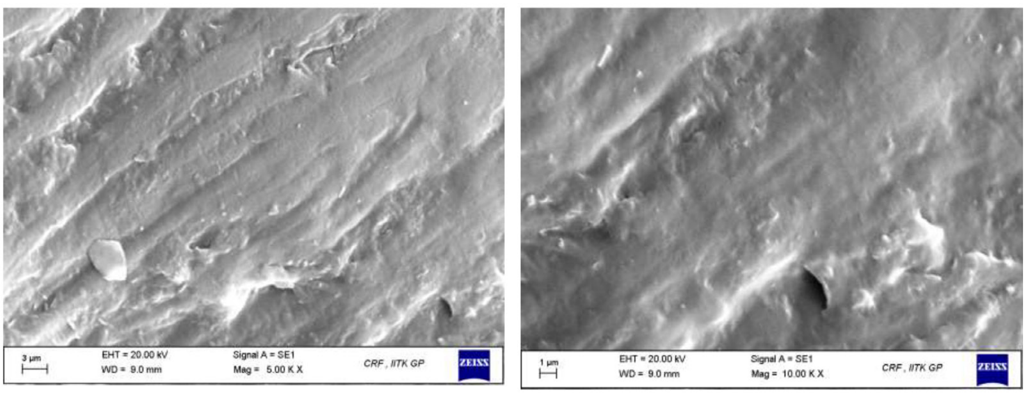
(a)



(b)



(c)



(b)

Figure 3. SEM analysis of LGR (a. surface, b. cross-section) and raw rice (c. surface, d. cross-section)

Table 4. Pasting properties of LGR and raw rice

Parameter	LGR	Raw rice (*Swarna*)
Peak viscosity (cP)	299.65 ± 12.05^b	2,428.50 ± 42.50^a
Peak temperature (°C)	95.00 ± 0.00^b	95.35 ± 0.05^a
Peak time (minutes)	6.81 ± 0.01^a	5.28 ± 0.08^b
Pasting temperature (°C)	94.05 ± 0.45^a	75.00 ± 0.59^b
Final viscosity (cP)	740.05 ± 43.25^b	3,270.50 ± 99.50^a
Setback viscosity (cP)	445.05 ± 32.15b	2,067.00 ± 70.00^a
Breakdown viscosity (cP)	4.65 ± 0.95^b	1,225.00 ± 13.00^a

Results are expressed as Mean ± SD from triplicates ($n = 3$). Values in the same row with different letters are significantly different at $p \leq 0.05$

4. Conclusion

Low Glycemic Rice (LGR) was prepared from rice broken, and low glycemic ingredients viz., foxtail millet, barnyard millet, and quinoa using extrusion technology. The physicochemical properties, cooking characteristics, starch digestibility, and microstructure of LGR were compared with raw rice (*Swarna Cv*). The LGR (GI: 55.03) contained significantly high ($p \leq 0.05$) nutritional values (protein, fiber, fat, ash, Fe, Ca, Mg and Na) as compared to the raw rice (*Swarna Cv*.). The physicochemical properties and cooking characteristics viz., CL, WSI and ΔE of LGR were significantly higher ($p \leq 0.05$) whereas CT was significantly lower ($p \leq 0.05$) than the raw rice (*Swarna Cv*.). However, no significant differences ($p \leq 0.05$) were observed in WAI and WAR. The LGR showed significantly different ($p \leq 0.05$) pasting properties as compared to the raw rice. Several cracks and voids were observed in LGR as indicated by the SEM analysis. The low GI and high nutritional values indicate that the LGR has the potential to act as anti-diabetic nutrition-rich food which can reduce the risk of diabetes and malnutrition.

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Availability of data and material (Data transparency)

No research data is shared.

Conflicts of interest

Authors have no conflicts of interest.

References

[1] Rizkalla SW, Bellisle F, Slama G. Health benefits of low glycaemic index foods, such as pulses, in diabetic patients and healthy individuals. *British Journal of Nutrition*. 2002; 88(S3): 255-262. Available from: doi: 10.1079/BJN2002715.

[2] Ludwig DS, Majzoub JA, Al-Zahrani A, Dallal GE, Blanco I, Roberts SB. High glycemic index foods, overeating, and obesity. *Pediatrics*. 1999; 103(3): e26-e26. Available from: doi: 10.1542/peds.103.3.e26.

[3] Brand-Miller J, Dickinson S, Barclay A, Celermajer D. The glycemic index and cardiovascular disease risk. *Current Atherosclerosis Reports*. 2007; 9(6): 479-485. Available from: doi: 10.1007/s11883-007-0064-x.

[4] Hussain SZ, Beigh MA, Qadri T, Naseer B, Zargar I. Development of low glycemic index muffins using water chestnut and barley flour. *Journal of Food Processing & Preservation*. 2019; 43(8): e14049. Available from: doi: 10.1111/jfpp.14049.

[5] Kaur B, Ranawana V, Henry J. The glycemic index of rice and rice products: a review, and table of GI values. *Critical Reviews in Food Science and Nutrition*. 2016; 56(2): 215-236. Available from: doi: 10.1080/10408398.2012.717976.

[6] National Health Portal of India, Gateway of Automatic Health Information, Disease/Conditions: A-Z (Obesity). Available from: http://nhp.gov.in/ [Accessed 5th October 2016].

[7] Rodge SM, Bornare DT, Babar KP. Formulation and quality evaluation of instant upma mix of foxtail millet and garden cress seed. *International Journal of Chemical Studies*. 2018; 6(3): 1854-1857.

[8] Patangare Suwarna S, Pawar VS, Syed HM, Shinde ST. Studies on physical properties and nutritional profile of foxtail millet. 2019.

[9] Nithiyanantham S, Kalaiselvi P, Mahomoodally MF, Zengin G, Abirami A, Srinivasan G. Nutritional and functional roles of millets - A review. *Journal of Food Biochemistry*. 2019; 43(7): e12859. Available from: doi: 10.1111/jfbc.12859.

[10] Ugare R, Chimmad B, Naik R, Bharati P, Itagi S. Glycemic index and significance of barnyard millet (*Echinochloa frumentacae*) in type-II diabetics. *Journal of Food Science & Technology*. 2014; 51(2): 392-395. Available from: doi: 10.1007/s13197-011-0516-8.

[11] Xu X, Luo Z, Yang Q, Xiao Z, Lu X. Effect of quinoa flour on baking performance, antioxidant properties and digestibility of wheat bread. *Food Chemistry*. 2019; 294: 87-95. Available from: doi: 10.1016/j.foodchem.2019.05.037.

[12] Navruz-Varli S, Sanlier N. Nutritional and health benefits of quinoa (*Chenopodium quinoa Willd.*). *Journal of Cereal Science*. 2016; 69: 371-376. Available from: doi: 10.1016/j.jcs.2016.05.004.

[13] Yadav GP, Dalbhagat CG, Mishra HN. Development of instant low glycemic rice using extrusion technology and its characterization. *Journal of Food Processing and Preservation*. 2021; 45: e16077. Available from: doi: 10.1111/jfpp.16077.

[14] Sukumar A, Athmaselvi KA. Optimization of process parameters for the development of finger millet based multigrain extruded snack food fortified with banana powder using RSM. *Journal of Food Science & Technology*. 2019; 56(2): 705-712. Available from: doi: 10.1007/s13197-018-3527-x.

[15] Ding QB, Ainsworth P, Tucker G, Marson H. The effect of extrusion conditions on the physicochemical properties and sensory characteristics of rice-based expanded snacks. *Journal of Food Engineering*. 2005; 66(3): 283-289. Available from: doi: 10.1016/j.jfoodeng.2004.03.019.

[16] Yoo J, Alavi S, Adhikari K, Haub MD, Aberle RA, Huber G. Rice-shaped extruded kernels: physical, sensory, and nutritional properties. *International Journal of Food Properties*. 2013; 16(2): 301-321. Available from: doi: 10.1080/10942912.2010.495042.

[17] Moretti D, Lee TC, Zimmermann MB, Nuessli J, Hurrell RF. Development and evaluation of iron-fortified extruded rice grains. *Journal of Food Science*. 2005; 70(5): S330-S336. Available from: doi: 10.1111/j.1365-2621.2005.tb09987.x.

[18] Herawat H, Kusnandar F, Adawiyah DR, Budijanto S, Rahman MS. Thermal characteristics and state diagram of extruded instant artificial rice. *Thermochimica Acta*. 2014; 593: 50-57. Available from: doi: 10.1016/j.tca.2014.08.017.

[19] Wang JP, An HZ, Jin ZY, Xie ZJ, Zhuang HN, Kim, JM. Emulsifiers and thickeners on extrusion-cooked instant rice product. *Journal of Food Science & Technology*. 2013; 50(4): 655-666. Available from: doi: 10.1007/s13197-011-0400-6.

[20] Liu C, Zhang Y, Liu W, Wan J, Wang W, Wu L, Yin Z. Preparation, physicochemical and texture properties of

texturized rice produce by improved extrusion cooking technology. *Journal of Cereal Science*. 2011; 54(3): 473-480. Available from: doi: 10.1016/j.jcs.2011.09.001.
[21] AOAC. *Official Methods of Analysis* (18th ed.). Association of Official Analytical Chemists, Gaithersburg; 2005.
[22] Thakur A, Pandey P, Dalbhagat CG, Mishra HN. Development of grain-based carbonated beverage premix using maize (*Zea Mays*), Bengal gram (*Cicer Arietinum*), and finger millet (*Eleusine Coracana*). *Journal of Food Science & Technology*. 2021; 59: 1637-1648. Available from: doi: 10.1007/s13197-021-05175-5.
[23] Balasubramanian S, Singh KK, Patil RT, Onkar KK. Quality evaluation of millet-soy blended extrudates formulated through linear programming. *Journal of Food Science and Technology*. 2012; 49(4): 450-458. Available from: doi: 10.1007/s13197-011-0297-0.
[24] Semasaka C, Kong X, Hua Y. Optimization of extrusion on blend flour composed of corn, millet and soybean. *Pakistan Journal of Nutrition*. 2010; 9(3): 291-297. Available from: doi: 10.3923/pjn.2010.291.297.
[25] Dalbhagat CG, Mishra HN. Drying modeling, cooking characteristics, pasting properties, and crystallinity of fortified rice kernels. *Journal of Food Processing and Preservation*. 2021; 45(6): 1-9. Available from: doi: 10.1111/jfpp.15579.
[26] Goñi I, Garcia-Alonso A, Saura-Calixto F. A starch hydrolysis procedure to estimate glycemic index. *Nutrition Research*. 1997; 17(3): 427-437. Available from: doi: 10.1016/S0271-5317(97)00010-9.
[27] Dalbhagat CG, Mishra HN. Effect of the drying process on the color change, fissure development, and morphology of fortified rice kernels. *Journal of Food Process Engineering*. 2021; 44(7): 1-10. Available from: doi: 10.1111/jfpe.13719.
[28] Grech V. WASP (Write a Scientific Paper) using Excel-8: t-Tests. *Early Human Development*. 2018; 121: 58-61. Available from: doi: 10.1016/j.earlhumdev.2018.02.018.
[29] Anju T, Sarita S. Suitability of foxtail millet (*Setaria italica*) and barnyard millet (*Echinochloa frumentacea*) for development of low glycemic index biscuits. *Malaysian Journal of Nutrition*. 2010; 16(3): 361-368.
[30] Ritudomphol O, Luangsakul N. Optimization of processing condition of instant rice to lower the glycemic index. *Journal of Food Science*. 2019; 84(1): 101-110. Available from: doi: 10.1111/1750-3841.14406.
[31] Wang L, Duan W, Zhou S, Qian H, Zhang H, Qi X. Effects of extrusion conditions on the extrusion responses and the quality of brown rice pasta. *Food Chemistry*. 2016; 204: 320-325. Available from: doi: 10.1016/j.foodchem.2016.02.053.
[32] Jongsutjarittam O, Charoenrein S. The effect of moisture content on physicochemical properties of extruded waxy and non-waxy rice flour. *Carbohydrate Polymers*. 2014; 114: 133-140. Available from: doi: 10.1016/j.carbpol.2014.07.074.
[33] Bouasla A, Wójtowicz A, Zidoune MN. Gluten-free precooked rice pasta enriched with legumes flours: Physical properties, texture, sensory attributes and microstructure. *LWT-Food Science & Technology*. 2017; 75: 569-577. Available from: doi: 10.1016/j.lwt.2016.10.005.
[34] Yadav DN, Anand T, Singh AK. Co-extrusion of pearl millet-whey protein concentrate for expanded snacks. *International Journal of Food Science & Technology*. 2014; 49(3): 840-846. Available from: doi: 10.1111/ijfs.12373.
[35] Kharat S, Medina-Meza IG, Kowalski RJ, Hosamani A, Ramachandra CT, Hiregoudar S, et al. Extrusion processing characteristics of whole grain flours of select major millets (foxtail, finger, and pearl). *Food & Bioproducts Processing*. 2019; 114: 60-71. Available from: doi: 10.1016/j.fbp.2018.07.002.
[36] Yadav GP, Dalbhagat CG, Mishra HN. Effects of extrusion process parameters on cooking characteristics and physicochemical, textural, thermal, pasting, microstructure, and nutritional properties of millet-based extruded products: A review. *Journal of Food Process Engineering*. 2022; 45(9): e14106. Available from: doi: 10.1111/jfpe.14106.
[37] Hagenimana A, Ding X, Fang T. Evaluation of rice flour modified by extrusion cooking. *Journal of Cereal Science*. 2006; 43(1): 38-46. Available from: doi: 10.1016/j.jcs.2005.09.003.
[38] Kaur K, Singh N. Amylose-lipid complex formation during cooking of rice flour. *Food Chemistry*. 2000; 71(4): 511-517. Available from: doi: 10.1016/S0308-8146(00)00202-8.
[39] Singh N, Kaur L, Sodhi NS, Sekhon KS. Physicochemical, cooking and textural properties of milled rice from different Indian rice cultivars. *Food Chemistry*. 2005; 89(2): 253-259. Available from: doi: 10.1016/j.foodchem.2004.02.032.