Indian Journal of Agricultural Sciences **95** (9): 1028–1035, September 2025/Article
https://doi.org/10.56093/ijas.v95i9.164378

Valorization of grape pomace and okara for the development of nutritionally and functionally enriched extrudates: A circular economy approach in snack production

SINDHU P M[1], SHRUTI SETHI[1]*, BINDVI ARORA[1], ALKA JOSHI[1],
CHAVLESH KUMAR[1] and LEKSHMI S G[2]

ICAR-Indian Agricultural Research Institute, New Delhi 110 012, India

Received: 2 February 2025; Accepted: 1 September 2025

ABSTRACT

With the growing emphasis on sustainable development and the circular economy, the valorization of agro-industrial biomass has emerged as a critical strategy to enhance both environmental and economic sustainability. The present study carried out during 2023–24 at ICAR-Indian Agricultural Research Institute, New Delhi reported the development of a novel corn-based extruded snack fortified with grape pomace (GP), a phenolic-rich byproduct of winemaking and okara, an insoluble residue from soybean [*Glycine max* L. (Merr)] milk and tofu production. Extrusion process optimization was carried out using a Box-Behnken Design (BBD) within the framework of Response Surface Methodology (RSM), considering grape pomace content, feed moisture, and screw speed as independent variables. Optimal extrusion conditions were identified as 7.5% grape pomace inclusion, 11% feed moisture, a screw speed of 300 rpm, and a barrel temperature of 117–121°C, yielding a desirability value of 0.76. Under these conditions, the optimized product demonstrated desirable characteristics, including an expansion ratio of 1.92, porosity of 0.72, total phenolic content of 784.69 mg GAE/100 g, antioxidant activity (FRAP) of 182.47 μmol TE/g, and a sensory acceptability score of 6.54. In addition to improved textural and sensory attributes, the incorporation of GP and okara significantly enhanced the nutritional and functional quality of the product. This work not only valorizes underutilized agro-industrial residues but also contributes to the development of nutritionally improved and environmentally sustainable ready-to-eat snacks.

Keywords: By-product, Extrusion, Ready-to-eat snacks, Sustainability

Valorization of agro-industrial byproducts is rapidly assuming importance in the wake of an increasing environmental consciousness. Adaption of valorization of biomass promises to reduce the carbon footprint and enhance sustainability in the food industry. Unexplored resources in this field is grape pomace (GP), which was considered an unpreferred process residue of the winery process, accounting for massive volumes of waste stream generation for the wine industry. GP, which accounts for about 20–25% of the grape weight in the winemaking or juice extraction process, is composed of grape skins, seeds, stems, and sometimes a small portion of pulp (Davila *et al.* 2017). Traditionally considered a by-product to be discarded, GP has lately gained attention due to its potential health benefits and versatility. Okara, an insoluble by-product from the preparation of soybean (*Glycine max* L.) milk or tofu is a massive problem in the industry. This can create new challenges requiring solutions that utilize it effectively. One kg of soybeans that are used in making tofu or soybean milk generates 1.2 kg of wet (fresh) okara which has a moisture content of 70–80% (Colletti *et al.* 2020).

Both soybean-derived okara and GP have nutritional and functional attributes, their integration into food products is a challenge. Exploring and successfully integrating these secondary raw materials could be a new route towards innovation and sustainable solutions for the food industry and will aid in utilizing its bioactive compounds as well. Okara is a nutrient-dense by-product, rich in protein and dietary fiber, whereas grape pomace is abundant in polyphenols and anthocyanins. The combination of these two by-products in extruded snacks offers a synergistic approach in developing a functional food with enhanced nutritional and bioactive properties. This is a first attempt to valorize two underutilized by-products while enhancing the nutritional and functional quality of ready-to-eat products. This promotes sustainable industrial practices and

[1]ICAR-Indian Agricultural Research Institute, New Delhi; [2]Agriculture Development and Farmers Welfare, Thiruvananthapuram, Kerala. *Corresponding author email: docsethi@gmail.com

spurs innovation, which can also help achieve Sustainable Developmental Goal (SDG) 9 (Industry, Innovation, and Infrastructure) and SDG 12 (Responsible Consumption and Production). Extrusion process is a popular technology for manufacturing numerous convenience foods because of its flexibility, cost-effectiveness, energy efficiency, and better shelf stability of extruded products. The global 'Puffed and Extruded Snack Market' reached a value of USD 50.78 Billion in 2023 and is expected to reach USD 119.31 Billion by 2031 at a compound annual growth rate (CAGR) of 15.3% from 2024 to 2031 (LP Information 2024). These snacks are popular among young customers due to their affordability and attractive appearance. Extrusion causes significant alterations to native starch, which includes reduced relative crystallinity and molecular breakdown, often interacting with lipids in the mixture (Singh *et al.* 2007).

This research aims to formulate a ready-to-eat extruded snack using a combination of maize flour, okara, GP, sugar, and cocoa. All other ingredients and process conditions were maintained constant, as determined from previous experiments. The level of GP, screw speed of the extruder, and feed moisture were optimized. The present study highlights the effects of GP and okara inclusion on the physicochemical and functional properties of the extruded snack.

MATERIALS AND METHODS

The present study was carried out during 2023–24 at ICAR-Indian Agricultural Research Institute, New Delhi. Pusa Navrang grapes were sourced from the vineyards at the ICAR-Indian Agricultural Research Institute, New Delhi. Harvested grapes were washed, blanched in hot water (5 min), and crushed in a hydraulic press (Johnston Automation Co., New Delhi) for juice extraction. For okara preparation, soybeans sourced from the market were utilized for milk extraction. The soybeans underwent boiling, overnight soaking in water, dehulling, grinding, and milk extraction followed by separation. The wet pomace and okara were dried at 60°C for 6 h to achieve a moisture content of 8.50%. Then both were finely powdered using a Bajaj grinder (220–240 V, 500 W) and sieved through a BSS 36 sieve to attain uniform-sized particles ($\leq$420 μm). The powdered material was packed in airtight zip pouches (low density polyethylene) and stored at a low temperature (4 ± 1°C) for subsequent use. Maize flour was obtained from a local mill, while sugar and cocoa were acquired from a nearby supermarket. High-quality analytical-grade chemicals from Sigma-Aldrich were used.

The feed mixture for extrusion was prepared using maize flour, GP, okara, sugar, and cocoa. Okara, sugar, and cocoa powder concentrations in the mix were fixed at 10%, 10%, and 1%, respectively, while GP was varied at 2.5%, 5%, and 7.5% on a maize flour replacement basis (Table 1). The feed moisture (FC) was kept at 11%, 13%, and 15% while screw speed (SS) was set at 200, 250, and 300 rpm (Table 2). After moisture addition, the mixture was packed in zip pouches and kept undisturbed overnight for uniform moisture distribution. Extrusion was carried out using a twin-screw extruder (BTPL-Lab model twin screw extruder, Kolkata, India). The formulations were fed into the extrusion system using a feeder. The temperature of the extruder barrel was maintained within the range of 117–121°C with a fixed feeder speed set at 30 rpm. A circular die (5 mm dia) was fixed on the extruder. The extrusion trials were performed as per the process variables mentioned in Table 2. Subsequently, the extrudates were manually collected, cut into uniform sizes, and then dried in an oven at 60°C for 15 min. The dried extrudates were carefully packed in airtight zip pouches and stored for subsequent analysis.

The expansion ratio (ER) was determined as the ratio of the diameter of the extrudate to that of the die (Thymi *et al.* 2005). The porosity of the samples is calculated using the provided equation (Dogan and Kokini 2007).

$$\text{Porosity (E)} = \frac{\text{Apparent Density-Piece Density}}{\text{Solid Density}}$$

Total phenolic content was estimated by following the methodology of Sulaimankhil *et al.* (2021); Total antioxidant activity (TAA) was assessed by FRAP method (Sethi *et al.* 2020). The sensory analysis of the GP extrudates was

Table 1 Formulation of the blend used in extrusion

Runs	Maize flour (%)	Grape pomace (%)	Okara (%)	Sugar (%)	Cocoa powder (%)
1	76.5	2.5	10	10	1
2	71.5	7.5	10	10	1
3	74.0	5.0	10	10	1
4	71.5	7.5	10	10	1
5	74.0	5.0	10	10	1
6	71.5	7.5	10	10	1
7	74.0	5.0	10	10	1
8	74.0	5.0	10	10	1
9	74.0	5.0	10	10	1
10	74.0	5.0	10	10	1
11	74.0	5.0	10	10	1
12	76.5	2.5	10	10	1
13	71.5	7.5	10	10	1
14	76.5	2.5	10	10	1
15	74.0	5.0	10	10	1
16	74.0	5.0	10	10	1
17	76.5	2.5	10	10	1

Table 2 Coded values of independent variables and their ranges used for experiment design

Independent variables	Factors	Levels		
		-1	0	+1
Grape pomace (%)	A	2.5	5.0	7.5
Screw speed (rpm)	B	200	250	300
Feed moisture (%)	C	11	13	15

done using a thirty-membered trained panel, panellists who underwent 2 h training session to familiarize themselves with the attributes and scaling methods for the GP extrudates being studied. The evaluation utilized a nine-point hedonic rating scale (1-dislike extremely; 2-dislike very much; 3-dislike moderately; 4-dislike slightly; 5-neither like nor dislike; 6-like slightly; 7-like moderately; 8-like very much; 9-like extremely). Sensory parameters evaluated included colour and appearance, texture, taste, flavour, and overall acceptability, following the methodology described by Ranganna (2007). The investigation into the influence of factors on the response was conducted using a Box-Behnken design (BBD) featuring three levels and three factors. GP (%), SS (rpm), and FM (%) were the three independent variables. Table 3 provides the coded and actual levels of these variables. Total 17 experiments were performed, incorporating five replicates at the centre point. Numerical optimization was performed using Design Expert software. Additionally, the optimal response was validated. Each experiment was conducted in duplicate and the outcomes underwent analysis of variance (ANOVA) using Design-Expert version 13.0 (Statease Inc., Minneapolis, USA). The statistical significance of the model terms was assessed by computing the F-value at confidence level of 95% ($p < 0.05$).

RESULTS AND DISCUSSION

The present study highlighted the inclusion of GP and okara in a corn based extrudates and its impact on the physical and biochemical properties. The expansion ratio (ER) of the extrudates varied from 1.40 and 2.20 (Fig. 1A and 1B). Notably, the SS exhibited a positive influence on the ER, while the GP content and FM displayed negative influences. An increased ER was observed due to higher SS. The interactive effect of GP and FM positively affected the extrudates' ER, contrasting with the negative interactions observed between other variable pairs. The analysis of the experimental data employing multiple linear regression resulted in a second-order polynomial model representing the ER in coded variables (Table 1). Empirical data underwent regression analysis, employing the quadratic model for fitting, as depicted below:

$$Y = \beta_0 + \sum_{i=1}^{3} \beta_i X_i + \sum_{i=1}^{3} \beta_{ii} X_i^2 + \sum_{i=1}^{2} \sum_{j=i+1}^{3} \beta_{ij} X_i X_j$$

In the provided equations, Y denotes the dependent variable, with β_0, β_i, β_{ii} and β_{ij} representing the regression coefficients for the constant, linear, quadratic, and interactive effects, respectively. X_i and X_j represent the independent variables.

The regression equation relating to independent variables and the ER of the extrudates is given by the equation below. The independent variables in the equation were represented by A, B, and C namely GP, SS, and FM, respectively.

Expansion ratio = 1.96-0.2419A+0.0813B-0.0595C-0.0029AB+0.0179AC-0.0504BC-0.1683A2-0.0783B2-0.0830C2

Furthermore, the quadratic effect of independent variables on the ER was noted to be negative. A substantial reduction in the product's ER was evident with an elevation in GP content. This can be ascribed to the high insoluble fiber (IDF) content of GP as previous studies by Jing and Chi (2013) and Fleischman *et al.* (2016) have indicated

Table 3 Experimental design and response attributes of the extruded samples

Run	Independent variable			Product responses				
	Grape pomace powder (%)	Screw speed (rpm)	Feed moisture (%)	Expansion ratio	Porosity	Phenols (mg GAE/100 g)	FRAP (µmol TE/g)	Sensory score
1	5(0)	250(0)	13(0)	1.93	0.80	379.00	136.20	4.74
2	7.5(1)	300(1)	13(0)	1.49	0.68	794.00	208.75	4.80
3	7.5(1)	250(0)	15(1)	1.85	0.67	541.75	133.51	5.05
4	2.5(-1)	250(0)	15(1)	1.41	0.62	813.75	215.77	5.59
5	5(0)	250(0)	13(0)	1.71	0.80	513.50	168.93	5.80
6	2.5(-1)	300(1)	13(0)	1.57	0.63	790.75	214.33	4.90
7	5(0)	250(0)	13(0)	1.87	0.68	569.25	174.46	5.71
8	5(0)	250(0)	13(0)	2.20	0.66	518.25	165.28	5.31
9	7.5(1)	250(0)	11(-1)	1.95	0.65	524.75	166.45	5.14
10	5(0)	200(-1)	11(-1)	1.89	0.65	548.50	166.23	4.53
11	2.5(-1)	200(-1)	13(0)	1.98	0.69	567.00	138.06	6.73
12	5(0)	300(1)	11(-1)	2.02	0.70	364.50	137.61	6.64
13	7.5(1)	200(-1)	13(0)	1.40	0.73	749.75	211.45	3.83
14	5(0)	300(1)	15(1)	1.81	0.83	339.50	133.11	5.41
15	2.5(-1)	250(0)	11(-1)	1.87	0.59	547.75	170.59	5.58
16	5(0)	200(-1)	15(1)	1.64	0.67	570.75	170.68	4.75
17	5(0)	250(0)	13(0)	2.05	0.66	414.00	135.72	7.19
CD ($p<0.05$)				0.17	0.06	113.97	22.74	0.60

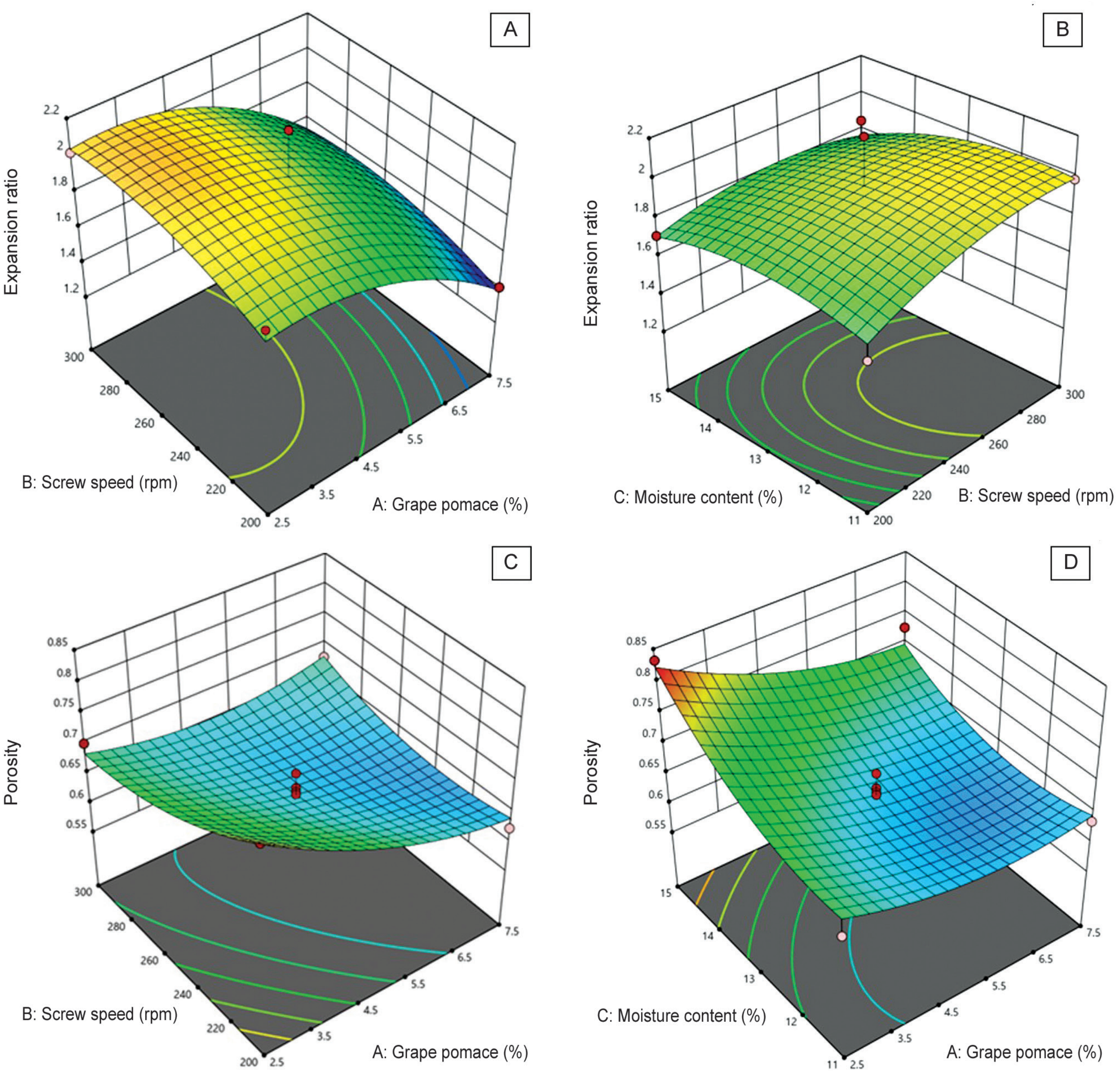

Fig. 1 3D response curves of extrudates. A, Effect of screw speed and grape pomace content on expansion ratio of the extrudates; B, Effect of moisture content and screw speed expansion ratio of the extrudates; C, Effect of screw speed and grape pomace content on porosity of the extrudates; D, Effect of moisture content and grape pomace content on porosity of the extrudates.

that elevated IDF content results in reduced ER and denser products. Observations revealed that at lower FM levels, ER was higher, but higher moisture levels yielded denser and tougher products. This is linked to the decreasing viscosity due to higher moisture content and delayed melt solidification thereby reducing the ER, as noted by Obradovic *et al.* (2014). Baik *et al.* (2004) study on barley extrudate properties also supported this trend, with the expansion index increasing as moisture content decreased. Kokini *et al.* (1992) reported that the optimal moisture level utilized in our study facilitated proper gelatinization of starch and contributed to the production of better-expanded products with elevated moisture levels from 11–15%. Thymi *et al.* (2005) suggested that radial expansion is highly dependent on melt elasticity, where an increased FM content during extrusion alters the amylopectin molecular structure, reducing melt elasticity and subsequently decreasing the radial ER. Increasing the SS results in a higher ER demonstrating a clear relationship between speed levels and expansion. This corresponds with the conclusions drawn by Sandrin *et al.* (2018), who observed that the greatest ER was achieved at the highest SS during the extrusion cooking of corn grits. Gulati *et al.* (2016) also supported this trend, concluding that SS positively impacted both the ER and overall expansion in the extruded products. An additional observation pertains to the interaction between FM and GP levels. Higher GP levels combined with increased FM led to a reduction in the ER observed in the extrudates.

Consequently, meticulous control of FM and GP levels in the feed formula is imperative to attain the desired puffy property in the extrudate.

The porosity values of the extrudates fall within the range of 0.55–0.85. The linear effects of GP and SS on the extrudate porosity exhibited a negative influence, while FM content had a positive impact. The interactive effect of GP and SS was positive. Additionally, the quadratic effect of all variables was significant, with a positive influence on porosity. The regression equation describing the link between independent variables and the extrudate porosity is provided below:

$$\text{Porosity} = 0.6474 - 0.0415A - 0.0195B + 0.0467C + 0.0388AB - 0.0204\,AC - 0.0381BC + 0.0275A2 + 0.0262\,B2 + 0.038$$

The porosity of the extrudates exhibited a decrease with an increase in GP content, potentially due to the presence of insoluble dietary fiber (IDF) in the pomace, resulting in a less porous and denser product. Notably, the FM content had a significant impact on porosity, contrary to the usual expectation of decreased porosity with increased moisture content in the feed. In this case, porosity increased linearly with higher FM, likely due to the well-defined moisture range set in the feed formula from preliminary trials, contributing to these results (Fig. 1C and 1D). The increase in FM ensures more effective water absorption by starch granules, promoting their swelling and subsequent gelatinization during extrusion. This enhanced gelatinization, in turn, leads to the formation of a more open and porous structure within the extrudates, as noted by Yagci and Gogus (2008). Higher moisture content can act as a plasticizer, reducing melt viscosity and promoting bubble expansion, which increases porosity (Zambrano *et al.* 2022).

The phenolic content of the extrudates ranges from 300–900 mg GAE/100 g (Fig. 2A and 2B) and their values

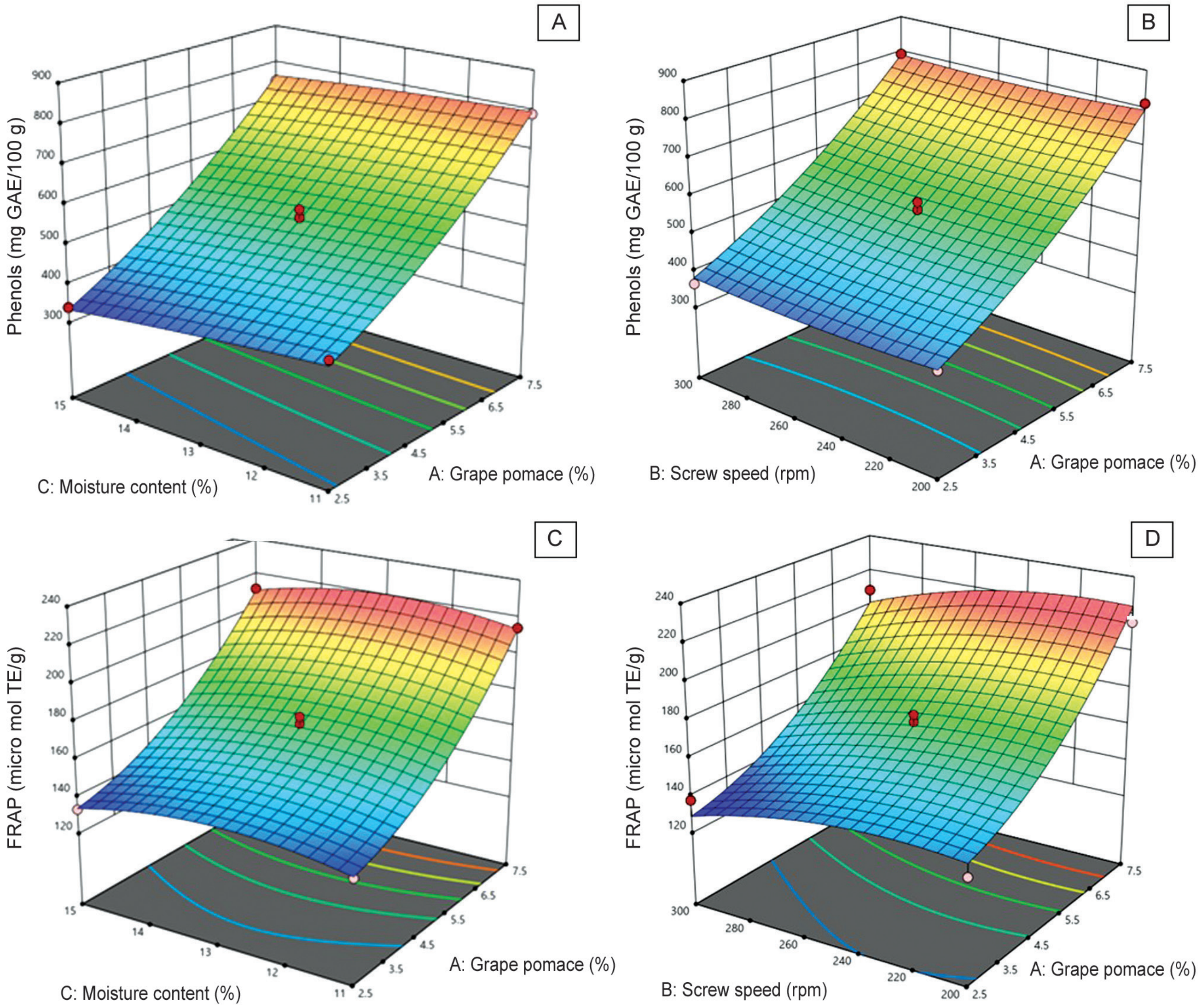

Fig. 2 3D response curves of extrudates. A, Effect of screw speed and grape pomace content on phenolic content of the extrudates; B, Effect of screw speed and grape pomace content on phenolic content of the extrudates; C, Effect of moisture content and grape pomace content on antioxidant activity (FRAP) of the extrudates; D, Effect of screw speed and grape pomace content on antioxidant activity (FRAP) of the extrudates.

fit in the quadratic model with a high significance (p<0.05). The equation in terms of coded factors is given below:

$$\text{Phenols} = 541.70 + 206.41A - 1.22B - 24.75C - 1.31AB + 8.38AC + 8.00BC + 35.68A^2 + 10.43B^2 - 3.88C^2$$

The impact of GP on the phenolic content of the extrudates revealed a positive linear effect, while both the quadratic effects of GP and SS were also positive. GP showed positive interactive effects with FM and SS, while the interaction of FM with SS was also positive. However, the remaining interactions had a negative influence. The expected increase in phenolic content with higher GP levels aligns with the well-established knowledge that GP is rich in polyphenols, as noted by Yu and Ahmedna (2013).

The FRAP-measured antioxidant activity of the extruded product exhibited a significant impact, with a positive linear effect from GP, while the effects of FM and SS were negative (Fig. 2C and 2D). The combined interaction effect of all three independent variables demonstrated a negative influence on antioxidant activity and the quadratic effect of GP alone was positive, contrasting with the negative effects observed for the other two variables. The coded equation representing these relationships is provided below:

$$\text{FRAP} = 168.61 + 38.46A - 9.21B - 1.47C - 2.11AB - 0.0675AC - 0.6975BC + 13.42A^2 - 7.44B^2 - 8.37C^2$$

The antioxidant activity of the extrudates ranged between 120–240 µmol TE/g, and increased as GP content was elevated. FM in the specified experimental range was non-significant ($p \leq 0.05$) affecting antioxidant activity of extrudates and the same effect of non-significance on extrudates' antioxidant activity was found at different SS. The increased antioxidant activity is contributed by the increased phenolic content present in the pomace, which in turn influences the antioxidant activity of the extrudates.

Supplementary Fig. 1 shows the extrudates made from the 17 runs. The sensory evaluation scores for overall acceptability were regarded as an indicator of the product's desirability. These scores, ranging from 3–8 as illustrated in Fig. 3A and 3B, were fitted to a 2FI model their values demonstrated high significance at $p \leq 0.05$. The regression equation, expressed in terms of coded factors, describes the impact of independent variables on the sensory score and is provided below:

$$\text{Sensory score} = 5.39 - 0.6075A + 0.2925B - 0.4350C - 0.6725AB + 0.1775AC - 0.6825BC$$

The mathematical model indicated that the overall acceptability of the extrudates was adversely impacted by independent variables such as GP and FM, while SS exerted a positive influence. This can be ascribed to the positive effect of SS on product crispness, resulting in a crisper product with increasing SS and consequently positively influencing the sensory score of the extrudates. The interaction effect of FM and GP content had a positive impact on the sensory score, while the other two interactions yielded negative effects. Consumer acceptance decreased with an increase in GP levels due to its effects on extrudate colour, texture and a decrease in ER and crispness. FM alone had a relatively minor effect on sensory scores, but the interaction effect of FM and GP content significantly reduced overall product acceptance, affecting characteristics such as texture, hardness, and colour of the extrudates, as observed in the study by Karun *et al.* (2023).

To enhance the production of a novel extruded snack incorporating GP, the optimization of independent variables such as FM and SS was carried out within specified ranges. The objective was to maximize GP content while optimizing

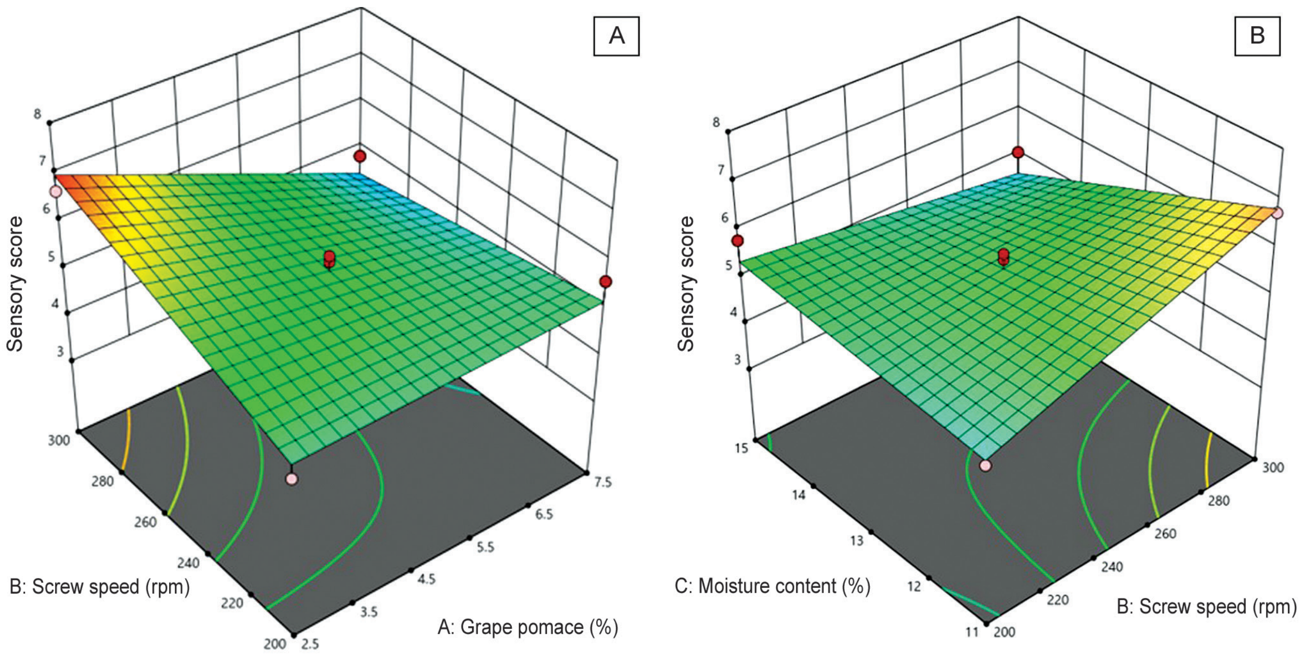

Fig. 3 3D response curves of sensory scores of extrudates. A, Effect of screw speed and grape pomace content; B, Effect of moisture content and screw speed.

responses like the crispness, sensory score, phenols, FRAP and anthocyanin while keeping ER and porosity within desired limits. The identified optimal process parameters were determined to be 7.5% GP, a SS 300 rpm, and a FM of 11%. Subsequent extrusion cooking at these optimized parameters yielded results that closely matched the predicted values, affirming the validity and effectiveness of the experimental design model proposed. The model predicted values for the optimized extrudate were expansion ratio (ER) of 1.56, porosity of 0.72, total phenolic content of 796.07 mg GAE/100 g, FRAP antioxidant activity of 197.06 μmol TE/g, and a sensory score of 5.24. The corresponding experimental (actual) values obtained were an ER of 1.92, porosity of 0.72, phenolic content of 784.69 mg GAE/100 g, FRAP value of 182.47 μmol TE/g, and sensory acceptability score of 6.54. The close agreement between predicted and experimental values, especially the higher sensory score and expansion ratio observed in practice, confirms the effectiveness and desirability of the optimized extrusion conditions. There is a great opportunity to exploit GP and okara as functional food ingredients in extruded snacks with increasing environmental concerns and the global trend toward sustainability. Beyond their role as functional additives, the inclusion of these byproducts transforms the extruded product into a functional food, offering additional health benefits due to its richness in phenols, antioxidants, flavonoids, and anthocyanins. While sensory and textural properties were somewhat impacted by the added grape pomace and okara, consumer acceptability is hardly impacted. After all, ER, and porosity reduced only to a minor extent from being alone maize extrudates the values are still within good acceptable ranges. This exemplifies the two-edged benefit of keeping consumer acceptance but improving functional benefits to the product.

In this study, extruded snacks enriched with grape pomace and okara were successfully developed, demonstrating the potential to valorize agro-industrial by-products into functional foods. Optimal extrusion conditions; 7.5% grape pomace inclusion, 11% feed moisture, a screw speed of 300 rpm, and a barrel temperature of 117–121°C yielded a desirability value of 0.76, indicating a balanced improvement in nutritional, functional, and sensory properties. This work highlights a sustainable approach to producing nutrient-rich, ready-to-eat snacks while contributing to circular economy practices.

REFERENCES

Baik B-K, Powers J and Nguyen L T. 2004. Extrusion of regular and waxy barley flours for production of expanded cereals. *Cereal Chemistry* **81**(1): 94–99. https://doi.org/10.1094/CCHEM.2004.81.1.94

Colletti A, Attrovio A, Boffa L, Mantegna S and Cravotto G. 2020. Valorisation of by-products from soybean [*Glycine max* (L.) Merr.] processing. *Molecules* **25**(9): 2129. https://doi.org/10.3390/molecules25092129

Davila I, Robles E, Egues I, Labidi J and Gullon P. 2017. The biorefinery concept for the industrial valorization of grape processing by-products. *(In) Handbook of Grape Processing By-products,* pp. 29–53. Academic Press. https://doi.org/10.1016/B978-0-12-809870-7.00002-8

Dogan H and Kokini J L. 2007. Psychophysical markers for crispness and influence of phase behaviour and structure. *Journal of Texture Studies* **38**(3): 324–54. https://doi.org/10.1111/j.1745-4603.2007.00100.x

Fleischman E F, Kowalski R J, Morris C F, Nguyen T, Li C, Ganjyal G and Ross C F. 2016. Physical, textural and antioxidant properties of extruded waxy wheat flour snack supplemented with several varieties of bran. *Journal of Food Science* **81**(11): E2726–33. https://doi.org/10.1111/1750-3841.13511

Gulati P, Weier S A, Santra D, Subbiah J and Rose D J. 2016. Effects of feed moisture and extruder screw speed and temperature on physical characteristics and antioxidant activity of extruded proso millet (*Panicum miliaceum*) flour. *International Journal of Food Science and Technology* **51**(1): 114–22. https://doi.org/10.1111/ijfs.12974

Jing Y and Chi Y J. 2013. Effects of twin-screw extrusion on soluble dietary fibre and physicochemical properties of soybean residue. *Food Chemistry* **138**(2–3): 884–89. https://doi.org/10.1016/j.foodchem.2012.12.003

Karun G, Sukumar A, Nagamaniammai G and Preetha R. 2023. Development of multigrain ready-to-eat extruded snack and process parameter optimization using response surface methodology. *Journal of Food Science and Technology* **60**(3): 947–57. https://doi.org/10.1007/s13197-022-05390-8

Kokini J L, Chang C N and Lai L S. 1992. The role of rheological properties on extrudate expansion. *Food Extrusion Science and Technology* **740**: 631–52. https://doi.org/10.001/j.910-26287.1992.01221.x

LP Information. 2024. *Global Puffed and Extruded Snack Market Growth 2024–2030*. January 12, 2024. Retrieved from https://www.lpinformationdata.com/reports/1008610/puffed-extruded-snack

Obradovic V, Babic J, Subaric D, Ackar D and Jozinovic A. 2014. Improvement of nutritional and functional properties of extruded food products. *Journal of Food and Nutrition Research* **53**: 189–206.

Ranganna S. 2007. *Handbook of Analysis and Quality Control for Fruit and Vegetable Products*, 4th edn. Tata McGraw Hill Publishing Company Ltd.

Sandrin R, Caon T, Zibetti A W and de Francisco A. 2018. Effect of extrusion temperature and screw speed on properties of oat and rice flour extrudates. *Journal of the Science of Food and Agriculture* **98**(9): 3427–36. https://doi.org/10.1002/jsfa.8855

Sethi S, Joshi A, Arora B, Bhowmik A, Sharma R R and Kumar P. 2020. Significance of FRAP, DPPH and CUPRAC assays for antioxidant activity determination in apple fruit extracts. *European Food Research and Technology* **246**: 591–98. https://doi.org/10.1007/s00217-020-03432-z

Singh S, Gamlath S and Wakeling L. 2007. Nutritional aspects of food extrusion: A review. *International Journal of Food Science and Technology* **42**(8): 916–29. https://doi.org/10.1111/j.1365-2621.2006.01309.x

Sulaimankhil Z, Sethi S, Sharma R R, Verma M K and Dahuja A. 2021. Influence of aqueous hexanal on quality of 'Royal Delicious' apple during cold storage. *Acta Physiologae Plantarum* **43**: 134–44. https://doi.org/10.1007/s11738-021-03301-6

Thymi S, Krokida M K, Pappa A and Maroulis Z B. 2005. Structural properties of extruded corn starch. *Journal of Food Engineering* **68**(4): 519–26. https://doi.org/10.1016/j.

jfoodeng.2004.07.002

Yagci S and Goguş F. 2008. Response surface methodology for evaluation of physical and functional properties of extruded snack foods developed from food-by-products. *Journal of Food Engineering* **86**(1): 122–32. https://doi.org/10.1016/j.jfoodeng.2007.09.018

Yu J and Ahmedna M. 2013. Functional components of grape pomace: Their composition, biological properties and potential applications. *International Journal of Food Science and Technology* **48**: 221–27. https://doi.org/10.1111/j.1365-2621.2012.03197

Zambrano Y, Contardo I, Moreno M C and Bouchon P. 2022. Effect of extrusion temperature and feed moisture content on the microstructural properties of rice-flour pellets and their impact on the expanded product. *Food Research International* **157**: 111254. https://doi.org/10.1016/j.foodres.2022.111254