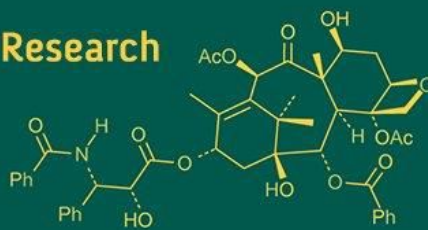


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Pooja P Thul
Ph.D. Scholar, Department of
Processing and Food
Engineering, CAET,
Dr. BSKKV, Dapoli,
Ratnagiri, Maharashtra, India

AA Sawant
Professor and Head,
Department of Processing and
Food Engineering, CAET,
Dr. BSKKV, Dapoli,
Ratnagiri, Maharashtra, India

AG Mohod
Professor and Head,
Department of Renewable
Energy Engineering, CAET,
Dr. BSKKV, Dapoli,
Ratnagiri, Maharashtra, India

PS Sawant
Associate Professor,
Department of Soil Science and
Agricultural Chemistry, COA,
Dr. BSKKV, Dapoli,
Ratnagiri, Maharashtra, India

PB Bansode
Assistant Professor (Statistics),
Department of Soil and Water
Conservation Engineering,
CAET, Dr. BSKKV, Dapoli,
Ratnagiri, Maharashtra, India

SB Kalse
Assistant Professor,
Department of Processing and
Food Engineering, CAET,
Dr. BSKKV, Dapoli,
Ratnagiri, Maharashtra, India

Corresponding Author:
Pooja P Thul
Ph.D. Scholar, Department of
Processing and Food
Engineering, CAET,
Dr. BSKKV, Dapoli,
Ratnagiri, Maharashtra, India

Physicochemical and functional characterization of selected tuber crops and millet flours for extrusion

Pooja P Thul, AA Sawant, AG Mohod, PS Sawant, PB Bansode and SB Kalse

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Abstract

Tuber crops and millets are nutritionally rich yet underutilized resources with considerable potential for value-added food product development. The present study aimed to evaluate the physicochemical and functional properties of flours obtained from sweet potato, cassava, lesser yam and barnyard millet to assess their suitability for extrusion processing. Proximate analysis revealed that protein content ranged from 1.56 to 10.44%, fat from 0.47 to 3.12%, fiber from 1.72% to 6.12% and carbohydrate from 70.26 to 85.78%. Bulk density varied from 0.48 to 0.63 g/cm³. Functional properties indicated that water absorption index (WAI) ranged from 2.40 to 3.35 g/g, while water solubility index (WSI) ranged from 8.20 to 12.80%. Tuber flours exhibited higher carbohydrate content and WAI, whereas millet flour showed higher protein and fiber content. These complementary characteristics suggest that blending tuber and millet flours can improve both nutritional quality and processing performance. The study concludes that flours of sweet potato, cassava, lesser yam and barnyard millet are suitable for the development of extrusion-based food products.

Keywords: Tuber crops, cassava, sweet potato, lesser yam, barnyard millet, physicochemical properties, extrusion processing

1. Introduction

The demand for convenient, ready-to-eat (RTE) and nutritionally balanced foods has increased significantly due to rapid urbanization and changing dietary patterns. Market projections indicate that the global extruded snacks sector is expected to reach approximately USD 74.5-82.3 billion by 2030, driven by high consumer acceptability and processing versatility (Grand View Research, 2025) [7]. Extrusion cooking, a high-temperature short-time (HTST) process, integrates mixing, cooking and shaping into a single continuous operation. It is widely preferred due to its high productivity, energy efficiency and ability to improve starch digestibility, reduce anti-nutritional factors, and enhance shelf life (Prabha *et al.*, 2021; Yadav *et al.*, 2025) [14, 24].

Tuber crops, including sweet potato (*Ipomoea batatas* L.), cassava (*Manihot esculenta* Crantz), and lesser yam (*Dioscorea esculenta* L.), are important staples rich in carbohydrates (80-85% dry matter). Their starch-rich composition makes them highly suitable for extrusion processing, as starch plays a critical role in gelatinization, melt formation, and expansion during high-temperature processing. Tuber flours exhibit higher water absorption index (WAI), facilitating hydration and heat transfer, which promotes expansion and desirable texture with low bulk density and crispness (Seth *et al.*, 2013; Vargas-Aguilar *et al.*, 2016; Zeng *et al.*, 2024) [16, 21, 25]. However, their low protein and fiber content limits structural strength and nutritional quality. Additionally, their high perishability leads to post-harvest losses of 20-30%, emphasizing the need for value addition (Chandrasekara and Kumar, 2016; Arutselvan *et al.*, 2023) [6, 2].

In contrast, millets such as barnyard millet (*Echinochloa frumentacea*) are rich in protein (10-14%) and dietary fiber (8-16%), along with essential micronutrients (Kalse *et al.*, 2025; Singh *et al.*, 2025) [10, 17]. In extrusion processing, these components influence melt rheology; higher protein and fiber may reduce expansion by disrupting starch matrix formation, but they improve structural stability, texture and nutritional quality. Dietary fiber also affects water solubility index (WSI) and bulk density, influencing product texture and digestibility.

Millet-based blends show improved extrusion performance under optimal moisture (12-20%) and temperature (120-140 °C) Kharat *et al.*, 2019; Yadav *et al.*, 2022; Sudha Devi and Palanimuthu, 2020) [11, 23, 18].

The combination of tuber and millet flours offers a synergistic advantage in extrusion processing. Tuber starch promotes gelatinization, expansion, and structure formation, while millet contributes protein and fiber, enhancing nutritional quality and product strength. This blending improves functional properties such as expansion ratio, bulk density, and water solubility index, while also enhancing digestibility and reducing anti-nutritional factors (Wadikar *et al.*, 2014; Seth *et al.*, 2013; Yadav *et al.*, 2022) [22, 16, 23].

Despite their potential, tuber crops and millets remain underutilized in industrial food applications in India, despite increasing recognition of millets as “Nutri-cereals.” A comprehensive understanding of their physicochemical and functional properties is essential for optimizing extrusion processing. Parameters such as proximate composition, bulk density, water absorption index (WAI), and water solubility index (WSI) play a critical role in determining processing behaviour and product quality (Thilagavathi *et al.*, 2015; Jung *et al.*, 2025; Yadav *et al.*, 2025) [20, 9, 24]. Hence, the present study was undertaken to evaluate the physicochemical and functional characteristics of selected tuber crops (sweet potato, cassava and lesser yam) and barnyard millet flours, with the objective of assessing their suitability for the development of high-quality extruded food products.

2. Materials and Methods

2.1 Materials

Tuber crops such as sweet potato, lesser yam and cassava were procured from University Farm, AICRP on Tuber Crops, Wakawali, Dapoli. Barnyard millet grains were purchased from local markets.

2.2 Methods

2.2.1 Flour Preparation

Tuber crops were washed thoroughly, peeled manually and sliced into 2-3 mm thickness to maximize drying efficiency. Slices were dried in a tray dryer at 60±2 °C until constant weight (moisture <10% w.b.), then milled using a laboratory hammer mill and sieved through a 60-mesh sieve to obtain fine flour. Barnyard millet grains were cleaned, oven-dried at 55 °C, dehusked manually and ground similarly. All flours were packed and stored until further analysis.

2.2.2 Determination of physicochemical properties

2.2.2.1 Proximate analysis

Proximate analysis of the flour samples, including moisture, protein, fat, crude fiber, ash and carbohydrate content, was carried out according to standard methods of AOAC (2000), with all measurements performed in triplicate. Moisture content was determined using the oven drying method, while protein content was estimated by the Micro-Kjeldahl method (Gerhardt GmbH & Co., Germany). Fat content was analyzed using a Soxhlet extraction system (SOXS INFRA SIS 06, Pelican Equipments, India) and crude fiber content was determined from the defatted samples. Ash content was estimated using a muffle furnace. Carbohydrate content was calculated by the difference method. The energy value of the samples was calculated using Atwater factors based on the obtained proximate composition (Iombor *et al.*, 2009) [18].

2.2.2.2 Bulk density

A 50 g flour sample was placed in a 100 mL measuring cylinder and tapped gently until constant volume was achieved. Bulk density (g/cm³) was calculated as flour weight (g) divided by flour volume (cm³) (Oladele and Aina, 2007) [13].

2.2.3 Determination of Functional Properties

In addition to proximate composition, functional properties play a crucial role in determining the behaviour of flours during extrusion processing, particularly influencing water interaction, swelling and structural development. Functional properties of the flours were determined as follows:

2.2.3.1 Water Absorption Index (WAI)

The water absorption index (WAI) was determined in triplicate following the method described by Carine *et al.* (2010) [5]. A 1 g flour sample was suspended in 20 mL distilled water in a tared 45 mL centrifuge tube, stirred with a glass rod and incubated in a water bath at 30 °C for 30 min. The suspension was centrifuged at 3000 rpm for 15 min and WAI was calculated as the weight of sediment per unit weight of original dry sample.

$$\text{WAI (g/g)} = \frac{\text{Weight of sediment (g)}}{\text{Dry sample weight (g)}} \dots \quad (1)$$

2.2.3.2 Water Solubility Index (WSI)

The water solubility index (WSI) was determined in triplicate following the method described by Carine *et al.* (2010) [5]. The supernatant obtained after centrifugation was poured into pre-weighed evaporating dishes, dried overnight at 120 °C, and WSI was calculated as the weight of dried solids per unit weight of original dry sample, expressed as percentage.

$$\text{WSI (\%)} = \frac{\text{Weight of dried supernatant (g)}}{\text{Dry sample weight (g)}} \times 100 \dots \quad (2)$$

2.2.4 Statistical Analysis

Experiments were conducted in triplicate. Data were analyzed using one-way ANOVA followed by Duncan's Multiple Range Test (DMRT) at $p \leq 0.05$ using RStudio (4.5.3). Results are presented as Mean ± SD (n = 3).

3. Results and Discussion

3.1 Physicochemical Composition of Flours

The proximate composition of selected tuber and millet flours is presented in Table 1. The results revealed significant variations ($p \leq 0.05$) among all samples, indicating distinct nutritional profiles of tuber crops and barnyard millet.

3.1.1 Moisture Content

Moisture content varied between 7.69±0.08% and 8.74±0.10%, with sweet potato having the highest moisture as shown in the Fig. 1. All samples maintained moisture below 10%, which is desirable for flour storage stability and extrusion processing. Proper moisture content is essential for extrusion, as it influences starch gelatinization and product expansion (Jung *et al.*, 2025) [9].

3.1.2 Protein Content

Protein content ranged from 1.56 to 10.44%. As shown in the Fig. 1, barnyard millet exhibited significantly higher

protein ($10.44 \pm 0.12\%$) compared to all tuber flours, followed by lesser yam ($4.17 \pm 0.07\%$), sweet potato ($2.31 \pm 0.05\%$) and cassava ($1.56 \pm 0.04\%$). Similar trends have been reported by Kalse *et al.* (2025) [10] and Chandrasekara and Kumar, (2016) [6], for protein content in barnyard millets and tuber crops, respectively. The low protein content in tubers is primarily due to their starch-rich composition (Chandrasekara and Kumar, 2016) [6]. The higher protein content of millet indicates its suitability for protein enrichment in extruded products (Yadav *et al.*, 2022) [23].

3.1.3 Fat Content

Fat content varied significantly from 0.47 to 3.12% as shown in the Fig. 1. Barnyard millet recorded the highest fat content ($3.12 \pm 0.05\%$), while lesser yam had the lowest ($0.47 \pm 0.02\%$). These findings are consistent with previous studies reporting higher fat content in millets compared to tuber crops (Kalse *et al.*, 2025) [10]. The low fat content observed in tuber flours is advantageous for extrusion, as excess fat can hinder expansion by forming complexes with starch and reducing gelatinization efficiency (Chandrasekara and Kumar, 2016; Azam and Pandey, 2023) [6, 3].

3.1.4 Fiber Content

Fiber content ranged from 1.72 to 6.12%. As shown in the Fig. 1, barnyard millet showed significantly higher fiber ($6.12 \pm 0.08\%$) compared to tuber crops. Among tubers, lesser yam ($2.38 \pm 0.05\%$) and cassava ($2.19 \pm 0.04\%$) exhibited moderate values, while sweet potato had the lowest ($1.72 \pm 0.04\%$). Similar results have been reported by Thilagavathi *et al.* (2015) [20], who observed higher dietary fiber in millets compared to starchy tubers. Although higher fiber improves nutritional quality, it may reduce expansion during extrusion by disrupting the starch matrix (Wadikar *et al.*, 2014) [22].

3.1.5 Ash Content

Ash content ranged from 2.14 to 2.92%, with sweet potato showing the highest mineral content ($2.92 \pm 0.06\%$) as shown in the Fig. 1. Lesser yam had the lowest ash content ($2.14 \pm 0.05\%$). The variation in ash content reflects differences in mineral composition, which may influence nutritional value but has minimal direct effect on extrusion behaviour.

3.1.6 Carbohydrates

Carbohydrate content was highest in cassava ($85.78 \pm 0.32\%$), followed by sweet potato ($83.75 \pm 0.30\%$) and lesser yam ($82.51 \pm 0.28\%$), whereas barnyard millet had significantly lower carbohydrate content ($70.26 \pm 0.35\%$) as shown in the Fig. 1. The high starch content is essential for extrusion, as it promotes gelatinization, melt formation and expansion (Seth *et al.*, 2013; Vargas-Aguilar *et al.*, 2016) [16, 21].

3.1.7 Energy Value

Energy content ranged from 349.28 to 354.49 kcal/100 g, with cassava showing the highest energy value due to its higher carbohydrate content as shown in the Fig. 1. The narrow variation in energy values suggests that all flours can serve as good energy sources in formulated products.

3.1.8 Bulk Density

Bulk density ranged from 0.48 to 0.63 g/cm³ and the differences among samples were found to be statistically significant ($p \leq 0.05$) as shown in the Fig. 1. Barnyard millet exhibited significantly higher bulk density (0.63 ± 0.02 g/cm³), while sweet potato had the lowest (0.48 ± 0.01 g/cm³). The lower bulk density of tuber flours indicates a less compact structure and higher porosity, which is favourable for extrusion as it promotes greater expansion and reduced product hardness (Tellez-Morales *et al.*, 2022) [19].

Table 1: Physicochemical properties of Tuber Crops and Barnyard Millet Flours

Parameter	Sweet Potato	Lesser Yam	Cassava	Barnyard Millet
Moisture (%)	8.74 ± 0.10^a	8.33 ± 0.09^b	7.69 ± 0.08^c	7.87 ± 0.09^c
Protein (%)	2.31 ± 0.05^c	4.17 ± 0.07^b	1.56 ± 0.04^d	10.44 ± 0.12^a
Fat (%)	0.56 ± 0.02^c	0.47 ± 0.02^d	0.57 ± 0.02^c	3.12 ± 0.05^a
Fiber (%)	1.72 ± 0.04^d	2.38 ± 0.05^c	2.19 ± 0.04^c	6.12 ± 0.08^a
Ash (%)	2.92 ± 0.06^a	2.14 ± 0.05^c	2.21 ± 0.05^b	2.19 ± 0.06^b
Carbohydrates (%)	83.75 ± 0.30^b	82.51 ± 0.28^c	85.78 ± 0.32^a	70.26 ± 0.35^d
Energy (kcal/100 g)	349.28 ± 1.25^c	350.95 ± 1.30^b	354.49 ± 1.40^a	350.88 ± 1.28^b
Bulk density	0.48 ± 0.01^c	0.52 ± 0.02^b	0.50 ± 0.02^{bc}	0.63 ± 0.02^a

Note: Values are Mean $\pm$ SD (n = 3). Means with different superscripts (a-d) within rows differ significantly ($p \leq 0.05$, DMRT).

The overall results demonstrate distinct differences in the physicochemical properties of tuber flours and barnyard millet flour. Tuber flours were characterized by significantly higher carbohydrate content and lower bulk density, along with comparatively lower levels of protein, fat, and fiber, indicating their starch-rich nature. These properties are favorable for extrusion, as starch plays a key role in gelatinization and expansion, while lower bulk density reflects higher porosity. In contrast, barnyard millet flour

exhibited higher protein, fat, fiber content, and greater bulk density, indicating a more compact structure and superior nutritional profile but relatively lower starch availability. These contrasting yet complementary physicochemical characteristics suggest that blending tuber and millet flours can effectively balance their individual limitations, enabling the development of nutritionally enhanced extruded products with improved structural properties.

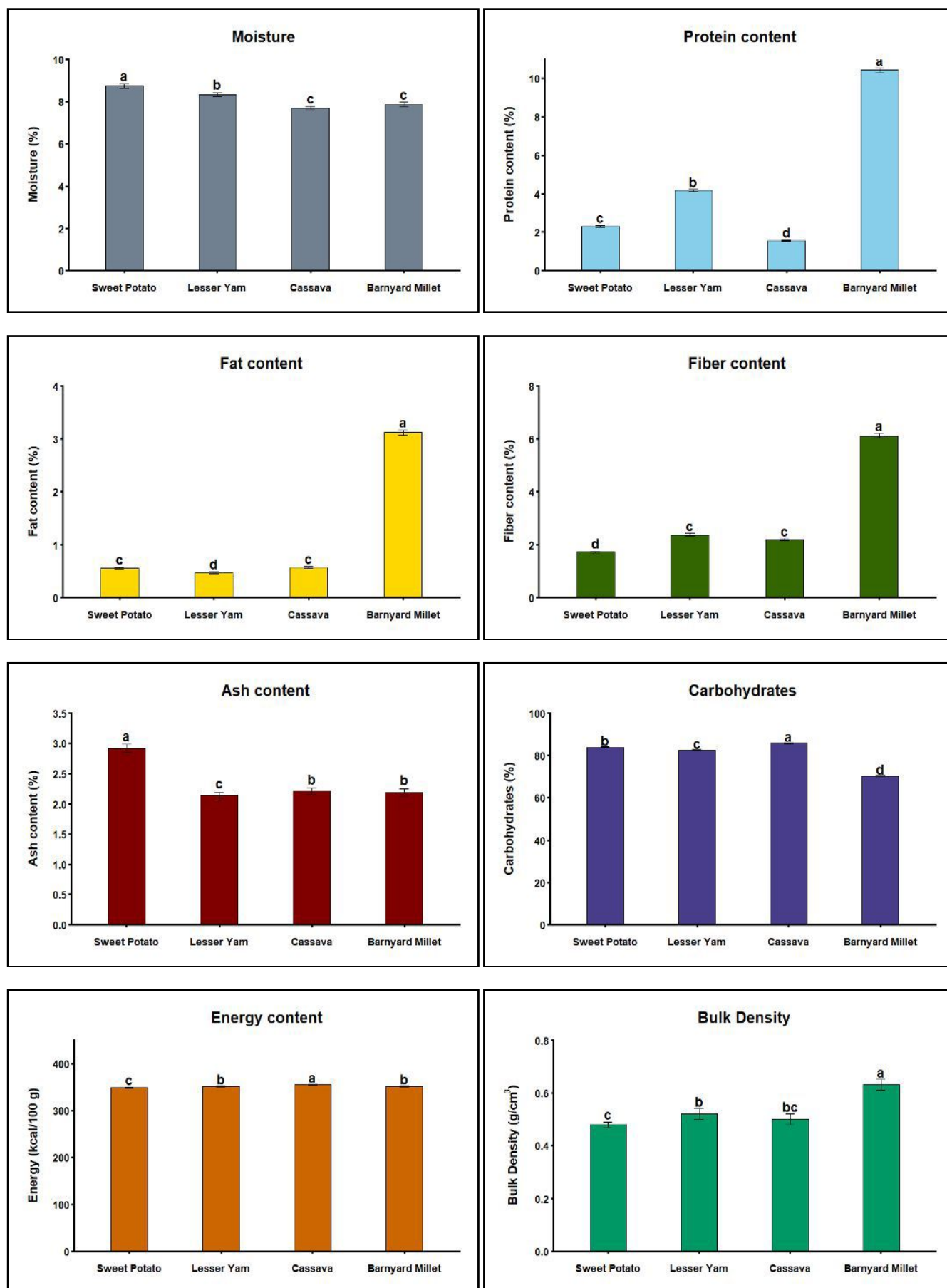


Fig 1: Graphical representation of Physicochemical Composition of Selected Tuber Crops and Barnyard Millet Flours

3.2 Functional Properties

In addition to physicochemical composition, functional properties play a crucial role in determining the behaviour

of flours during extrusion processing. The results are presented in Table 2.

3.2.1 Water Absorption Index (WAI)

WAI values ranged from 2.40 to 3.35 g/g with significant differences observed among the flours ($p \leq 0.05$). Sweet potato flour showed the highest WAI (3.35 ± 0.04 g/g), followed by cassava (3.10 ± 0.04 g/g) and lesser yam (2.95 ± 0.03 g/g), while barnyard millet recorded the lowest (2.40 ± 0.03 g/g) as shown in the Fig. 2. The statistically higher WAI in tuber flours can be attributed to the presence of readily gelatinizable starch, which enhances water-binding capacity. This significantly influences extrusion performance by promoting starch gelatinization, thereby improving expansion and texture of the final product (Tellez-Morales *et al.*, 2022) [19].

3.2.2 Water Solubility Index (WSI)

WSI ranged from 8.20 to 12.80% and the variation among

samples was also statistically significant ($p \leq 0.05$). Sweet potato exhibited the highest solubility ($12.80 \pm 0.15\%$) and barnyard millet the lowest ($8.20 \pm 0.10\%$) as shown in the Fig. 2. The higher WSI values indicate greater solubilisation of starch components due to molecular breakdown during extrusion processing. The statistically significant higher WSI in tuber flours suggests enhanced digestibility and improved crispiness of extruded products (Tellez-Morales *et al.*, 2022) [19].

Table 2: Functional Properties of Tuber Crops and Millet Flours

Property	Sweet Potato	Lesser Yam	Cassava	Barnyard Millet
WAI (g/g)	3.35 ± 0.04^a	2.95 ± 0.03^c	3.10 ± 0.04^b	2.40 ± 0.03^d
WSI (%)	12.80 ± 0.15^a	10.60 ± 0.12^c	11.90 ± 0.14^b	8.20 ± 0.10^d

Note: Values are Mean $\pm$ SD (n = 3). Means with different superscripts (a-d) within rows differ significantly ($p \leq 0.05$, DMRT).

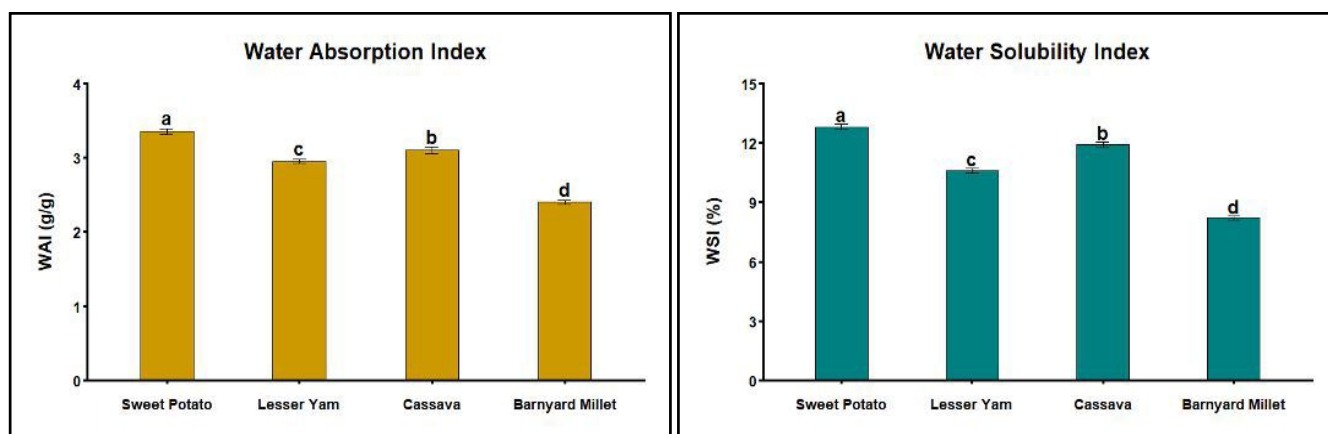


Fig 2: Graphical representation of Functional Properties of Selected Tuber Crops and Barnyard Millet Flours

The functional properties of the flours, particularly water absorption index (WAI) and water solubility index (WSI), showed significant variation among the samples, reflecting their different behaviours during extrusion processing. Tuber flours exhibited higher WAI and WSI values, indicating greater water absorption capacity and enhanced solubilization of starch components, which are associated with improved gelatinization, expansion and desirable textural characteristics in extruded products. In contrast, barnyard millet flour showed lower WAI and WSI, suggesting limited swelling and solubility due to its higher protein and fiber content, which restricts starch availability. These differences in functional properties highlight the complementary roles of tuber and millet flours, where tubers contribute to expansion and texture, while millet enhances structural stability in extruded products.

3.3 Suitability in Extrusion Processing

The combined analysis of physicochemical and functional properties suggests that tuber crops and barnyard millet possess complementary characteristics essential for extrusion processing. Tuber flours contribute high starch content and superior water absorption capacity, facilitating expansion and desirable texture formation. In contrast, barnyard millet enhances protein, fiber and bulk density, contributing to nutritional enrichment and product structure. Therefore, an optimized blend of tuber and millet flours can overcome individual limitations and result in extruded products with improved nutritional quality, functional performance, and consumer acceptability.

4. Conclusion

The present study demonstrated that the selected tuber crops and barnyard millet flour possess distinct yet complementary physicochemical and functional properties suitable for extrusion processing. Tuber flours, characterized by high carbohydrate content and superior water absorption and solubility indices, play a significant role in promoting starch gelatinization, expansion and desirable textural attributes in extruded products. In contrast, barnyard millet contributes higher protein and dietary fiber content along with greater bulk density, which enhances the nutritional profile and structural integrity of the final product. The statistically significant differences observed among the flours ($p \leq 0.05$) further confirm their unique functional roles. Overall, the synergistic combination of tuber and millet flours offers strong potential for the development of nutritionally enriched, value-added extruded food products with improved quality characteristics.

References

1. AOAC. Official methods of analysis. 18th ed. Rev 3. Washington (DC): Association of Official Analytical Chemists; 2010.
2. Arutselvan R, Raja K, Pati K, Chauhan VBS, Nedunchezhyyan M. Tuber crops and their potential in food and nutritional security. In: Pandemics and innovative food systems. 1st ed. Boca Raton: CRC Press; 2023. p. 15-29.
3. Azam M, Pandey S. Effects of extrusion on the nutritional properties of millet-based extruded products: a review. Mysore J Agric Sci. 2023;57(3):1-14.

4. Borku AW. Cassava (*Manihot esculenta* Crantz): its nutritional composition insights for future research and development in Ethiopia. *Discov Sustain*. 2025;6(1):404.
5. Carine S, Kong X, Hua Y. Optimization of extrusion on blend flour composed of corn, millet and soybean. *Pak J Nutr*. 2010;9(3):291-297.
6. Chandrasekara A, Kumar TS. Roots and tuber crops as functional foods: a review on phytochemical constituents and their potential health benefits. *Int J Food Sci*. 2016;2016:1-15.
7. Grand View Research. Extruded snacks market size, share and trends analysis report by product (potato, corn), by distribution channel (supermarkets & hypermarkets, online retailers), by region, and segment forecasts, 2025-2030. 2025.
8. Iombor TT, Umoh EJ, Olakumi E. Proximate composition and organoleptic properties of complementary food formulated from millet (*Pennisetum polystachyum*), soybeans (*Glycine max*) and crayfish (*Euastacus* spp.). *Pak J Nutr*. 2009;8(10):1676-1679.
9. Jung H, Han A, Jeon H, Gu BJ. Extrusion processing in the food industry: principles, process variables, applications, and challenges. *Food Preserv Process Ind*. 2025;24(2):109-118.
10. Kalse SB, Swami SB, Jain SK. Millet: a review of its nutritional content, processing and machineries. *Int J Food Ferment Technol*. 2025;12(1):7-70.
11. Kharat S, Medina-Meza IG, Kowalski RJ, Hosamani AC, Hiregoudar S, Ganjyal GM. Extrusion processing characteristics of whole grain flours of select major millets (foxtail, finger, and pearl). *Food Bioprod Process*. 2019;114:60-71.
12. Nazni P, Shobana DR. Effect of processing on the characteristic changes in barnyard and foxtail millet. *J Food Process Technol*. 2016;7(3):1-9.
13. Oladele AK, Aina JO. Chemical composition and functional properties of flour produced from two varieties of tigernut (*Cyperus esculentus*). *Afr J Biotechnol*. 2007;6(21):2473-2476.
14. Prabha K, Ghosh P, Abdullah S, Joseph RM, Krishnan R, Rana SS, *et al*. Recent development, challenges, and prospects of extrusion technology. *Future Foods*. 2021;3:100019.
15. Saini S, Saxena S, Samtiya M, Puniya M, Dhewa T. Potential of underutilized millets as nutri-cereal: an overview. *J Food Sci Technol*. 2021;58(12):4465-4477.
16. Seth D, Badwaik LS, Ganapathy V. Effect of feed composition, moisture content and extrusion temperature on extrudate characteristics of yam-corn-rice based snack food. *J Food Sci Technol*. 2013;52(3):1830-1838.
17. Singh M, Singh R, Sabharwal PK, Sachchan TK, Sharanagat VS. Barnyard millet: a review of its nutritional, anti-nutritional characteristics, processing and value-added products. *J Food Compos Anal*. 2025;148:108262.
18. Sudha Devi G, Palanimuthu V. Study and development of barnyard millet-based ready-to-eat product. *Int J Curr Microbiol Appl Sci*. 2020;9(10):738-746.
19. Tellez-Morales JA, Hernández-Santos B, Juárez-Barrientos JM, Lerdo-Reyes AA, Rodríguez-Miranda J. The use of tubers in the development of extruded snacks: a review. *J Food Process Preserv*. 2022;46(7):e16693.
20. Thilagavathi T, Kanchana S, Banumathi P, Hemalatha G, Vanniarajan C, Sundar M, *et al*. Physico-chemical and functional characteristics of selected millets and pulses. *Indian J Sci Technol*. 2015;8(S7):147-155.
21. Vargas-Aguilar P. Flours and starches made from cassava (yuca), yam, sweet potatoes and ñampi: functional properties and possible applications in the food industry. *Rev Tecnol Marcha*. 2016;29(5):86-94.
22. Wadikar DD, Kangane SS, Parate V, Patki PE. Optimisation of a multi-millet ready-to-eat extruded snack with digestibility and nutritional perspective. *Indian J Nutr*. 2014;1(1):104.
23. 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. *J Food Process Eng*. 2022;45(9):e14106.
24. Yadav N, Suvedi D, Sharma A, Khanal S, Verma R, Kumar D, *et al*. Extrusion technology in food processing: principles, innovations and applications in sustainable product development. *Food Humanit*. 2025;5:100672.
25. Zeng F, Guo H, Liu G. Processing and utilization technology of root and tuber food. *Foods*. 2024;13(13):2082.