

Comprehensive Characterization of Soy Protein, Cowpea, Moth Bean and Wheat Gluten as Functional Ingredients for the Development of Plant-Based Extruded Meat Analogues

Gugulothu Swaroopa*¹, B.S Agarkar², R.B Kshirsagar³

¹Ph.D Research Scholar, Department of Food Engineering, CFT, VNMKV, Parbhani (MS), India, 431402

²Associate Professor, Department of Food Engineering, CFT, VNMKV, Parbhani (MS), India, 431402

³Professor and head, Department of Food Engineering, CFT, VNMKV, Parbhani (MS), India, 431402

*Corresponding Author: gswaroopa12@gmail.com

Abstract. The production of meat analogs using low-moisture extrusion is a complex process influenced by the composition of raw materials, processing parameters, and equipment design. Achieving a meat-like texture depends on the physicochemical and functional properties of the ingredients, which directly affect extrusion behavior and final product quality. This study aimed to evaluate the characteristics of various protein-rich plant-based raw materials are soy protein isolate (SPI), defatted soy flour (DFS), cowpea flour (CPF), moth bean flour (MBF), and wheat gluten (WG) for their suitability in meat analog production. The materials were analyzed for proximate composition (moisture, carbohydrate, protein, fat, ash, and dietary fiber), bulk density, water and oil absorption capacity, solubility indices, particle size distribution, and viscosity. The results provide valuable insights for optimizing raw material selection and processing conditions to improve extrusion performance and enhance the texture and quality of plant-based meat analogs.

KEY WORDS: Plant based meat analogue, Raw materials, Physicochemical and Proximate

1. INTRODUCTION

Meat consumption has played a crucial role in human evolution and continues to be a major component of diets worldwide. Commonly consumed meats include chicken, beef, mutton, and pork, with countries like the USA and Australia leading in per capita consumption [1]. Over the past two decades, global meat demand has risen by 58%, driven largely by population growth and economic development [2]. Meat and its products are valuable sources of essential nutrients such as proteins, iron, and various vitamins. Despite these benefits, the environmental consequences of meat production are substantial [3]. As a result, many individuals are choosing to reduce their intake of animal-based foods in favor of plant-based alternatives. This shift is primarily motivated by the low carbon efficiency of meat production, concerns over human health, environmental degradation from livestock farming, and ethical issues surrounding animal welfare [4].

Plant-based (PB) meat analogs are designed to replicate the sensory and functional characteristics of animal meat, including appearance, flavor, aroma, texture, and cooking performance. These substitutes are typically made from plant proteins such as soy, wheat, peas, and seeds, and are formulated to provide a meat-like chewing experience while offering added

health benefits. In light of the high costs associated with traditional meat production and growing environmental concerns, there is increasing interest in developing low-cost alternative proteins that not only serve as meat substitutes but also improve sensory, nutritional, and textural attributes [5]. The plant-based meat analog market is experiencing rapid growth, with projections by UBS indicating an increase from \$4.6 billion in 2018 to \$85 billion by 2030, and an estimated value of \$30.9 billion by 2026 [1]. This expanding market is driven by continuous innovation aimed at improving the quality of meat alternatives to match the nutritional value and consumer appeal of animal-derived products [6].

During this period, in industrialized countries, interest in developing the range of textured vegetable proteins from cereals, legumes, or nuts as raw materials increased in the context of agriculture expansion [7]. The correct choice of protein-rich raw materials is responsible for solving the problems of obtaining an appropriate fibrous structure for meat analogs, which is as close as possible to that of meat. The degree of using vegetable protein sources in manufacturing meat analogs depends on their availability, price, and technological properties [8].

Plants positively influence the process of biodiversity conservation, agriculture, and soil fertility preservation. Various legumes (20–35% protein content), nuts (39.4–42.1% protein content), oilseeds (about 45% proteins), and microalgae with an average of over 50% protein content could be an important source of plant-based protein in manufacturing meat analogs if they meet the respective requirements. The technological functions (solubility, thermal stability, emulsification, flavor binding capacity, and digestibility) of proteins are most relevant to the creation of meat analogs, as they are manifested

through their use as a formulation, concentrate, or isolate. Of all the types of proteins contained in plant sources, albumin is of particular importance because it can form complex bonds with carbohydrates, lipids, and nucleic acids [9].

The purpose of this research work was to characterize the quality indices of plant based raw materials (Cowpea flour (CPF), Moth bean flour (MBF), Defatted soy flour (DFS) soy protein isolate (SPI) and wheat gluten with potential for use in the manufacture of meat analogs.

2. MATERIALS AND METHODS

2.1 Raw materials

Defatted soy flour, soy protein isolate and wheat gluten were directly procured from local market of Parbani, Maharashtra.

2.1.1 Preparation of cow pea and moth bean flours

Cow pea and moth bean were procured from local market, Parbhani, Maharashtra. Moisture content of cow pea and moth bean approximately 8% were used for flour production. Before processing, the grains underwent a cleaning procedure to eliminate impurities and foreign matter. This cleaning step involved the use of water which effectively removed unwanted debris, ensuring grain purity. The cleaned grains were then soaking in portable water for 24 hr and dried at 89°C for by using cabinet drier for 4 to 5 hr. After complete drying of grains milled to produce flour using a hammer mill equipped with a 250-µm size screen. The resulting legumes flour was packed in polyethylene bags and stored in a cool and dry place until further use [10].

2.2. Proximate composition

Proximate composition were conducted through measuring the moisture content with the gravimetric method, Ash content with the gravimetric method, Fat content with soxhlet method, Protein content with kjeldahl method, and Carbohydrate content with carbohydrate by difference. Dietary fiber of the sample will be estimated by using moisture and fat free samples and expressed as gram per 100g or per cent of the samples used [11].

2.3. Bulk density

Bulk density was determined using a method described by [12]. About 4 g of flour sample was weighed into a 10 ml cylinder in triplicates. The cylinder was gently tapped on a laboratory bench until no further diminution and flour filled to the volume

mark. This was done to eliminate air spaces. Volume was recorded after taping, and the results were calculated and expressed as a weight-to-volume ratio using following equation.

$$\text{Bulk density (g/cm}^3\text{)} = \frac{\text{Weight of sample (g)}}{\text{Volume of sample (cm}^3\text{)}}$$

2.4 Water absorption capacity

Water absorption capacity was determined by the method described by [13]. About 2.5 g of flour sample was measured and placed in a 50 ml falcon tube, and 30 ml distilled water was added to the tube and mixed. The sample was agitated for 10 min and centrifuged at 3000 rpm for 10 min. The free water recovered from the sediment flour sample was removed and the tube was drained for 10 min to separate the surface water, and water absorption capacity was calculated using equation

$$\text{WAC} \left(\frac{\text{g H}_2\text{O}}{\text{g sample}} \right) = \frac{\text{Final weight of solid pellet} - \text{initial weight of sample}}{\text{Initial weight of sample}}$$

2.5 Oil absorption capacity

Oil absorption capacity was determined using the method of [13]. About 2.5 g of cowpeas flour sample was measured and placed in a 50 ml falcon tube, and 30 ml of vegetable oil was added to the tube and mixed. The sample was then agitated for 10 min and centrifuged at 3000 rpm for 10 min. The free oil recovered from the sentimental flour sample was removed and the tube was drained for 10 min to separate the surface oil, and oil absorption capacity was calculated using equation

$$\text{OAC} \left(\frac{\text{g Oil}}{\text{g sample}} \right) = \frac{\text{Final weight of solid pellet} - \text{initial weight of sample}}{\text{Initial weight of sample}}$$

2.6 Water absorption and solubility index

Water absorption and solubility index were determined using the method of [12]. A portion (3 g) of flour sample was measured and mixed with 25 ml of distilled water in a 50 ml falcon tube and heated in a water bath for 15 min at 90 °C. The cooked paste was cool to room temperature and centrifuged at 1500 rpm for 20 min. afterward, the supernatant was decanted into a pre-weighed Petri dish to determine the solid content and the sediment weight. The weight of dry solids was obtained by evaporating the supernatant overnight at 105 °C, and the water absorption index and water solubility index were calculated using equation

$$\text{Water absorption index (g/g)} = \frac{\text{Weight of precipitate}}{\text{Weight of the sample}}$$

$$\text{Water solubility index (\%)} = \frac{\text{Weight of dissolved solid in supernatant}}{\text{Weight of sample}} \times 100$$

2.7 Particle size

The standard AACC method 66-20.01 was used to determine the particle size, in which five sieves with descending mesh size were stacked in a sieve shaker [14]. The mesh sizes of the sieves used were 250 µm, 220 µm, 180 µm, 150 µm and a base catchment respectively. After shaking 100 g of each sample for 5 min, the different powder fractions were collected and weighed. The percentage of material retained was determined for each sieve. The total amount of powder retained on each sieve and the

amount in the previous sieves were added to estimate the cumulative percentage of powder retained on each sieve. The measurements were carried out in triplicate for each protein material.

2.8 Viscosity

Viscosity of raw materials as a function of temperature was evaluated utilizing Brookfield viscosity analyzer following the AACC Method 76–21 STD 2 with slight modification [15]. Homogeneous slurry from the samples was prepared with 8 g solids and 72 g distilled water. The temperature was gradually increased from 30 °C to 93 °C at a heating rate of 7.5 °C per min. It was then maintained at 93 °C for 5 min before being cooled down to 50 °C at a cooling rate of 7.5 °C per min. The final temperature of 50 °C was held for 1 min. The instrument measures the viscosity in M pass at a fixed torque noted every second. To ensure accuracy, duplicate measurements were conducted for each sample and results were expressed as mean values.

2.9 Statistical analysis

All the data were statistically evaluated by one way analysis of variance (ANOVA) and the significance of differences between means were determined by Duncan's multiple comparison test at a 5% significance level ($P < 0.05$) by using IBM SPSS statistics software, version 20.0 (IBM, SPSS, Inc., Chicago, IL, USA).

3. RESULTS AND DISCUSSION

3.1. Proximate composition of raw materials

Shifting from animal-based proteins to plant-based alternatives can be carried out progressively and efficiently by utilizing protein-rich ingredients such as plant protein isolates, protein-dense flours, and wheat gluten, all of which can help mimic the texture and flavor of meat, enabling full replacement in meals. The plant-based meat analog industry has access to a wide range of raw materials, including legume protein

isolates and concentrates (like soy and peas), cereal and legume flours (particularly those high in gluten and starch) [8]. Therefore, assessing the quality and suitability of these plant protein sources is a critical step in planning effective production of meat analogs. The proximate characteristics of the selected raw materials are detailed in Table 1.

Table 1: Proximate composition of raw materials

Parameter	Moisture (%)	Carbohydrate (%)	Protein (%)	Fat (%)	Ash (%)	Dietary fiber (%)
Defatted soy flour	6.16 ± 0.76 ^b	26.16 ± 0.58 ^c	52.66 ± 0.58 ^c	3.00±0.5 ^a	2.00 ± 0.5 ^c	10.02 ± 0.00 ^a
Soy protein isolate	4.83 ± 0.29 ^d	1.83 ± 0.58 ^c	89.33 ± 1.15 ^a	2.01±1.15 ^c	1.33 ± 0.29 ^d	0.67 ± 0.29 ^c
Cowpea flour	7.64 ± 0.58 ^c	55.87 ± 0.29 ^a	23.33 ± 1.15 ^d	1.83± 0.58 ^c	3.50 ± 0.00 ^a	7.83 ± 0.58 ^b
Moth bean flour	8.36 ± 0.05 ^a	58.03 ± 0.05 ^a	21.05 ± 0.08 ^c	3.09± 0.08 ^a	3.25± 0.04 ^a	6.22 ± 0.04 ^c
Wheat gluten	8.27 ± 0.23 ^a	12.63 ± 0.23 ^d	75.00 ± 0.00 ^b	2.00± 0.00 ^c	1.10 ± 0.00 ^d	1.00 ± 0.00 ^d

Values are expressed as mean ± SD (n=3). The values in the same column with different superscript letters are significantly different ($p < 0.05$) according to the Duncan multiple comparison test.

The moisture content of the tested samples was largely influenced by their protein and carbohydrate composition. Across all raw materials, moisture levels varied within a specific ranged from (6.16 ± 0.7 to 8.36 ± 0.05 %). Soy protein isolate (SPI) showed the lowest moisture content ($P < 0.05$), likely due to its extensive extraction, purification, and processing steps that effectively eliminate moisture. On the other hand, moth bean flour (MBF) recorded the highest moisture content (8.36 ± 0.05 %). In terms of protein concentration, the samples proved to be valuable protein sources, with SPI (89.33 ± 1.15) and defatted soy flour (DFS) showing the highest protein content (52.66 ± 0.58), followed by cowpea flour (CPF) (23.33 ± 1.15) and MBF (21.05 ± 0.08). These findings are consistent with the results reported that soy protein isolate (96.10 ± 0.66 per cent) and wheat gluten (82.76 ± 0.91 per cent) contain high protein levels on a dry basis. Fat content among the samples was not notably high and ranged within a specific percentage. The highest fat levels were observed in MBF (3.09 %), followed by DFS (3.00 %), SPI (2.01 %) and wheat gluten (2.00 %), while CPF (1.83 %) had the lowest fat content. This result aligns with expectations, as cowpea typically contains less fat than the other raw materials analyzed.

Plant-based ingredients generally contain less fat and cholesterol compared to animal-derived products. They are also richer in polyunsaturated fatty acids, which can fulfill approximately 60% of an adult's daily requirement. The carbohydrate content among the tested raw materials varied, with moth bean flour showing the highest (58.03 ± 0.05 per cent) percentage, followed by cowpea flour (55.87 ± 0.29

per cent). Soy protein isolate, in contrast, had the lowest carbohydrate content (1.83 ± 0.58%). Regarding dietary fiber, defatted soy flour recorded the highest levels (10.02 ± 0.00 per cent), followed by cowpea flour (7.83 ± 0.58 per cent), while soy protein isolate contained the least fiber (0.67 ± 0.29 per cent). Ash content showed minimal variation between cowpea flour (3.50 ± 0.00 per cent) and moth bean flour (1.10 ± 0.00 per cent), with both having relatively high values. However, wheat gluten had the lowest ash content (1.10 ± 0.00 per cent), which was significantly different from the other samples.

3.2. Physical and functional properties of raw materials

Table 2: Physical and functional properties of raw materials

Parameter	Bulk density (g/cm ³)	Water absorption Capacity (g/g)	Oil absorption capacity (g/g)	WAI (g/g)	WSI (%)
Defatted soy flour	0.78 ± 0.01 ^a	2.42 ± 0.03 ^b	1.03 ± 0.03 ^a	2.58 ± 0.07 ^b	7.33 ± 0.58 ^d
Soy protein isolate	0.55 ± 0.01 ^c	3.16 ± 0.02 ^a	0.73 ± 0.03 ^c	3.01 ± 0.01 ^a	15.00 ± 1.00 ^b
Cowpea flour	0.65 ± 0.04 ^b	1.91 ± 0.02 ^c	0.70 ± 0.01 ^c	1.85 ± 0.05 ^c	14.33 ± 0.58 ^c
Moth bean flour	0.71 ± 0.01 ^a	1.73 ± 0.02 ^d	0.91 ± 0.02 ^b	1.65 ± 0.05 ^c	15.67 ± 1.53 ^a
Wheat gluten	0.73 ± 0.03 ^a	1.55 ± 0.05 ^c	0.92 ± 0.03 ^b	1.75 ± 0.04 ^c	5.67 ± 0.58 ^a

Values are expressed as mean ± SD (n=3). The values in the same column with different superscript letters are significantly different (p < 0.05) according to the Duncan multiple comparison test.

The density of the powder was determined because it can influence the mass flow rate. The bulk density of the raw materials ranged from 0.55 ± 0.01 to 0.78 ± 0.01 g/cm³. Among them, soy protein isolate had the lowest bulk density (0.55 ± 0.01 g/cm³) due to its bulky structure. The water absorption capacity (WAC) of the raw materials ranged from 1.55 ± 0.05 to 3.16 ± 0.02. Soy protein isolate exhibited the highest WAC (3.16 ± 0.02) due to the presence of water-soluble proteins. In contrast, wheat gluten had the lowest WAC because of its hydrophobic protein content. These values were significantly different (P < 0.05). WAC is also influenced by carbohydrate and fiber content. Previous studies reported that coarse fractions obtained by air classification of pulse flours have a higher WAC than fine fractions, which aligns with our findings. WAC is further affected by the hydrophilic characteristics of protein and carbohydrate components, the plant protein source, processing conditions during protein extraction, and particle size [21]. The oil

Absorption capacity (OAC) of the raw materials ranged from 0.70 ± 0.01 to 1.03 ± 0.03. Among them, defatted soy flour exhibited the highest OAC (1.03 ± 0.03).

Moth bean flour and soy protein isolate recorded the highest WSI among the raw materials, with values significantly different according to Duncan's multiple comparison test. Variations in the

functional properties of raw materials, including moth bean flour, soy protein isolate, defatted soy flour, and wheat gluten, were influenced by their protein content, inherent properties, and bioactive compounds. The WAI of the raw materials ranged from 1.65 ± 0.05 to 3.01 ± 0.01 g/g, with soy protein isolate exhibiting the highest WAI (3.01 ± 0.01 g/g). Meanwhile, the WSI ranged from 7.33 ± 0.58 to 15.67 ± 1.53 across the raw materials. Similar results were reported by [22], where low WAI (< 4.0 g/g) was observed in wheat gluten. This is because it consists of prolamins and glutelins, which are more soluble in alcohols or acids rather than in water. In contrast, soy protein isolate (SPI) had the highest WAI (> 4.0 g/g) due to its highly water-soluble proteins.

3.3 Particle size analysis of different raw materials

Table 3: Particle size analysis of raw materials

Sieve size (µm)	Soy protein isolate (%)	Wheat gluten (%)	Defatted soy flour (%)	Cowpea flour (%)	Moth bean flour (%)
<150	60.14± 1.25 ^a	58.02± 1.65 ^a	15.5± 1.44 ^c	8.94± 1.15 ^d	8.94± 0.15 ^d
150	32.02± 1.64 ^b	36.47± 1.47 ^b	56.5± 0.16 ^a	50.09± 0.32 ^a	49.95± 1.69 ^a
180	5.37± 0.58 ^c	2.22± 0.96 ^c	20.08± 1.75 ^b	23.54± 0.96 ^b	24.12± 1.45 ^b
220	1.52± 1.01 ^d	1.02± 1.15 ^d	5.03± 0.96 ^d	14.25± 1.27 ^c	9.13± 2.64 ^c
250	0.59± 2.96 ^e	0.9± 1.15 ^d	2.34± 2.46 ^e	3.01± 0.56 ^e	6.88± 1.97 ^e
Sieved powder (%)	99.64± 0.45 ^a	98.63 ±1.15 ^b	99.45± 0.84 ^a	99.83± 0.84 ^a	99.02± 1.94 ^b

Values are expressed as mean ± SD (n=3). The values in the same column with different superscript letters are significantly different ($p < 0.05$) according to the Duncan multiple comparison test.

The particle size distribution of the raw materials were presented in Table 3, determined using the sieving technique. Significant differences ($P < 0.05$) were observed in the mass of particles retained in the sieve within the range of 220 µm and 180 to 220 µm. Sieve fractionation revealed that more than 50% of defatted soy flour (DSF), cowpea flour (CPF), and moth bean flour (MBF) particles were between 150 and 180 µm. In contrast, more than 40% of soy protein isolates (SPI) and wheat gluten (WG) particles were larger than 150 µm. Based on the experimental results, SPI and

WG had smaller particle sizes compared to DSF, CPF, and MBF. This finding indicates that a uniform particle size facilitates smooth flow during the extrusion process. The particle size of the raw materials plays a crucial role in their functional behavior, with finer particles exhibiting greater water absorption rates and capacities. Moreover, the distribution of particle sizes among the samples significantly impacts key functional properties such as swelling and water-binding ability, which are essential factors influencing the overall quality of the final meat analog products.

3.4: Viscosity properties of raw materials

Table 4: Viscosity properties of raw materials

Raw materials	Hot viscosity (M Pas)	Time of peak viscosity (min)	peak viscosity Temp (°C)	Cold viscosity (M Pas)	Torque (rpm)	Spindle no
Defatted soy flour	883.33±14.47 ^b	4	94	1130.00±2.00 ^a	20	64
Soy protein isolate	461.33 ± 1.15 ^b	2	84	641.00 ± 1.73 ^a	20	64
Cowpea flour	863.33 ± 1.15 ^b	4	91	1095.33±1.15 ^a	20	64
Moth bean flour	851.67 ± 2.08 ^b	4	92.5	1023.00±5.20 ^a	20	64
Wheat gluten	522.33 ± 2.08 ^b	3	79	727.00 ± 1.27 ^a	20	64

Values are expressed as mean ± SD (n=3). The values in the same column with different superscript letters are significantly different (p < 0.05) according to the Duncan multiple comparison test.

The paste viscosity of proteins and flours is presented in Table 4. Soy protein isolate (SPI) exhibited hot swelling at the beginning (461.33 ± 1.15) and showed an increase upon cooling. Defatted soy flour (DSF) and cowpea flour (CPF) displayed the highest peak viscosity with slight differences (883.33 ± 14.47 and 863.33 ± 1.15, respectively), followed by moth bean flour (MBF) (851.67 ± 2.08), SPI (461.33 ± 1.15), and wheat gluten (WG) (522.33 ± 2.08). A similar trend was observed at the end of the cooling phase, where the final viscosities were recorded as 1130.00 ± 2.00

for DSF, 1095.33 ± 1.15 for CPF, 1023.00 ± 5.20 for MBF, 641.00 ± 1.73 for SPI, and 727.00 ± 1.27 for WG.

All raw materials were showed peak temperature range from 79°C to 94 °C and wheat gluten exhibited very less temperature is require to form paste and defatted soy flour required more temperature (94 °C) for denaturation of protein in presence of heat while cowpea and moth bean were denatured at temperature of 91 °C and 92.5°C respectively. The result showed that all raw materials were denaturant at less than 100°C. Time of peak viscosity was ranged from 3-4 min.

4. CONCLUSION

This study conclude that incorporating these ingredients into meat analog formulations demands a balanced approaches like optimizing nutrition, sensory quality, and production efficiency. Their use supports sustainability by reducing reliance on resource-intensive livestock systems and aligning with goals related to food security and climate change mitigation. The feasibility of each ingredient depends on targeted product innovation, efficient processing technologies,

and alignment with consumer trends that value health, affordability, and environmental responsibility. Utilizing by-products such as Defatted soy flour enhances circular economy potential, while the higher-impact ingredients like SPI, CPF, BMF and WG may benefit from strategies such as renewable energy use or waste reduction to offset environmental costs and also helps more consumption of underutilized legumes.

REFERENCES

1. M. A. R. Mazumder, W. Panpipat, M. Chaijan, K. Shetty, & S. Rawdkuen. Role of plant protein on the quality and structure of meat analogs: A new perspective for vegetarian foods. *Future Foods*. 8, 100280 (2023).
2. T. Whitnall, N. Pitts, N. Global trends in meat consumption. *Agric. Commodit.* 9, 96–99 (2019).
3. A.M. Salter. The effects of meat consumption on global health. *Rev. Off. Int. Epizoot.* 37 (1), 47–55 (2018).
4. R. Sanchez-Sabate, J. Sabate. Consumer attitudes towards environmental concerns of meat consumption: a systematic review. *Int. J. Environ. Res. Public Health* 16, 1220 (2019).
5. M. Thakur. *Sustainable Food Systems (Volume I)*. World Sustainability Series, Springer, Cham (2024).
6. K. Kyriakopoulou, J. K. Keppler, & A. J. van Der Goot. Functionality of ingredients and additives in plant-based meat analogues. *Foods*, 10(3), 600 (2021).
7. I. Anum, I. Shafeeqa, S. Arooba, K. Nauman. Plant-based meat analogs: A review with reference to formulation and gastrointestinal fate. *CRFS*. 5, 973–983 (2022).
8. K. Kołodziejczak, A. Onopiuk, A. Szpicer, A. Poltorak. Meat Analogues in the Perspective of Recent Scientific Research: A Review. *Foods*. 11, 105 (2022).
9. V. Bulgaru, M. Mazur, N. Netreba, S. Paiu, V. Dragancea, A. Gurev & A. Ghendov-Mosanu. Characterization of Plant-Based Raw Materials Used in Meat Analog Manufacture. *Foods*. 14(3), 483 (2025).
10. X. Rui, J.I. Boye, S. Ribereau, B.K. Simpson, S.O. Prasher. Comparative study of the composition and thermal properties of protein isolates prepared from nine *Phaseolus vulgaris* legume varieties. *Food Res Int.* (44) :2497–2504 (2011).
11. M. Thakur & V.K. Modi. *Emerging Technologies in Food Science – Focus on the Developing World*. Springer Nature (2020).
12. J. Atukuri, B.B. Odong, & J. H. Muyonga. Multi-response optimization of extrusion conditions of grain amaranth flour by response surface methodology. *Food Science & Nutrition*, 7(12), 4147–4162 (2019).
13. Chandla, N. K., Saxena, D. C., & Singh, S. Amaranth (*Amaranthus* spp.) starch isolation, characterization, and utilization in development of clear edible films. *Journal of Food Processing and Preservation*, 41(6), e13217. (2017).
14. AACC. AACC Method 66–20.01. Determination of granularity of semolina and farina: Sieving method. AACC Approved Methods of Analysis ((11th ed.) American Association of Cereal Chemists International. (1999).
15. AACC. General pasting method for wheat or rye flour or starch using the rapid visco analyzer. In American Association of Cereal Chemists International. (1997).