

Optimisation of a Multi-Millet Ready-to-Eat Extruded Snack with Digestibility and Nutritional Perspective

Research Article

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Abstract

A blend of flours of Finger millet, Pearl millet and Foxtail millet was attempted to get a nutritionally superior product. The in-vitro starch digestibility of the flours was studied and the blend of flours was used to develop an extruded ready-to-eat snack using response surface methodology. The aim was to achieve a product with optimum extrusion in terms of expansion ratio and a best flour blend to have better digestibility and the overall sensory acceptance of the product. The central composite rotatable design with flours of three millets (as independent variables) was studied with 20 design points against the three crucial responses namely, expansion ratio, digestibility and sensory acceptability of the extruded product. The quadratic models were best fit in case of digestibility and expansion ratio while for the sensory score linear model was found suitable. The equations obtained were validated for the predictability of responses. The proximate composition, mineral and fibre profile of the product revealed its nutritional strength. The product being a ready-to-eat snack has excellent potential for its commercialisation as the raw materials are not costly and are readily available locally.

Keywords: Finger millet; Pearl millet; Foxtail millet; Digestibility; Extrusion; RSM

Introduction

The millets are a group of highly variable small-seeded grasses, widely grown around the world as cereal crops or grains for both human food and fodder. These are important crops in semiarid and tropical regions of the world (in particular in Afro-Asian countries) due to their resistance to pests and diseases, short growing season and productivity under heat and drought conditions. The Finger millet (*Eleusine coracana*), Pearl millet (*Pennisetum glaucum*) and Foxtail millet (*Setaria italica*) are good source of carbohydrate, dietary fibre and micronutrients. The rejuvenated nutritional strengths of millets have made them functional grains. Though different millets are available with localised areas of production and usage, their wide spread use can only be possible through food technological approaches leading to globally acceptable products, so that the health benefits of millets reach to everyone everywhere and can be a booster for the growers of millets.

In past few decades, the consumption of foods mainly based on refined flours has resulted in reduced intake of dietary fibres and other micronutrients as a result of urbanized life styles, changes in practices and level of physical activity. This may be associated with rising affluence induced by developmental transition contributed to increasing prevalence of overweight/obesity [1]. Of late consumer inclination towards foods based on multiple grains has brought the research on multiple grains in for front. However, millets are still considered as the food for poor and traditional consumers because of non-availability of ready-to-use or ready-to-eat convenience food products from the millet [2,3] and also the limited efforts made to diversify its food uses by application of traditional and contemporary food-processing methods [4]. Modifying the staple sources of starch itself by incorporating millets through technological approaches can deliver substantiated health benefits while retaining consumer appeal. The combination of low cost and nutrient rich millets has

not been much explored. Extrusion technology, well-known in the plastics industry, has now become a widely used technology in the agri-food processing industry, where it is referred to as extrusion-cooking. With the help of shear energy, exerted by the rotating screw, and additional heating of the barrel, the food material is heated to its melting point or plasticizing point [5]. It is one of the contemporary food processing technologies applied for preparation of variety of snacks, speciality and supplementary foods [6] and offers advantages of preparation of ready-to-eat foods of desired shape, size, texture and sensory characteristics at very low processing cost [7]. Extrusion cooking also reduces the anti-nutritional factors, renders the product microbiologically safe and enhances the consumer acceptability [8]. Besides, extrusion cooking of millets offers additional benefits; namely, inactivation of lipases and enhancing the shelf-life of its products. It may be noted that keeping quality of the millet products is normally very poor because of its relatively higher proportion of lipid contents and presence of active lipase in the millet, which facilitates onset of hydrolytic rancidity during storage [9]. The digestibility of nutrients must be known in order to evaluate fully the significance of nutrient concentration. The chemical composition of millets varies with the cultivars, agronomic conditions and soil fertility level, but a generalised composition can be considered for most practical purposes. The carbohydrates are crucial for extrusion and the three millets in the present context have it in the range of 63-73%. An efficient combination of these millets to achieve best possible extrusion with the set conditions and to optimise a product with better digestibility, micronutrient profile and sensory attributes was the aim of the present work.

Materials and Methods

Raw material & its processing

Finger millet (*Eleusine coracana*), Pearl millet (*Pennisetum glaucum*) and Foxtail millet (*Setaria italica*) were procured from local market. The millet grains were cleaned, aspirated manually and ground into fine flour in a table top laboratory mill (City mill, M/s Patel Industries, India). The flour was sieved through 60 mesh sieve for the further processing/ analysis.

Chemicals

All the chemicals and reagents used for analysis were of AR grade and procured from M/s. s d fine Chemicals Ltd, Mumbai and M/s. Himedia Laboratories Ltd, Mumbai and M/s. Merck specialties Pvt. Ltd, Mumbai.

Extrusion Method (Product Preparation)

Extrusion of samples was performed using a co-rotating twin-screw extruder (Basic Technology Pvt. Ltd., Kolkata, India). The main drive of extruder was provided with a 7.5 HP motor (400 V, 3 ph, 50 cycles). The output shaft of worm reduction gear was provided with a torque limiter coupling. The barrel of the extruder received the feed from a co-rotating variable speed feeder. The barrel was provided with two electric band heaters and two water cooling jackets. The die was required to be fixed on the face of barrel by a screw nut tightened by a special wrench provided. The die diameter was selected at 3mm for better expansion such product (Table 1). The twin screw extruder

Table 1: Parameters of Twin Screw Extruder.

No.	Parameter	Value
1.	Screw Speed	350 rpm
2.	Extruder Torque	10.8
3.	Heater Temperature (Barrel)	120 °C
4.	Final Mass temperature	124±2 °C
5.	Cutter Speed	18 rpm

was kept on for 30 min to stabilize the set temperatures and samples were then poured in to feed hopper and the feed rate was adjusted to 4 kg/h for easy and non-choking operation. The product was collected at the die end and kept at 60 ± 0.5 °C in a hot air oven (M/s. Scientific Works, New Delhi) for 4 hours to remove extra moisture from it. The samples were packed in PFP (paper/Al foil/polythene) bags for further analysis.

Experimental Design

A statistical software Design expert® version 8.0 from Statease Inc; USA, was used to construct as well as to analyze the design. Finger millet, Pearl millet and Foxtail millet flours were taken as independent variable with digestibility, expansion ratio and sensory score as the responses. The central composite rotatable design (CCRD) based on these three independent variables resulted in 20 experimental combinations. Such designs are found to be quite useful in several process/product optimisations [10,11]. The center points were selected with ingredients at levels expected to yield satisfactory experimental results. The α -values in the design outside the ranges were selected for rotatability of the design [12]. The independent variables with their actual value ranges taken for study are given in Table 2. The regression analysis of the responses was conducted by fitting suitable models represented by equations 1 & 2.

$$Y = \beta_0 + \sum_{i=1}^n \beta_i X_i \quad (1)$$

$$Y = \beta_0 + \sum_{i=1}^n \beta_i X_i + \sum_{i=1}^n \beta_{ii} X_i^2 + \sum_{i \neq j=1}^n \beta_{ij} X_i X_j \quad (2)$$

where, β_0 was the value of the fitted response at the center point of the design, i.e., point (0, 0, 0); β_i , β_{ii} and β_{ij} were the linear, quadratic and cross product (interaction effect) regression terms respectively and 'n' denoted the number of independent variables. The formulations that were fed to the extruder are given in Table 3.

Product (extruded snack) characteristics

Proximate analysis of the extrudate was carried out by standard AOAC procedures [13,14]. Carbohydrate content was estimated by difference and the calorific value of the extrudates was determined by computation. *Final mass temperature* was measure using Ray-Temp 38 Infrared thermometer (digital gun (www.etiltd.com)). The expansion ratio (ER) of the dried extruded snack was measured as the ratio of the cross-sectional areas of the extruder rods to that of the die. The radial expansion of the extrudates was measured using a Vernier Calliper and the average of 6 measurements was recorded.

$$ER = \frac{\text{Cross sectional area of the extrudate}}{\text{Cross sectional area of the die}}$$

Table 2: Ranges and levels of independent variables used in the experimental design(CCRD) in terms of actual values.

Factor	Name	Unit	Minimum	Maximum	-1 Actual	+1 Actual	Mean	Std. Dev.
A	Finger millet	g	13.18	46.82	20.00	40.00	30.00	8.26
B	Foxtail millet	g	13.18	46.82	20.00	40.00	30.00	8.26
C	Pearl millet	g	23.18	56.82	30.00	50.00	40.00	8.26

Table 3: CCRD for Multigrain blends used for extrusion & their properties.

Std. order	Run Order	Finger millet, g (A)	Foxtail millet,g (B)	Pearl millet, g (C)	Digestibility mg/g	Expansion Ratio	Sensory score
8	1	40.00	40.00	50.00	5.118	6.91	7.35
5	2	20.00	20.00	50.00	2.098	8.12	7.21
11	3	30.00	13.18	40.00	3.977	7.12	7.94
2	4	40.00	20.00	30.00	6.245	5.71	7.46
16	5	30.00	30.00	40.00	3.529	6.08	7.15
20	6	30.00	30.00	40.00	4.395	8.72	7.34
19	7	30.00	30.00	40.00	4.202	6.83	7.22
9	8	13.18	30.00	40.00	2.151	6.66	6.79
1	9	20.00	20.00	30.00	3.624	7.33	7.32
15	10	30.00	30.00	40.00	4.271	7.01	7.55
4	11	40.00	40.00	30.00	5.371	6.61	6.76
7	12	20.00	40.00	50.00	2.907	5.71	6.99
18	13	30.00	30.00	40.00	2.891	6.89	7.49
17	14	30.00	30.00	40.00	3.866	5.93	7.38
10	15	46.82	30.00	40.00	4.121	6.83	7.58
12	16	30.00	46.82	40.00	4.615	4.91	6.19
6	17	40.00	20.00	50.00	4.664	10.12	7.75
3	18	20.00	40.00	30.00	4.731	8.12	6.35
14	19	30.00	30.00	56.82	4.381	10.89	7.72
13	20	30.00	30.00	23.18	6.852	9.632	6.78

In-vitro Starch digestibility: It was determined in the samples using pancreatic α -amylase [15]. 50mg sample was weighed, dispersed in 1.0ml of 0.2M phosphate buffer, 0.5ml of pancreatic α -amylase (1.25mg) added and incubated at 37 °C for 2h. After the incubation period, 2ml of 3-5 dinitrosalicylic acid reagents was added and the mixture heated for 5min in a boiling water bath. The solution was cooled and volume made up to 25ml with distilled water, filtered prior to measurement of the absorbance at 550nm against blank. Maltose was used as the standard and the graph plotted. The values were expressed as mg of maltose released per gram of sample.

Elemental analysis

The elemental analysis of samples was done by ICPOES (JY-Horiba, Ultima model). 5g exactly weighed samples was calcinated at 550 °C for 6 hours. The ashes were then diluted in nitric acid finally making a volume of 100ml with acid strength of 2.5% and filtered. For analysis, standard operating protocol for JY ICPOES was used with Win-IMAGE software for quantitative analysis. The nebulised sample was transferred to argon plasma. It was decomposed; atomised and ionised thereby the atoms and ions are excited. The intensity of the light emitted when the atoms/ions return to lower levels of energy was measured. Each element emits light at a characteristic wavelength and these lines were used to quantitative analysis after calibration.

Sensory Evaluation

All the combinations of the Multi-millet snack were evaluated for their sensory score consisting colour, aroma, taste, texture and overall acceptability on 9-point hedonic scale by semi-trained panel

of 15 members. The 9-point Hedonic scale grading was as follows: 9=Excellent, 8=Very good, 7=Good, 6= Good above fair, 5= Fair, 4= Fair above poor, 3= Poor, 2= Very poor, 1= extremely poor. The statistical analysis for significance was carried out using IBM® SPSS® 19 trial version software.

Results and Discussion

The extrusion process being a high temperature short time (HTST) process, the temperature and equilibrium moisture of the flour plays an important role in gelatinization process which in turn influences the texture, physical characteristics such as expansion ratio, appearance and determines the sensory quality of the product. Extrusion of different millet such as kodomillet [16], foxtail millet [17], finger millet [18], pearl millet [19] have been reported mainly reported the extrusion parameters and the physicochemical properties of the extruded product. The combination of two millets and other blends' extrusion also has been reported [20,21]. The recommended moisture by extruder manufacturer was 10-16% depending upon the material being extruded. The multigrain flour mix was extruded with 10-14% equilibrated moisture and at temperature of 110-120 °C. The good extrusion in terms of expansion ratio occurred with 11% moisture and 110 °C, Hence, the same was used for further studies. The standardised parameters of extrusion process are represented in Table 1. The extrusion cooking, in general improves the sensory and nutritional profile of the processed native material. Digestibility being one of the important criteria for the nutritional output from a starchy product, it was analysed in the fresh flours of the three millets viz. finger millet, pearl millet and foxtail millet. Results revealed that

among the millets, in-vitro starch digestibility of finger millet flour was high as compared to that of foxtail millet and pearl millet i.e. 7.32mg/g, 5.77 mg/g, and 4.675 mg/g, respectively. The higher digestibility of finger millet can be attributed to comparatively higher starch content and lower gelatinisation initiation temperature. The low starch digestibility of pearl millet has also been reported [22]. The in-vitro starch digestibility of raw flours of finger millet was reported in the range 7.2-9.9 mg/g [23].

For forming a nutritionally superior multi-millet blend, the pearl millet being the better source of minerals was kept at higher level, while finger millet and foxtail millet were varied at similar levels. The initial trials of multimillet extrusion with optimised conditions were done with flours in the ratio as Pearlmillet (40): Foxmillet (30): Fingermillet (30) to get insight of the extrusion pattern of the blend.

For optimising the best proportion of the millet flours, statistical designing of the experiment using CCRD was done. Response Surface Methodology (RSM) uses polynomial model with the help of least square technique to fit the response behaviour with minimum possible points. Ozer et al. [24] used RSM to analyze the effect of screw speed (220-255rpm), feed moisture (10-11.5%) feed rate (22-30kg/h) on the physical properties of nutritionally balanced extruded snacks food during its development. Larrea et al. [25] evaluated the effects of operational parameters of extrusion on functional properties during preparation of biscuit-like cookies incorporating orange pulp. In the present study, for developing a multi-millet extruded snack, total of 20 design points were obtained for a CCRD with three independent variables. Table 3 represents the various combinations studied and the responses observed. The extrusions were carried at 110 °C and product analysed for ER and sensory score. The responses studied had direct effect on the quality and were dependent directly on specific composition of the product. The expansion ratio is a primary attribute to judge quality of the snack product and suitability of raw material for extrusion. The effect of all the variation in levels of independent factor in the design, on different response can be seen in the predictive graphs (Figure 1) for each response of the product with optimum level.

The in-vitro starch digestibility ranged from 2.8 to 6.8mg/g in the experimental space. Finger millet and foxtail millet had significant effect on digestibility of the flour blend. The increase in the level of finger millet leads to proportional increase in digestibility of the flour blend and vice versa. The effect was reverse in case of pearl millet while the foxtail millet marginally improved the digestibility with increase in its level. It has been reported [20] extrusion of sorghum, pearl millet or finger millet along with mung beans and milk powder blend; however the in-vitro carbohydrate digestibility was not different markedly from the unprocessed blends. While the carbohydrate digestibility of cereals and millets was reported [26] to be improved substantially post extrusion. However, effect of blending the multiple millets on their digestibility has not been dealt wherein the present work (Figure 2) reveals that the blending may affect the digestibility of the flours adversely. The in-vitro digestibility of the optimised blend was increased post extrusion so as to get a multimillet blend with better digestibility. Deshpande and Poshadri [27] reported on foxtail millet composite flours extrusion however digestibility aspect was not reported.

The ER of the extruded product ranged between 4.91 and 10.89. It was influenced in descending order by pearl, foxtail and finger millets. The increase in pearl millet level proportionately increased the ER

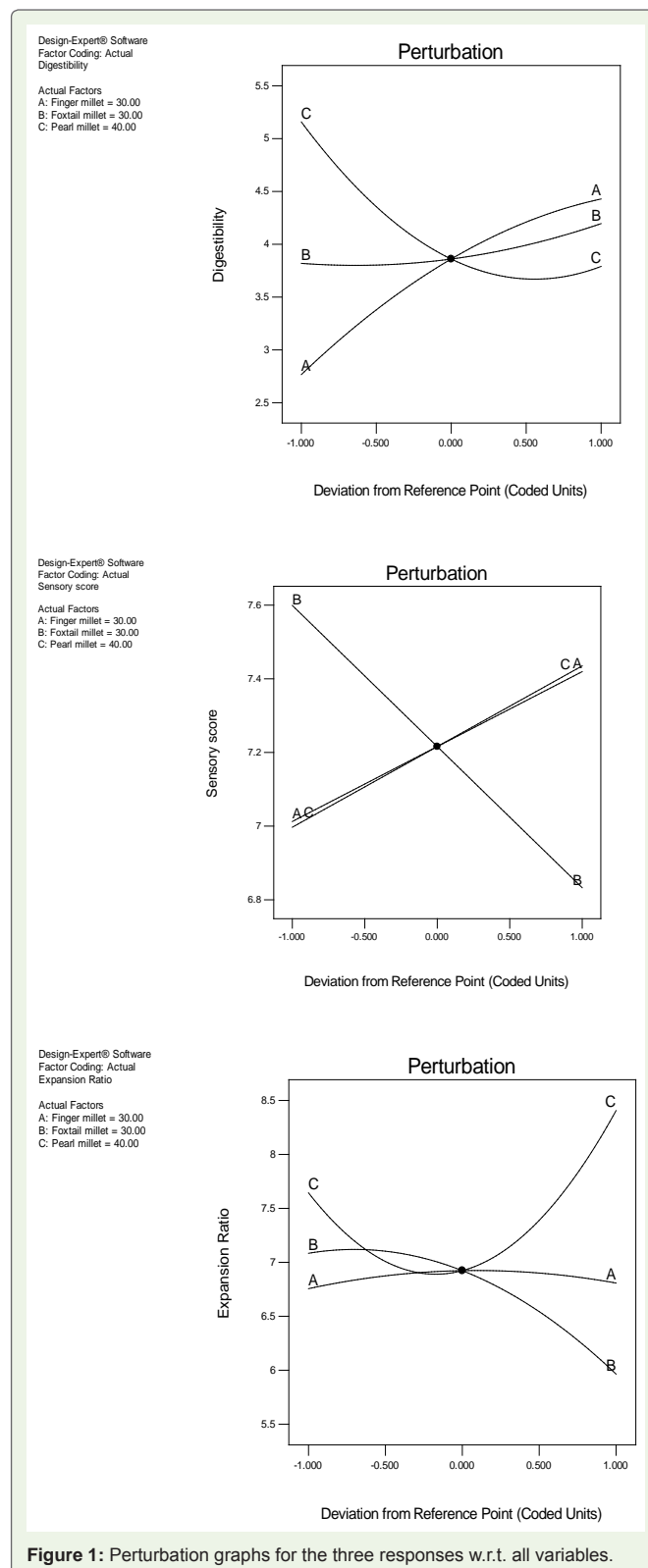


Figure 1: Perturbation graphs for the three responses w.r.t. all variables.

while the increased level of foxtail millet drastically reduced ER. The finger millet did not influence the ER of the extrudates significantly. The reduced ER with increase in the level of foxtail millet has also been

reported [27] in an extruded product prepared from a composite flour blend. Expansion ratio for various rice sorghum blend extrudates has been reported [21] between 9 to 12.

The sensory score was mainly affected by the level of foxtail millet resulting in reduced score with increased level while the increase in the levels of finger and pearl millet resulted in better sensory scores and had similar effect.

To fit these responses with regression models to represent them, ANOVA and model diagnostic tools of design expert software were used. The details of the ANOVA for each response are represented in Table 4. Not much information on the digestibility of millet blends could be available in the literature. Many times a quadratic model has been reported to be best fit for the sensory score response [11]. However, in the present context the sensory score very clearly influenced by variations the ingredient levels; a linear model was found highly suitable. The digestibility and ER response showed a quadratic pattern and the same models were fit with non significant lack of fit. The coefficients of each term of the models fit for the respective response are represented in terms of equation below.

$$\text{Digestibility} = +3.86 + 0.83 A + 0.19 B - 0.68 C - 0.29 A B + 0.19 A C + 0.13 B C - 0.26 A^2 + 0.15 B^2 + 0.61 C^2$$

$$\text{Expansion Ratio} = +6.92 + 0.026 A - 0.56 B + 0.38 C - 0.086 AB + 0.79 AC - 0.91 BC - 0.14 A^2 - 0.40 B^2 + 1.10 C^2$$

$$\text{Sensory score} = +7.22 + 0.20 A - 0.38 B + 0.22 C$$

With such weird responses to the variations in the ingredient levels (independent factors), optimization of the levels to get best combination was resolved through graphical optimisation procedure of design expert software by giving criteria to maximise ER, digestibility as well as the sensory score. Higher desirability value indicates how best the criteria given for optimization are meeting. The optimised solutions obtained for the ingredient levels and expected response values with a desirability value of 0.822 indicated the same (Figure 3). This was validated by conducting the experiment and comparing with the predicted values of the responses to the actual observed responses. The observed value of digestibility response for the optimised combination was 4.65mg/g against the prediction of 4.65mg/g. while the actual observation. The expansion ratio obtained was 10.24 while the predicted value was 10.32. In case of third response, i.e. sensory score of the extruded snack; it was observed that the actual obtained

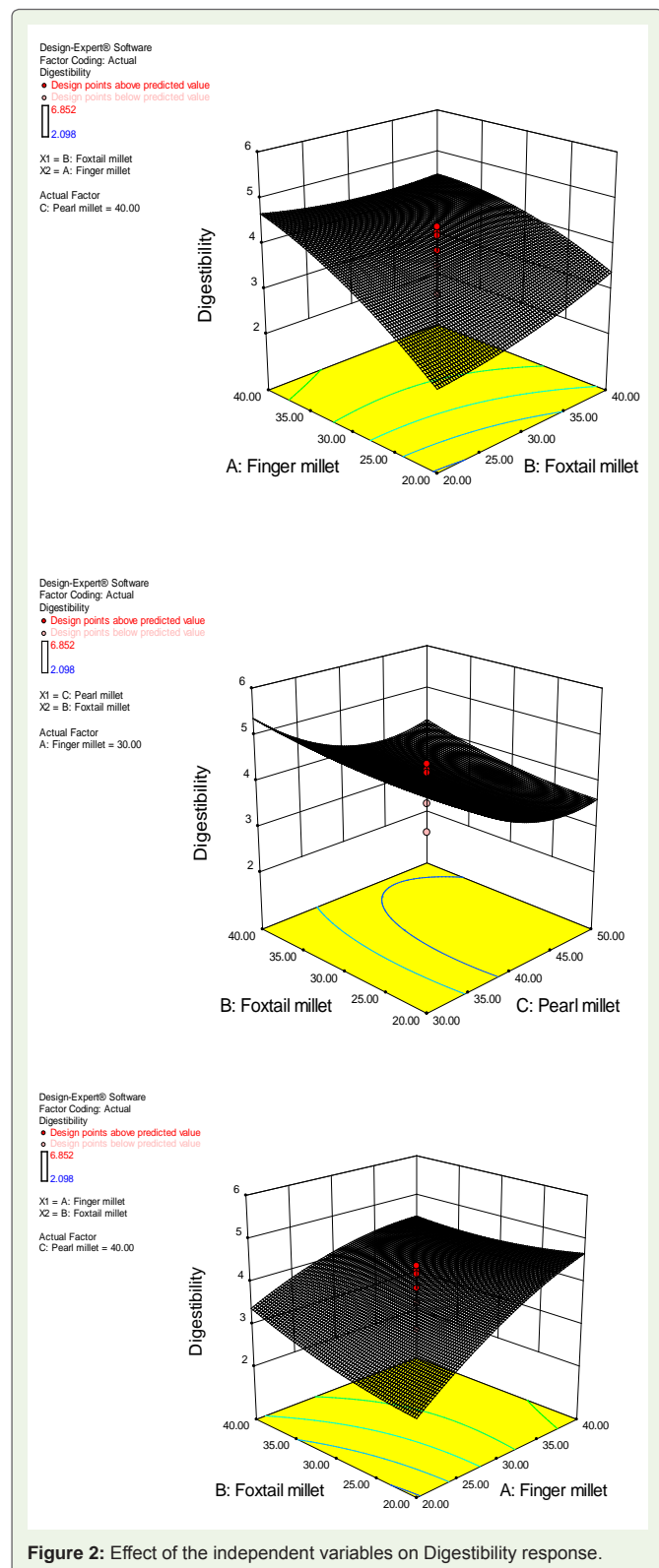


Figure 2: Effect of the independent variables on Digestibility response.

Table 4: Model statistics for responses of multigrain extruded snack.

Expansion Ratio	Std. Dev.	0.75	R-Squared	0.8763
	Mean	7.31	Adj R-Squared	0.7650
	C.V. %	10.27	Pred R-Squared	0.7257
	PRESS	12.49	Adeq Precision	10.984
Sensory score	Std. Dev.	0.21	R-Squared	0.8165
	Mean	7.22	Adj R-Squared	0.7821
	C.V. %	2.95	Pred R-Squared	0.7041
	PRESS	1.17	Adeq Precision	16.925
Digestibility	Std. Dev.	0.51	R-Squared	0.9056
	Mean	4.20	Adj R-Squared	0.8206
	C.V. %	12.05	Pred R-Squared	0.6313
	PRESS	10.00	Adeq Precision	14.050

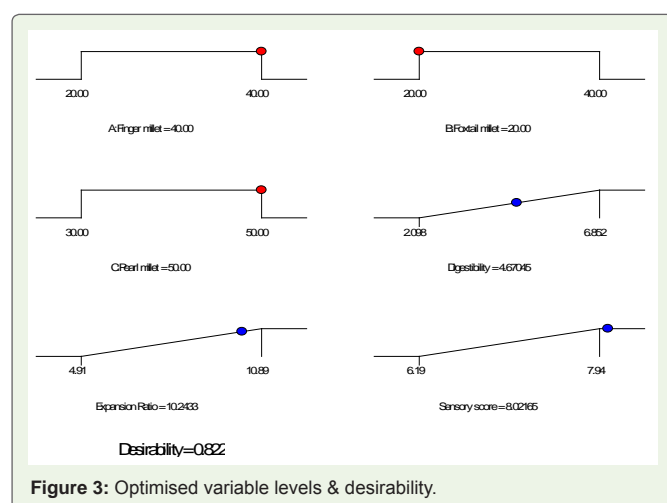


Figure 3: Optimised variable levels & desirability.

Table 5: Predicted Vs Actual response values for the optimized composition of Multi-millet extruded snack.

Response	PRV	ARV
Sensory Score	8.02	8.18
Expansion Ratio	10.24	10.32
Digestibility, mg/g	4.67	4.65

PRV: predicted response value, ARV: actual response value

Table 6: Nutritional cum Chemical composition of Multi-millet extruded snack.

Parameter (per 100g)	Extruded snack
Moisture	7.1
Ash	1.55
Protein	7.30
Fat	3.1
Crude fiber	2.11
Carbohydrates	78.84
Total Dietary fiber	16.168
Insoluble dietary fibre	12.58
Soluble dietary fibre	3.58
Acid Insoluble ash	0.566
Energy, Kcal	372
Sodium, mg	8.9
Calcium, mg	139.5
Magnesium, mg	120.2
Iron, mg	5.31
Zinc, mg	2.41
Copper, mg	0.79
Manganese, mg	2.28

score (8.02) and the predicted score (8.18) were almost similar. As the observed values of all the three responses for the extruded snack are in well concurrence with predicted values, it was concluded that the models could be used for predicting the responses with varied levels within the design space. The equations generated during the process can be used to predict the respective responses within the rotatable space of the design matrix. The optimized multi-millet extruded product was analyzed for proximate composition. Digestibility of optimised extruded product was 8mg/g and the sensory score obtained was 8.18 on the 9-point hedonic scale. The nutritional chemical composition of the RTE extruded snack is represented in

Tables 5 and Table 6. The carbohydrate rich multi-millet snack gives good amount of dietary fibre with 372 KCal energy per 100g of the product. The iron & calcium contents (mg/100g) of finger millet (3.9 & 350), pearl millet 11.0 & 42 and foxtail millet (2.8 & 31) have been reported [28]. The mineral profile of the extruded product determined by ICP-OES revealed that the product is an excellent cereal source of iron (5.31mg %) and calcium (139.5mg%). The multi-millet extruded snack also provides fair amounts of magnesium, sodium zinc and manganese.

Conclusion

The extrusion of multiple millets is an interesting phenomenon as the starches of different nature are co-extruded and the product parameters are influenced by synergetic effects. The product was optimised using RSM by maximising the responses such as expansion ratio, digestibility and the overall acceptability of the product. The developed product is a nutritionally superior product compared to individual millets. The concept of multi-millet combinations in development of products needs to be carefully executed as it affects the digestibility of the product. The developed extruded product offer better digestibility & nutrition in terms of mineral profile.

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