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Impact of Die Configuration on Physio-Chemical Properties, Anti-Nutritional Compounds, and Sensory Evaluation of Multi-Based Extruded Puffs

Anurag[1] and Amar P Garg[2]*

[1]*Banda University of Agriculture and Technology Banda, India*

[2]*Swami Vivekanand Subharti University Meerut, India*

***Corresponding author:** Amar P Garg, Dean Academics and Director Research, Swami Vivekanand Subharti University, NH-58, Subhartipuram, Meerut-250005, India

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ABSTRACT

In this study, Millet-based ready-to-eat snacks were prepared as a solution to the problem of prolonged soaking and cooking times required for using the Millets. Extrusion-cooking conditions were standardized, and the results indicated that the use of a star-shaped die resulted in a lower water solubility index, degree of starch gelatinization, expansion ratio, lightness (L*) values and higher bulk density compared to a circular die. The study examined the effect of star and circular shaped dies on 100% Millet (finger, pearl, and foxtail) based extruded food items and their anti-nutritional compounds, physicochemical properties, and sensory features of 100% Millet Puffs of pearl, finger, and foxtail Millet. We found no significant variation in phytates but showed non-univocal variations in oligosaccharides through die changes. The present study suggests that selecting the suitable die diameter can improve the sensory quality and physicochemical properties of Millet extrudates, providing a solution for preparing Millet-based ready-to-eat snacks that meet consumer satisfaction for pleasant sensory qualities with healthy food products. The panellists preferred spherical extrudates as compared to star-shaped products, indicating the importance of shape as an intrinsic factor in influencing food acceptability and consumer perception of products.

Keywords: Anti Nutritional; Dies Diameter; Extrudates; Millets; Sensory; Snacks

Abbreviations: BD: Bulk Density; SEI: Sectional Expansion Index; ER: Expansion Ratio; WAA: Water Absorption Index; WSI: Water Solubility Index; SG: Starch Gelatinization; L*: Lightness; a*: Redness; b*: Yellowness; RFOs: Raffinose-Family Oligosaccharides

Introduction

Millets are highly valued by vegetarians, vegans, and individuals with coeliac disease for their exceptional nutritional benefits [1]. These plant-based foods are abundant in proteins and complex carbohydrates while being low in fat [2]. Additionally, they are a rich source of dietary fiber, essential minerals, and B-group vitamins [3,4]. However, Millet preparation can be a time-consuming process as they require prolonged soaking and cooking, which reduces their consumption by consumers [5]. To overcome this challenge, novel food products like - ready-to-eat Millet-based snacks could be developed. Such products could encourage more individuals to incorporate Millet into their diet [6]. The food processing technique of extrusion-cooking is highly versatile, multifunctional, and cost-effective. Raw materials are exposed to heat, pressure and shear forces during this process, leading to various biochemical reactions such as protein denaturation, starch gelatinization, fiber degradation, amylose-lipid complex formation through Maillard reaction [7]. Extrusion-cooking is commonly employed to create expanded snacks that are ready-to-eat, come in different shapes and textures, and boast enhanced flavour and colour [8]. High concentrations of raffinose-family oligosaccharides (RFOs) in lentils cause stomach discomfort and reduce lentil quality for human consumption.

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To develop strategies for lentil quality improvement, variability, heritability and effects of environmental conditions on the content and composition of soluble carbohydrates in lentil seeds have been investigated in detail [9]. Over the past few years, there has been significant research on creating extruded products using Millets [10]. In most cases, these Millets are blended with wheat [11]. Numerous studies have examined the impact of various extrusion-cooking factors, including feed moisture, screw speed, extrusion temperature, nutritional characteristics [12] physico-chemical, sensory and textural properties of prepared product. These studies have also included trials conducted directly at the industrial level [13,14]. However, there has been a lack of research on how the die configuration, which determines the final product's shape and size, affects the extrusion of Millets. Food shape and size play a critical role in capturing the consumer's attention [15]. These features strongly influence the implicit associations with consumers concerning nutritional value [16]. Moreover, the shape and size of food can significantly impact the sensory qualities and physico-chemical properties of the extruded product [17]. Therefore, the present study was designed to examine the impact of star shaped and circular die configurations, which have two different diameters of 35.9 and19.6 mm^2, respectively, on the anti-nutritional component, physico-chemical properties, and sensory features of extruded snacks made from Millet flour.

Materials and Method

For the development of extruded puff products, germinated pearl Millet (Pennisetum glaucum), finger Millet (Eleusine coracana), sorghum (Sorghum bicolour), foxtail Millet (Setaria italic) and rice (Oryza sativa) as base were used as raw materials for the present study work. These Millets were procured from a nearby local market in Meerut, Uttar Pradesh [18].

Optimization of Single Screw Extruder Operating Parameters for Different Millet Based Extruded Puffs Products

The operating parameters of the twin screw extruder mainly, the temperature, feed moisture content and the screw speed, were optimized for the various "best selected" four Millet fortified with rice based extruded puff products formulation. Three feed moisture content (20%, 25%, and 30% wt.b.), screw speeds (180, 270, and 360 rpm) and 160, 180°C and 270°C temperature were selected to produce extrudes. The extruded samples were then analyzed for physical analysis like expansion ratio, water holding capacity, moisture content, puffing properties and texture analysis. Further experiment was carried out at three different level of temperature (100, 110 and 120°C) with keeping constant screw speed and feed moisture content.

Sample Preparation from Extrusion

Laboratory scale single-screw extruder (Model no: GTL-100), (Zigmo Agro Pvt. Ltd. New Delhi, India) was used for sample preparation. During each extruder run, the extruder machine was allowed to equilibrate for 5-10 min until a stable torque was achieved. Extruded samples were collected on metal screens to allow excess steam to flash off. The extruded samples were collected in a low-density polyethylene bag after cooling and stored in a cool and dried area.

Development of Extruded Puff Products Based on the Millet's Combinations

Extruded puffs preparation was done, and it mainly consists of puffs mixture of Millets in combination as shown in Tables 1 & 2 and rice is used as base. The blended puffs mixes at appropriate moisture content were extruded to produce extruded puff through the extrusion machine (manufacture: Jas Enterprises, Ahmadabad, India) into desired shaped products and developing extruded puff products based on Millet combinations involves a series of steps to create a desirable texture, flavor, and nutritional profile the process flow chart shown in Figure 1.

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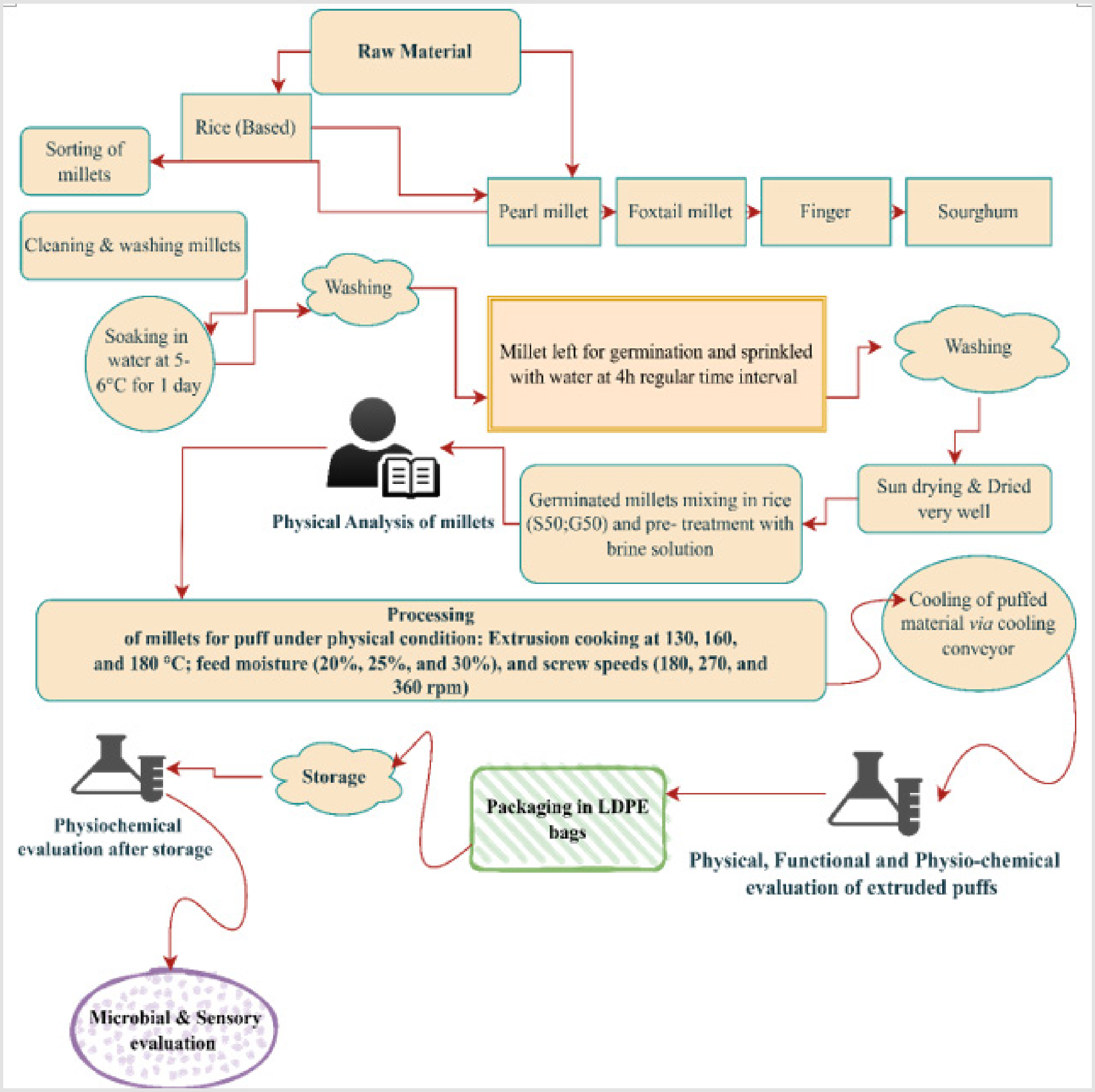

Figure 1: Flow chart for preparation of Millets fortified with rice based extruded puff products.

Multi Millet Conditioning

To achieve the optimal moisture concentration for extrusion (16 g/100 g), the Puffs were conditioned. The amount of water required to reach this moisture level was determined based on the initial moisture content of each flour type, which was 12.95 ± 0.01, 10.87 ± 0.01, and 12.54 ± 0.06 for pearl Millet, finger Millet and foxtail Millet, respectively. Water was added gradually to the flour in dough mixer at average speed to avoid the lumps formation. The process took approximately 20 minutes to obtain uniformly hydrated flour.

Extrusion-Cooking Process

Extrusion cooking is a food processing technology that integrates multiple operations such as mixing, cooking, kneading, shearing, shaping, and forming [19]. The DSE30 Lab Twin-screw extruder was used to carry out the extrusion-cooking process with a 12 kg/h capacity. The extruder machine design had two 38CrMoAl screws, a 5-kW motor and operating at maximum screw speed of 500 rpm, with three heating zones at 55, 95, and 125°C, respectively. The extrusion process was carried out using circular and star-shaped dies holes with

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cross-sections of 19.6 mm2 and 35.9 mm2, respectively. The circular die nozzle and star cross-section had a length of 6.35 mm. The feed rate was set to 2.5 g/s, the die temperature to 160°C, and the screw speed to 230 rpm. To examine the extruded products, the water absorption index, water solubility index, starch gelatinization degree, colour, phytate and oligosaccharides content were measured. For this purpose, extrudates were ground using an electrical grinder (HM-5735) from Home Electrical Appliance and passed through a 0.25 mm sieve sized blades for some analysis, while other analyses were performed on the entire extrudates.

Physical Assessment of Extruded Puff

Finger Millet (Eleusine coracana L.), pearl Millet (Pennisetum glaucum), foxtail Millet (Setaria italic) and sorghum (Sorghum bicolour) are three selected cereals that have been evaluated in terms of physical parameters, specifically bulk density, in the context of cereals and cereal-based products. The evaluation of bulk density for the three combinations of puff products made from the selected cereals would involve measuring the mass and volume of the cereal products. The mass can be measured using a scale, while the volume can be determined by various methods such as displacement or geometric calculations. By studying and analysing the obtained results of bulk density, these conclusions can help in understanding the texture, density, and overall quality of the products, which are important factors for consumer acceptance. It's worth noting that in addition to physical parameters like bulk density, other nutritional and sensory attributes of these cereals and their products are also crucial for evaluating their overall nutritional value and consumer appeal [20]. These may include factors such as nutrient composition, digestibility, taste, aroma, and shelf life, among others. By conducting such evaluations, can gain insights into the potential of these cereals and their products as staple foods and nutrient sources, both in developed and developing countries. Kjeldahl digestion methods (Advanced and ordinary) compared total nitrogen in non-germinated and germinated extruded puff products. Advanced Kjeldahl showed protein variations of (07.11% to 10.66%) and (09.45% to 11.98%), while ordinary Kjeldahl showed (05.11% to 10.96%) and (07.45% to 11.56%). Millet combinations revealed T3 with germinated Millets had higher protein, indicating nutritional value. Total ash, dietary fiber, and carbohydrates varied in extruded puff products. Statistical analysis indicated significant differences ($p<0.0001$) for each combination. Incorporating Millet and sorghum in rice flour (T3) resulted in higher protein and overall acceptable sensory properties. AOAC methods revealed significant differences ($p=0.05$) in proximate compositions of multi-Millet puffs with overall acceptable sensory properties [20]. This knowledge can be valuable for food scientists, policymakers, and nutritionists in promoting sustainable and nutritious food options worldwide.

Bulk Density and Expansion Ratio

Extruded products bulk density (BD) was studied by using the rapeseed displacement method and calibrated as per given equation (1) by [21]. For this purpose, the (10 ± 0.1 g) of randomly selected extruded product were weighted:

$$BD\left(\frac{g}{cm^3}\right) = W_t \times Vep^{(-1)} = W_e p \times \left(\rho_s \times W_s^{-1}\right) \quad (1)$$

Whereas Wt. and Vep-1 are the weight in (gm) and the equivalent volume (cm3) of the extruded products, respectively. Actually, Vep is multiplication ratio between the rapeseed density (ρs) and the rapeseed weight (Ws), with same volume as the extrudates. Five replicates for each sample were prepared to study the parameters. sectional expansion index (SEI), bulk density (BD), instrumental color, and dry and bowl-life texture were evaluated. SEI and BD responses were fixed by moisture variable is incorporated; darker products were produced. Nevertheless, high together with higher temperature and lower moisture levels produces better color appearance. At high ratio desirable low hardness and crispy expanded extrudates can be generated as long as moisture is lower than about 22% [22]. The calibration of expansion ratio (ER) was according to the ratio of extruded product diameter to determine the die hole diameter of extruder with the help of caliper device, as reported by Kokseland Masatcioglu. For this purpose, ten replicates were taken for (ER) assessment.

Water Absorption Activity

The extruded products water absorption index (WAI) and the water solubility index (WSI) were determined as per equations (2) and (3) [23].

$$(WAI)\frac{g}{g} = \frac{weightofsediment}{sampleweight} \quad (2)$$

$$(WSI)\frac{g}{100g} = \frac{drysolidsweightinsupernatant}{sampleweight \times 100} \quad (3)$$

The (WSI) is the dry solid weight in the extracted supernatant, whereas (WAI) is the sediment weight without the supernatant per unit weight of the sample analyzed. Each sample was tested in a triplicate manner.

Starch Gelatinization

The starch gelatinization (SG) of the extruded products determination follows the modified method based on the procedure outlined by [24]. This method involves the formation of a blue iodine complex when amylase is released during gelatinization. Specifically, 40 mg quantity of sample was dissolved in a 50 mL of 0.15 M KOH solution and mixed thoroughly for 15 minutes. The reaction mixture was then centrifuged at 4032 x g for 10 minutes to remove out insoluble sediment. Next, 1 mL quantity of the supernatant was neutralized by the addition of 9 mL of 0.017 M HCl, and 0.1 mL of iodine reagent (1 g iodine and 4 g potassium iodine dissolved in 100 mL water). The resultant solution was mixed, and read the absorbance at 600 nm (A1)

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using a Cary 60 UV-VIS spectrophotometer. In addition, 1 M KOH and 0.1 M HCl solution was used to prepare control samples. The overall value of DG was calibrated by using equation (4) based on the average of three replicates.

$$SG = \frac{A_1}{A_2} \quad (4)$$

Whereas (A1/A2) is the ratio of absorbance at 600nm of the sample to that of the control.

Phyto-Chemical Constituents of Selected Millets Puffs

The effect of extrusion processing on anti-nutrients factors namely tannin, phytate and saponin of extruded Millet-sorghum blend rice puffs puff product combinations were studied. Extrusion processing is necessary to absorb essential micro and macronutrients from added blends of puffs during extruded snacks preparations and eliminates a negative effect of anti-nutritional factors such as tannin, phytate and saponins. Thus, nutritional quality was maintained by extrusion through destruction of anti-nutritional components.

Color Determination

The CM-600d colorimeter (Konica Minolta Sensing Inc., Osaka, Japan) was used to determine the lightness (L*), redness (a*), and yellowness (b*) of both Puffs and extruded products with help of using the Spectra-Magic NX software (Konica Minolta, Tokyo, Japan). The series of experiments was replicated five times in a row.

Oligosaccharides Analysis

The presence of oligosaccharides namely verbascose, stachyose, and raffinose in Puffs and extruded products were investigated by using the HPLC with slight modifications in a method prescribed by [25]. Samples were mixed with deionized water, filtered, and separated isostatically on a cation exchange column. Identification was based on standard comparison, and quantification was based on calibration curves. Results are expressed in (mg/g dry matter) of each oligosaccharide after triplicate analysis.

Phytate Analysis

The phytate content of both Puffs and extruded products was determined by following the [26] method as its values were expressed in (mg/g) of dry matter of phytic acid. To calculate the phytate content, obtained values were multiplied by 0.282 and it is the molar ratio of phytate-phosphorus in a molecule of phytate. The analysis was done in a triplicate manner.

Sensory Evaluation

A panel of 28 semi-trained judges from University of Life Sciences and Technologies demonstrate Millet-based extruded snacks using a ranking test. Each sample is arranged in groups of three on glass plates to evaluate appearance, texture, taste, and aftertaste using an evaluation form as this form is generated through Fizz Acquisition 2.51 software. Warm black tea was used for taste neutralization between samples. The panelists ranked the samples as per most liked=1 to least liked=8 and the recorded results were calibrated as the summation of ranks for each sample (Figure 2).

Figure 2: Samples prepared in different treatments and packed in Low Density Polythene (LDPE) bags.

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Statistical Analysis

The recorded data of Millet Puffs and extruded products undergo one-way ANOVA and two-way ANOVA stats analysis, followed by Tukey's HSD test. The two-way ANOVA stats analysis considers two major factors namely Millet puffs type and die type for further analysis. Minitab-17 ver. statistical software (Minitab, Inc., State College, PA, USA, 2010) was used to determine the significant differences among all studied parameter values at $p < 0.05$. The sensory evaluation data were statistically analysed by using the Friedman test with Fizz calculation (Biosystems, Cousteron, France) and a $p<0.05$ level of significance.

Results and Discussion

The various multi-Millet utilized to produce extruded snacks were shown in Table 1. Table 1 showed the notable differences among (L*, a*, and b*) colour patterns. Pearl Millet flour exhibited the highest a* and b* values while it had lowest L* value. In contrast, foxtail Millet flour had lightest colour, followed by finger Millet flour. Foxtail Millet flour exhibited the lowest a* and b* values, with the latter being statistically insignificant in comparison to pearl Millet flour. Additionally, Table 2 calibrated values were significantly differed ($p<0.05$) as the amount of anti-nutritional compounds were studied among the Puffs. Millets are known to contain several anti-nutritional compounds, including non-digestible oligosaccharides and phytic acid, which has inherent chelating characteristics to capture important divalent cations such as Fe, Zn, Ca, and Mg, which leads to lowering of availability for absorption and use in the small intestine [27,28]. However, presence of raffinose, verbascose, and stachyose oligosaccharides in human diets in an ample amount causes flatulence and discomfort in humans after consumption [29,30].

Table 1: Color parameters of Millet flour of pearl Millet, finger Millet and foxtail Millets.

Color parameters	Pearl Millet (T_1)	Finger Millet(T_2)	Foxtail Millet(T_3)
L*	79.84±0.39	80.56±0.33	82.74±0.08
a*	8.66±0.13	2.44±0.06	1.32±0.03
b*	20.65±0.22	13.56±0.11	11.77±0.17

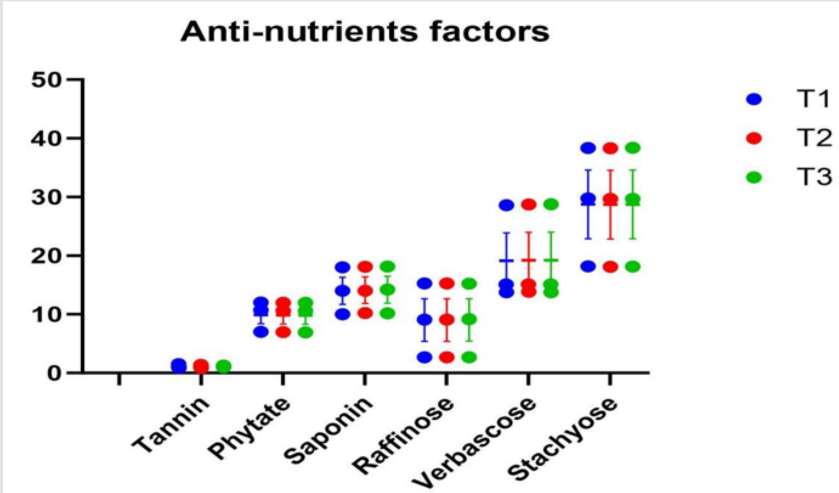
Note: *Each (n = 3) replica values were expressed as (mean ±standard deviation).

Table 2: Physicochemical parameters of spherical and star-shaped extruded products obtained from different Millets Puffs.

Die configuration	Millet	BD (g/cm^3)	ER	WAI (g/g)	WSI (g/100g)	SG (g/100g)
Spherical	Pearl	0.40±0.01	2.11±0.21	3.81±0.16	9.28±0.29	85.27±0.69
	Finger	0.20±0.02	2.44±0.13	3.20±0.07	15.77±0.26	89.25±0.26
	Foxtail	0.20±0.01	2.75±0.11	3.33±0.12	12.88±0.87	86.66±0.63
Star shaped	Pearl	0.61±0.03	1.12±0.03	4.06±0.21	7.55±0.55	86.72±0.32
	Finger	0.26±0.02	1.54±0.04	2.56±0.02	12.07±0.33	84.32±0.49
	Foxtail	0.26±0.01	1.75±0.16	3.31±0.01	10.53±0.22	83.14±0.25
Millet	Probability Values (p)	p<0.001	p<0.001	p<0.001	p<0.001	p<0.001
Die	Probability Values (p)	p<0.001	p<0.001	P=0.659	p<0.001	p<0.001
Millet×Die	Probability Values (p)	p<0.001	p<0.05	p<0.001	p<0.01	p<0.001

Note: *Each parameters value was expressed as (mean ± standard deviation) for (n=3).

Pearl Millet flour exhibited the highest concentration of phytates, followed by finger and foxtail Millets Puffs, respectively. Foxtail Millet flour contained the highest levels of verbascose, although it had stachyose in a lesser amount. Similarly, finger Millet flour had the highest amount of stachyose, while it has lowest amount of raffinose. However, the quantity of oligosaccharides in Millets varied as per the selected species and varieties, as well as the existing environmental conditions [31,32]. [33] reported significant variability in the amount of raffinose (4.10–10.30 mg/g), stachyose (10.70–26.7 mg/g) and verbascose (0.00–26.70 mg/g) among 18 different pea varieties. While Tahir et al. (2011) observed higher stachyose levels than raffinose and verbascose in 11 lentil varieties, as these findings were found in line with current findings. This difference in oligosaccharides level might be due to significant constraint on the extensive use of legumes at both domestic and industrial scale [34] (Figure 3).



Note: *Each (n = 3) replica values were expressed as (mean ±standard deviation) significantly ($p \leq 0.05$).

Figure 3: Changes in Anti-nutrient factors value of extruded products after extrusion processing.

Physico-Chemical Properties of Extruded Products

All physico-chemical parameters had significant differences ($p < 0.05$) among the extruded products, except water absorption index (WAI). These noticeable differences were attributed due to the type of Millet used, the type of die, and the (Millet x die) interaction, as shown in Table 3. However, it should be noted that the type of die had no significant effect on the WAI. Pearl Millet-based extruded products had the highest bulk density (BD) and water absorption index (WAI), whereas it has lowest expansion ratio (ER) and water solubility index (WSI) values. Similarly in foxtail Millet-based products had the highest (ER) and well-expanded spherical extrudates, while highest degree of starch gelatinization (SG) was recorded in finger Millet-based products. Higher ER, DG and WSI with lower BD was recorded in circular die configuration based extruded products as compared to star-shaped die. The effect of die shape on extruded product characteristics can be explained by change in friction and pressure strength. The circular die had a smaller cross-section, resulting in higher levels of friction and pressure and thus higher temperatures, which led to more expansion and lesser dense products, will obtain as it has greater ER and lower BD. On the other hand, the star-shaped cross-section had angles that could have mechanically broken bubbles in the gelatinized starchy matrix, which led to disturbance in expansion. However, with increment in the die nozzle diameter decreased radial expansion in yellow corn extrudates. Along with this, inducing higher extrusion pressure on starch gelatinization causes expansion of the extrudates products made from foxtail and finger except in pearl Millet-based products since it has higher fibre content that restricted starch gelatinization [1], [35]. Although ER and BD are important physical parameters that can influence consumer behavior in the sense of acceptability of extruded products [36].

Table 3: Color parameters of spherical and star-shaped extruded products obtained from different Millet Puffs.

Die configuration	Millets	Color parameters		
		L*	a*	b*
Spherical	Pearl	72.66±0.06	4.22±0.02	30.86±0.09
	Finger	68.34±0.18	2.69±0.07	21.56±0.07
	Foxtail	68.56±0.07	2.49±0.04	20.16±0.05
Star shaped	Pearl	72.92±0.07	4.82±0.03	34.22±0.08
	Finger	70.42±0.08	2.47±0.02	21.32±0.06
	Foxtail	71.34±0.03	2.12±0.01	20.02±0.04
Millet	Probability values (p)	p<0.001	p<0.001	p<0.001
Die	Probability values (p)	p<0.001	p<0.001	p<0.001
Millet×Die	Probability values (p)	p<0.001	p<0.001	p<0.001

Note: *Each parameters value was expressed as (mean±standard deviation) for (n=3).

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Earlier studies by [37] who reported an inverse relation between BD and ER, as observed in this work, where a negative correlation was found (r = -0.631; p = 0.093). The presence of huge number of fibres in the feed Puffs can also affect the ER and BD values by reducing overall expansion on account of cell-wall rupture, resulting in a compact and hard product with an undesirable texture. In this context, Red lentil flour, with the highest fibre content, led to extrudates with the lowest ER and highest BD indicating the importance of considering fibre content while developing extruded product as described by [38]. The extrusion-cooking conditions, including the die used, may also impact the WAI and WSI values, which represent the amount of water that can be absorbed by the extruded product and the quantity of soluble substances formed during the extrusion process from starch, proteins, and fibres. The presence of fibres in higher amount could also influence functional properties [39]. Instead of this, WSI was also influenced by other factors such as legume type, die shape, and legume-die interaction, while effect of die shape had no significant effect on WAI. Higher fibre levels in the legume led to an increase in WAI, as they absorbed and retained water within a well-developed starch-protein-polysaccharide network, as discussed previously by [40].

Extruded Products Color

Colour is a crucial aspect of food products that can significantly affect consumer acceptability. Extrusion-cooking affects the colour features of the products, making them darker than the Puffs. The colour components of the extrudates were influenced by Millet type, die configuration and their interaction. The observed colour features were attributed to existing pigments and the Maillard reaction occurring during extrusion-cooking (Table 4). Star-shaped extrudates had greater L* and lower a* values (except for pearl Millet) compared to spherical shape extrudates, while b* index had found non-uniform trend. This fluctuating trend is due to pigment degradation as temperature rises and shear stress during extrusion is responsible to alter color, especially for carotenoids. The decrement in L* and increment in a* values may be linked to the melanoidins formation during the Maillard reaction, while increment in b* may be results from the formation of yellowish compounds during the initial stages of the Maillard reaction or from lipid oxidation. An advantage of larger die cross-section reduces extrusion pressure and heat, leading to a less intense Maillard reaction and reduces browning and flavor development [41]. Thus, star-shaped extrudates were obtained with the help of larger cross-sectional die and a less drastic extrusion process involved to obtain lighter colour than spherical shaped extrudates [42].

Table 4: Anti-nutritional compounds of spherical and star-shaped extruded products obtained from different legume Puffs.

Die configuration	Millets Puffs	Phytates content (Mg Phytic acid/g d.m.)	Oligosaccharide Content (mg/g d.m.)		
			Verbascose	Stachyose	Raffinose
Spherical	Pearl	3.23±0.05	16.66±0.29	30.11±0.18	13.17±0.15
	Finger	5.89±0.20	14.76±0.11	40.65±0.49	4.77±0.05
	Foxtail	4.53±0.03	27.55±0.49	20.22±0.32	12.53±0.28
Star shaped	Pearl	3.23±0.06	15.43±0.33	29.66±0.62	18.64±0.11
	Finger	5.92±0.23	15.17±0.65	41.14±0.33	4.25±0.02
	Foxtail	4.11±0.02	27.82±0.54	20.92±0.33	12.12±0.08
Millet	Probability values (p)	p<0.001	p<0.001	p<0.001	p<0.001
Die	Probability values (p)	P=0.655	p<0.001	P=0.001	p<0.001
Millet×Die	Probability values (p)	p<0.05	p<0.001	p<0.001	p<0.001

Note: *Each parameters values were expressed as (mean± standard deviation; n = 3); indicating the significant differences ($p < 0.05$) among the sphere and star shaped products considering the interaction between the Millet and die.

Anti-Nutritional Component of Puffs and Extruded Products

The extrusion-cooking process and the type of raw material used can influence the levels of anti-nutritional compounds in legume extrudates [43,31]. A comparison of the native Puffs shown in Table 2 and the extrudates in Table 4 revealed different kind of behaviour for various anti-nutritional compounds. In present study the phytates content decreased as the extrusion-cooking of finger Millet (12% on average) and foxtail Millet (7.9% on average) Puffs initiated for both star-shaped and spherical products, possibly on account of thermal processing that is associated with the extrusion-cooking process. [12] found that total phytates were more greatly reduced in lentil flour extruded at 160°C compared to 140°C. However, oligosaccharides, particularly stachyose and raffinose increased during extrusion cooking. This could be attributed to the high temperature and pressure involved in extrusion-cooking, which break the bonding between oligosaccharides and other macromolecules, or alter the food matrix structure, leading to better extractability of anti-nutritional compounds [6]. Similar kind of results were observed in pea-rice gluten-free expanded products and extruded lentil snacks by other researchers [6,25]. It was observed that there were differences in verbascose, stachyose and raffinose content in Millets extrudates just because of Millet type, die configuration and their interaction, but their phytic acid was not affected by die shape. In case of pearl Millet based spherical extrudates have higher verbascose content than star-shaped, while raffinose content increased to 7% in the latter. Common bean-based star extrudates had higher stachyose and raffinose content compared to spheres made from the same flour, which decreased by 1.7% and 7.5%, respectively [23]. Extrusion conditions and legume type affected oligosaccharide behaviour, with a higher temperature and pressure increasing stachyose and raffinose contents. An obtained results showed that oligosaccharides content was found higher in spherical shaped products than the star-shaped after die inducing higher pressure and heat generation, particularly for raffinose [39].

Sensory Evaluation of the Extruded Products

The sensory attributes like appearance, texture, taste, and aftertaste of the extruded products were significantly ($p < 0.05$) affected by the type of flour and die used. The products ranking is decided as per test results (Table 5). As per sensory attributes the star-shaped extrudates prepared from pearl Millet were found to be least preferred acquiring lowest rank sum for "texture" due to their hard structure and difficult to chew, bland taste, and aftertaste. However, pearl Millet based spherical extrudates were liked for "appearance" and "aftertaste", similarly notified in spherical and star-shaped extrudates from finger and foxtail Millets. Previously [10] studies showed that high values of BD and hardness can produce undesirable products for consumers. In contrast, common Millet extrudates, particularly a spherical one, were preferred in terms of all considered attributes owing to their properly puffed and crunchy nature, pleasant taste and aftertaste as discussed by [28]. In another study, extrudates made from blends of red lentil and corn were found to be more accepted than including (100%) lentil extrudates [17]. In general, the spherical shaped extruded products were favored as compared to star-shaped ones, indicating that preferred shape plays a crucial role in consumer perception and acceptability of food products. This is supported by studies that suggest that shape can even affect taste perception. However, there was no significant difference observed between spherical and star-shaped extrudates in terms of taste and aftertaste, possibly because textural features, such as appearance and structure, had a greater impact.

Table 5: Sensory characteristics of extruded (spheres and stars) shaped products.

Die configuration	Millets Puffs	Sensory attributes			
		Appearance	Taste	Texture	After taste
Spherical	Pearl	125	174	165	150
	Finger	108	99	123	120
	Foxtail	109	106	100	112
Star shaped	Pearl	189	218	189	184
	Finger	159	120	127	120
	Foxtail	131	124	111	117

Note: *Each parameters values were expressed as (mean± standard deviation; n = 3).

Conclusion

The study aimed to understand how the die configuration affects the extrusion of Millets. Most industry dies have a circular cross section, but the effect of a star-shaped die on Millet was still unknown. Obtain results of the study showed that the die-hole diameter significantly affects the physicochemical properties and sensory qualities of the extruded snacks. The use of a star-shaped die to produce products with a lower ER and higher BD than spherical extrudates and it is preferred one on account of lowering the friction resistance during extrusion. The increased knowledge on die configuration could aid in the expansion of Millet-based raw materials at maximal level to meet consumer satisfaction for healthy and palatable food products.

Declarations

- Author contribution statement Anurag: Conceived and designed the experiments; Performed the experiments; Analysed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.
- Professor Dr. A.P. Garg: Designed and refined the experiments; Analysed and interpreted the data; Contributed reagents, materials, analysis tools and data; Finalized the paper.

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Declaration of Interest's Statement

The authors declare no conflict of interest.

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