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Optimization of Process Parameters and Effect of Vegetable Powder Incorporation on Physical Quality Attributes of Pearl Millet Extrudates

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Abstract: This study examined the extrusion cooking of pearl millet and maize blends, focusing changes in physical properties and the effects of incorporating spinach and beetroot powders. Single screw extruder powered by 5.0 kW motor and a rotational speed of 1450 rpm was used to produce extrudates. Pearl millet and maize grits having 13% moisture content and mixed in the ratio of 70:30, 50:50, and 30:70 on weight basis were used for extrusion. The study adopted simplex-lattice mixture design and augmented mixture design for blend formulations. The effect of blend proportions was studied on physical properties of extrudates such as expansion ratio, bulk density, volume mass and diameter. Extrudates expansion ratio decreased with higher pearl millet proportions, while maize improved expansion ratio. The expansion ratio was highest for 100% maize (4.64), decreasing with pearl millet addition. Spinach and beetroot powders mixed in the range of 1- 4% also reduced expansion and increased bulk density, attributed to fibre content which disrupt starch gelatinization. Optimal powder levels (3%) resulted in desirable physical properties. Bulk density peaked at 0.057 g cm^{-3} and 0.071 g cm^{-3} for spinach and beetroot powders, respectively, at 4%. Findings highlighted trade-offs between density and expansion when incorporating vegetable powders into extruded products. The study underscores the potential of optimized formulations for nutritious, shelf-stable, and texturally appealing snacks, addressing health-conscious consumer demands while ensuring product quality.

Key words: Extrudates, physical quality, Pearl Millet, Expansion Ratio

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Extrusion technology, recognized as the second-largest food processing method globally, was utilized in this study to develop extruded snack products from pearl millet. India, as the largest producer of pearl millet, offers significant potential for utilizing this nutritious grain in the snack food industry. However, pearl millet poses inherent challenges for processing, including small grain size, dark color, low dough elasticity, and limited shelf life (Patil and Kaur, 2018). This study aimed to address these limitations by leveraging extrusion cooking to create shelf-stable, nutritionally enriched, and palatable snack products.

Extrusion technology is promising method for developing nutritious and shelf-stable products. Pearl millet is nutritionally superior to other cereals like wheat and rice however, its utilization in food processing is very limited. Extrusion cooking is innovative processing technology that has been successfully implemented to produce snack products with starch containing cereals. Extrusion technology may addresses many of the limiting factors of millets through high temperature, pressure, and mechanical shear used in extrusion to stabilize the lipase enzyme, converting insoluble fibres into soluble fibres and increasing the bioavailability of protein present in millets. (Srivastava *et al.*, 2024).

Extrusion process not only enhances the physical and sensory properties of millet products but also improves the digestibility of proteins and starches, making them suitable for a variety of applications such as baby foods, breakfast cereals, and functional snacks. Furthermore, extrusion can reduce antinutritional factors like tannins and phytic acid, which are naturally present in millets, while retaining bioactive compounds under optimized conditions. The process also leads to a desirable texture, expanded structure, and enhanced flavor, making millet-based extrudates appealing to consumers (Srivastava *et al.*, 2024; Oladejo *et al.*, 2020).

Beetroot and spinach are rich in different nutrients like carbohydrate, fibre, minerals especially iron, potassium, magnesium, copper, vitamins A, B6, E (Tocopherol), and C and carotenoids, important for preventing malnutrition and anaemia while carotenoids are potent antioxidant posses multiple benebits for human health. Beetroot is rich source of iron than spinach (Joshi and Mathur, 2010; Kakade, 2015). The carotenoids present in beetroot and spinach can be used to replace artificial colours in food products and may incorporate nutritional benefits also.

Development of extrudates with different kind of cereals, millets and other ingredient like vegetable powder requires optimization of processing parameters like composition of feed mixture, feed moisture, barrel temperature, and screw speed critical to balance nutrient retention and product quality. This technology will provide a sustainable avenue for valorising millets and promoting their inclusion in processed products, aligning with health-conscious consumer trends and addressing food security concerns in developing regions (Bhattarai *et al.*, 2025; Pathare *et al.*, 2024; Diop *et al.*, 2024). The current research attempts to optimise the process for development of extrudates incorporating cereals, millets, and vegetable powders, emphasizing the need to balance nutrient retention and product quality.

Materials and Methods

Extruder consisted of a screw and barrel assembly with a length of 120 mm and a diameter of 34 mm. The screw design included a pitch of 15 mm at the feeding zone and 5 mm at the compression zone, with a die opening of 3 mm diameter for shaping the extrudates. A feeding hopper with a capacity of 1 to 1.25 kg was attached to ensure a steady supply of raw materials. The cutting unit, positioned at the die outlet, included a rotating blade that shaped the extrudates, and an outlet tray was placed below the cutting unit for collecting the final products.

The system was powered by a 3-phase induction motor with a capacity of 5.0 kW and a rotational speed of 1450 rpm. Power transmission to the screw was achieved through a belt-pulley assembly, rotating the screw at 400 rpm, while the cutting blade was driven by a gear assembly. Ergonomic and safety considerations were incorporated into the design, with protective covers installed over the cutting components to ensure operator safety during operation. This setup was specifically designed for extrusion cooking of pearl millet, aiming to enhance its usability and value in the food processing sector. The mechanical and operational parameters of the extruder were optimized to produce nutritionally rich, shelf-stable, and consumer-friendly snack products.

***Development of feed mixture*:** Pearl millet and maize grits were procured from local market. The raw mixtures were conditioned to moisture content of 13% (based on the results of initial trials). Spinach and beetroot powders were prepared by convective air drying of spinach leaves and beetroot shreds at 60°C for 12 h and grinded to make powder. Table-1 shows the proportional composition of composite grit samples used for extrusion, where the blends consist of varying ratios of pearl millet and maize. Sample A is 100% maize, Sample E is 100% pearl millet, and Samples B, C, and D represent grit mixtures of 30:70, 50:50, and 70:30 (pearl millet : maize), respectively. Sample A with 100% maize was treated as control for optimization of blend ratio for pearl millet extrudates. Results of earlier studies suggested that incorporation of vegetable powders compete for moisture present in cereals and their high fibre content may also negatively affect the extrudate physical parameters such as expansion and density (Khan *et al*. 2015; Ying *et al*., 2021). Therefore, rice grits were added to compensate the negative effect of vegetable powder incorporation on millet extrudates. 100% rice extrudates was treated as control in this case. Rather than the strict simplex-lattice mixture design (where the sum of components is constant), this experiment adopted augmented mixture design or mixture-process variable design commonly used in food material blend formulations. The incorporation of spinach and beetroot powders into the extrudates at varying concentrations (1 to 5%) follows a structured approach to evaluate their effects on dependent variables which were expansion ratio and bulk density. The study followed Simplex-lattice mixture design where all component levels were predefined at fixed intervals (0%, 30%, 50%, 70% and 100%).

Expansion ratio: Expansion is an important physical parameter of the snack food. It may be described as the degree of puffing by the sample when it exits the extruder. Ratio of diameter of extrudate and the diameter of die was used to express the expansion of extrudate (Fan, 1996; Ainsworth *et al*., 2006). Ten extrudate were selected at random during collection of each of the extruded samples, and allowed to cool to room temperature. The extrudates diameter was then measured by vernier calliper.

ER = Diameter of extrudate/Diameter of die hole

***Bulk density*:** The bulk density was calculated by measuring the actual dimensions of the extrudates according to the method described by Ding *et al*., 2005. The diameter and length of the extrudates were measured using vernier caliper. The bulk density was then calculated using the following formula. where: M= Mass (g), D= diameter (cm), L= length (cm). Ten replicates of extrudates were randomly selected and an average taken.

$$BD = 4\ m/\pi\ d^2 L$$

where, m = sample mass (g); d = diameter of sample (mm); L = Length of sample (mm)

***Mass and volume*:** The volume is the amount of space the object occupies. The volume of extrudates (cylinder) was calculated by the formula $\pi r^2 h$, where r is the radius of the extrudate (radius of circular base) and h is the height (length) of the extrudate. (diameter / 2) is the radius of the base (d = 2 x r). The diameter and length of the extrudates were measured using vernier caliper. Mass was calculated by multiplying density (g/cm^3) with volume (cm^3) as per the method of Avadhanulu and Kshirsagar, (2008).

Extrudate volume = πr2h

where, r = radius of sample (cm); h= Length/ height of sample (cm)

***Moisture*:** Moisture were estimated according to AOAC approved methods of AOAC, 1995.

Results and Discussion

Results indicated that extrusion cooking effectively transformed the pearl millet and maize blends into well-structured extrudates, with significant effects observed of blend ratios and process conditions. The initial moisture content of extrudates decreased with an increasing proportion of pearl millet, ranging from 8.14% to 5.75%. The conditioning of raw mixtures to 13% moisture before extrusion was critical in ensuring proper plasticization and flow during the extrusion process. Results highlight the influence of the blend composition on the extrusion efficiency and product quality. Notably, the addition of maize improved the processability of pearl millet, mitigating its inherent limitations such as low elasticity and small grain size due to lack of optimum starch content essential for puffing and development of porous texture during extrusion. Results further indicated that the expansion ratio (ER) of extrudates was highest (4.64) for 100% maize, while the inclusion of pearl millet in increasing ratio reduced the ER, reaching the lowest value (3.73) for 100% pearl millet.

Similarly, bulk density was inversely related to the expansion ratio, being lowest for 100%

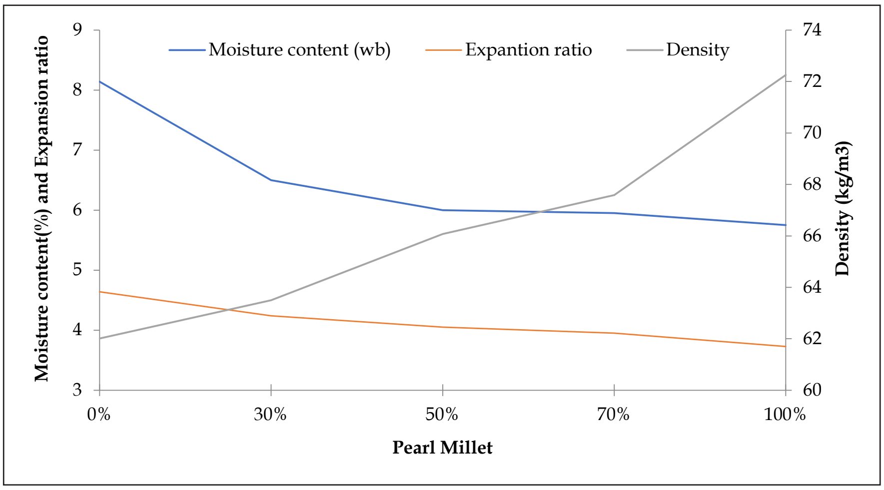

Fig. 1. Effect of Pearl millet concentration in feed mixture on extrudates physical properties.

maize extrudates (62.01 kg/m³) and increasing to 72.25 kg/m³ as the proportion of pearl millet increased. These findings indicate that up to 70% pearl millet can be effectively incorporated into the formulation without compromising the quality of the extrudates, balancing nutritional benefits with desirable physical properties.

Incorporation of spinach and beetroot powder in extrudates: Rice grits were mixed in the different blends of pearl millet and maize (as detailed in materials and methods). The quantity of rice grits was kept constant (5g 100g^{-1} blend). The proportion of spinach and beet root powder was varied from 1 to 4 g 100g^{-1} blend) The results of incorporating spinach and beetroot powders into pearl millet: maize based extrudates revealed distinct effects on the physical properties of the products. For spinach powder, increasing concentrations (1 to 4%) caused a progressive reduction in volume, diameter, and expansion ratio of extrudates, indicating reduced puffing capacity. The control sample had the highest expansion ratio (7.98) and the largest volume (8.88 cm³).

At 1% spinach powder, the expansion ratio dropped significantly to 4.13, with a further decrease to 2.95 at 3% concentration. Interestingly, at 4% spinach powder, a slight recovery in volume and diameter was observed, with the expansion ratio reaching 3.43, possibly due to adjustments in structural integrity at this concentration. Bulk density consistently increased with added spinach powder, peaking at 0.05 g cm^{-3} at 4%, reflecting a denser, more compact structure. Generally, the addition of fibrous plant materials, such as spinach and beetroot powders, leads to a decrease in the expansion ratio, as the high fibre content

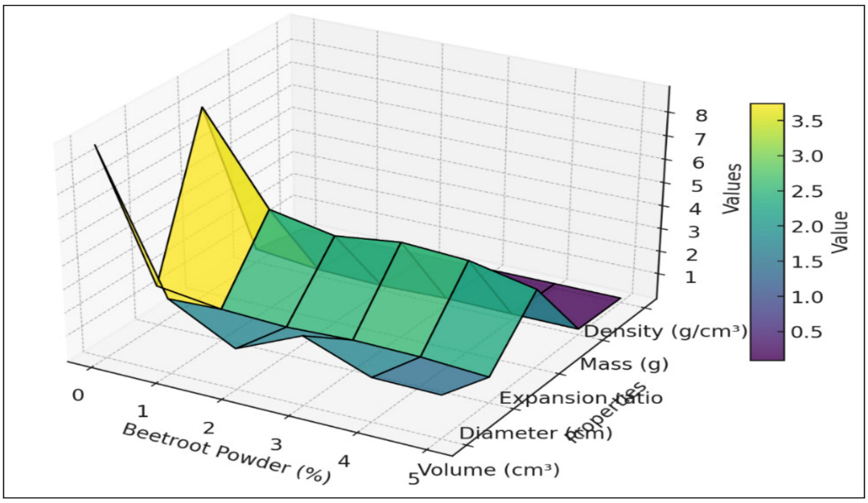

Fig. 2. Effect of spinach powder incorporation on extrudates physical properties.

competes with starch for moisture, disrupting starch gelatinization and reducing puffing potential during extrusion.

For beetroot powder, similar trends were observed. The control sample (100% rice) had the highest expansion ratio (7.98) and volume (8.88 cm³). The addition of 1% beetroot powder reduced the expansion ratio to 4.20 and volume to 3.10 cm³. These values further decreased with increased concentrations, reaching an expansion ratio of 3.28 and a volume of 1.74 cm³ at 5%. However, a slight increase in expansion ratio (4.02) and volume (2.86 cm³) was observed at 3% concentration, suggesting a brief optimization point before subsequent decreases at higher levels. Bulk density increased progressively with the addition of beetroot powder, with the highest density recorded at 4% (0.0701 g cm^{-3}).

Overall, the addition of both spinach and beetroot powders reduced the expansion potential of the extrudates while increasing their bulk density, attributed to the disruption of starch gelatinization and expansion caused by fiber and bioactive components in the powders. This indicates a trade-off between nutritional enhancement and desirable physical properties. Spinach and beetroot powders in concentrations of up to 3% may be optimal for balancing these factors, as higher levels lead to significantly denser and less expanded extrudates. These findings highlight the need for precise formulation to achieve the desired texture, volume, and nutritional value in functional extruded snacks.

The observed effects of adding spinach and beetroot powders to pearl millet and maize extrudates align with findings from other studies on the incorporation of vegetable powders into extruded products. Generally, the addition of fibrous plant materials, such as spinach and beetroot powders, leads to a decrease in the expansion ratio, because high fiber content competes with starch for moisture, which negatively affect starch gelatinization and its conversion into soft rubbery molten stage to get expanded and hence, reducing air incorporation and puffing potential during extrusion process. This is consistent with the work of Khan *et al*. (2015), who reported a similar reduction in expansion and volume in extrudates when incorporating vegetable powders like spinach, due to their higher fiber content and lower starch availability for expansion.

Furthermore, the observed increase in bulk density with higher powder concentrations corroborates the findings of other researchers, such as Ying *et al*. (2021), who noted that incorporating fruit and vegetable powders results in denser extrudates due to the displacement of starch with more compact, fibrous material. The increased density in the presence of beetroot and spinach powders suggests that the powders may provide structural reinforcement, leading to less aeration and a more compact structure, which has also been documented in extruded products with added vegetable powders by Peressini *et al*. (2015). However, the slight recovery in expansion ratio and volume at 3% concentrations for both powders, particularly

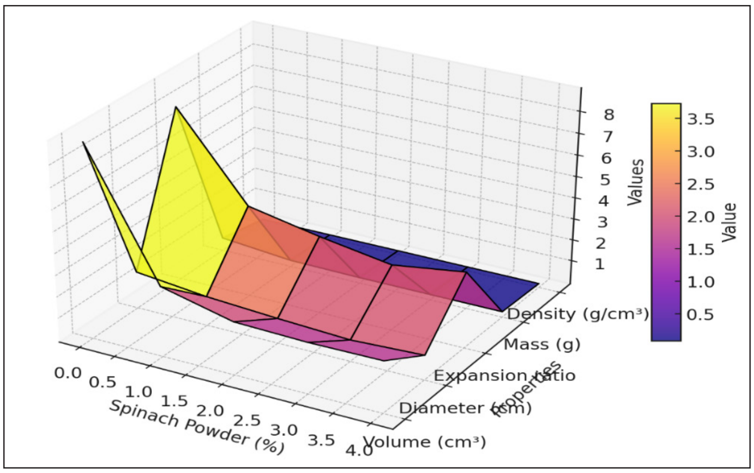

Fig. 3. Effect of beetroot powder incorporation on extrudates physical properties.

with beetroot powder, may reflect an optimal level of powder addition, where the powders contribute to the physical properties of the extrudates without overly inhibiting starch expansion. This observation is supported by similar studies, such as that by Korkerd *et al*. (2025), who found that certain concentrations of functional ingredients like beetroot and spinach could enhance the texture and sensory appeal of extrudates, providing a balance between expansion and density.

Thus, while higher concentrations of spinach and beetroot powders consistently reduce expansion and increase density, there is a clear threshold where the incorporation of these powders can enhance the physical properties without significantly compromising the textural qualities of the extrudates. The findings from this study are in line with current literature, emphasizing the importance of optimizing powder levels to balance nutritional enrichment with desirable physical characteristics in extruded snack foods (Diop *et al*., 2024). Results suggested that while higher concentrations of powders reduce expansion and increase density, there is an optimal concentration that maximizes both nutritional benefits and desirable product texture. Hence, the findings of the current study are supported by existing literature, emphasizing the importance of optimizing powder levels for achieving the right balance in extruded snacks.

Conclusion

In conclusion, the incorporation of spinach and beetroot powders into pearl millet and maize extrudates significantly impacted the physical properties of the products. Increasing concentrations of both powders resulted in reduced expansion ratios and increased bulk density, likely due to the competeing of moisture and disruption of starch gelatinization by the added fibers. These findings align with previous studies that demonstrate the effect of vegetable powders on extrusion behavior, where high-fiber ingredients tend to compact the structure and reduce puffing potential. However, a slight recovery in expansion and volume at specific concentrations (3%) suggests that there is an optimal level of powder addition that balances physical properties with desirable product texture. However, addition of small proportion of high starch containing material such as rice along with maize shown to substitute the negative effect on expansion and density and developed well-structured crunchy product in spite of addition of millet and vegetable powder which have reported negatively affecting extrudate physical properties. Moreover, vegetable powdwer are sourse of many carotenoid pigments provide rich colour and nutritional goodness along with millets. Results highlight the potential for producing functional, fiber-enriched extrudates that are both nutritionally beneficial and texturally acceptable, suggesting the feasibility of utilizing spinach and beetroot powders in extruded snack production. The study emphasizes the potential of pearl millet-maize extruded products as nutritious, shelf-stable snack options, catering to growing health-conscious consumer demands. Future research could focus on further optimizing powder concentrations to achieve the best combination of nutritional value, texture, and sensory appeal in extruded products.

References

Ainsworth, P., Ibanoglu, S., Plunkett, A., and Ozer, E.A. 2006. Physical and sensory evaluation of a nutritionally balanced gluten-free extruded snack. *Journal of Food Engineering* 75(4): 469-472.

AOAC. 1995. Official Methods of Analysis (20th ed.). Association of Official Analytical Chemists, Washington, D.C.

Avadhanulu, M.N., and Kshirsagar, P.G. 2008. A Textbook of Engineering Physics. S. Chand & Company Pvt. Ltd. New Delhi. p 1189

Bhattarai, R.R., Joshi, T.J., Sruthi, N.U., Rao, P.S., and Johnson, S. 2025. Effects of extrusion cooking on nutritional and health attributes of sorghum and millets: Special reference to protein and starch digestibility. *International Journal of Food Science and Technology.* DOI: 10.1093/ijfood/vvae093.

Ding, Q., Ainsworth, P., Tucker, G., and Marson, H. 2005. The effect of extrusion conditions on the physiochemical properties and sensory characteristics of rice-based expanded snacks. *Journal of Food Engineering* 66: 283-289.

Diop, M., Ndiaye, C., Lubaale, J., Séne, A., Gaye, M.L., and Traoré, D. 2024. Application of extrusion cooking to enhancing mineral bioaccessibility in millet flour enriched with natural fortificants for vulnerable populations. *Food and Nutrition Sciences* 15(12): 1186. DOI: 10.4236/fns.2024.1512086.

Fan, J., Mitchell, J.R., and Blanshard, J.M.V. 1996. The effect of sugars on the extrusion of maize grits: The role of the glass transition in determining product density and shape. International Journal of Food Science and Technology 31(1): 55-65.

Joshi, P., and Mathur, B. 2010. Bioavailability of iron from the leaf powders of dehydrated less utilized green leafy vegetables. *Asian Journal of Experimental Biological Sciences* 1(4): 845-854.

Kakade, S. 2015. Utilization of beetroot (*Beta vulgaris* L.) leaves powder in cereals-based extruded product. *International Research Journal of Engineering and Technology* 2(3): 2153-2161.

Khan, M. A., Mahesh, C., Semwal, A. D., & Sharma, G. K. 2015. Effect of spinach powder on physico-chemical, rheological, nutritional and sensory characteristics of chapati premixes. *Journal of Food Science and Technology* 52(4): 2359-2365. DOI: 10.1007/s13197-013-1198-1.

Korkerd, S., Wanlapa, S., Puttanlek, C., Uttapap, D., and Rungsardthong, V. 2015. Expansion and functional properties of extruded snacks enriched with nutrition sources from food processing by-products. *Journal of Food Science and Technology* 53(1): 561-570. DOI: 10.1007/s13197-015-2039-1.

Oladejo, A.A., Abah, C.R., Ishiwu, C.N., Obiegbuna, J.E., and Oladejo, A.A. 2020. Nutritional composition, functional properties, and food applications of millet grains. *Asian Food Science Journal* 14(2): 30124. DOI: 10.9734/afsj/2020/v14i230124.

Pathare, A.M., Singhal, R.S., Rao, B.D., and Gokhale, J.S. 2024. Extrusion inhibits lipolytic enzymes in pearl millet (*Pennisetum glaucum*) flour. *Innovative Food Science & Emerging Technologies* 93: 103605. DOI: 10.1016/j.ifset.2024.103605.

Patil, S.S., and Kaur, C. 2018. Current trends in extrusion: Development of functional foods and novel ingredients. *Food Science and Technology Research* 24(1): 23-34.

Peressini, D., Foschia, M., Tubaro, F., and Sensidoni, A. 2015. Impact of soluble dietary fibre on the characteristics of extruded snacks. *Food Hydrocolloids* 43: 73-81. DOI: 10.1016/j.foodhyd.2014.05.016.

Srivastava, S., Jain, D., and Gupta, N. 2024. Optimization of extrusion parameters and feed composition for enhanced quality of millet extrudates. *Annals of Arid Zone* 63(2). DOI: 10.56093/aaz.v63i2.146682.

Ying, D., Sanguansri, L., Cheng, L., and Augustin, M.A. 2021. Nutrient-dense shelf-stable vegetable powders and extruded snacks made from carrots and broccoli. *Foods* 10(10): 2298. DOI: 10.3390/foods10102298.

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