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Optimizing the Preparation of Fish-based Snack Chips Using Response Surface Methodology

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ABSTRACT

The experiment was conducted during the months of May to August in the year 2025 at the Department of Fish Processing Technology Laboratory, to study the optimization of fish-based snack chips through Response Surface Methodology (RSM) at College of Fishery Science, Muthukur. The increasing consumption of ready-to-eat snack foods has resulted in a higher intake of energy-dense products with limited nutritional value, particularly low protein content. Fish, being a rich source of high-quality protein and essential nutrients, offers significant potential for the development of nutritionally enriched snack products. Among freshwater fish species, *Oreochromis niloticus* (tilapia) is widely cultured, economical, and nutritionally superior, making it suitable for value-added product development. The present study aimed to develop protein-enriched fish-based snack chips from tilapia by optimizing composite flour formulation using RSM with a Box–Behnken Design (BBD). Fish chips were prepared using tilapia fish meat, sago flour, and potato starch as the major ingredients. Optimization of composite flour levels was carried out by selecting fish meat (20–30%), sago flour (25–35%), and potato starch (30–40%) as independent variables, while overall acceptability (OAA) and linear expansion (LE) were considered as response variables. The experimental data were statistically analyzed to determine the optimal combination of ingredients. The optimized composite flour formulation consisted of 25% fish meat, 30% sago flour, and 35% potato starch, which resulted in a high overall acceptability score of 8.31 and linear expansion of 42.92%. The results demonstrated that tilapia-based composite flour formulations could be effectively utilized to produce acceptable, protein-enriched snack chips with desirable expansion characteristics, highlighting their potential for nutritious snack development.

KEYWORDS: Fish chips, LE, composite flour formulation, RSM, OAA

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1. INTRODUCTION

The consumption of snacks and fast foods has increased significantly in India due to rapid urbanization, changing lifestyles, increased disposable income, and a growing preference for convenient, ready-to-eat food products (Sumarto et al., 2024). Snack foods are easily accessible, require minimal preparation, and effectively satisfy immediate hunger, making them popular across all age groups. However, most commercially available snack foods are primarily composed of refined carbohydrates and fats, making them energy-dense but nutritionally inadequate. These products are often deficient in high-quality protein, vitamins, and essential micronutrients, thereby contributing little to nutritional security (Hess et al., 2017).

The increasing reliance on nutritionally poor snack foods has raised serious public health concerns, particularly in developing countries like India where protein-energy malnutrition and micronutrient deficiencies remain prevalent (Chudasama et al., 2019). This situation highlights the need to reformulate conventional snack products into healthier alternatives by incorporating nutrient-rich ingredients. In recent years, increased consumer awareness regarding health and nutrition has led to greater demand for functional and protein-enriched foods. In this context, fish and fish-based products have gained attention due to their high nutritional value and consumer acceptability (Tettweiler, 1991).

Fish is an excellent source of high-quality protein, essential amino acids, omega-3 fatty acids, vitamins, and minerals, making it suitable for nutritionally superior snack development (Njike et al., 2016). Incorporation of fish meat into snack formulations enhances protein content and improves biological value. However, the development of fish-based snacks requires careful selection and optimization of complementary ingredients to ensure desirable texture, expansion, and sensory attributes.

Starches play a crucial role in fried snack formulations by improving dough machinability, expansion behavior, and crispiness of the final product (Hossain et al., 2024). High-amylose starches contribute to stronger film formation during cooking and drying, resulting in improved expansion and crisp texture (Idris et al., 2018). In the present study, sago flour and potato starch were selected for blending with fish meat to develop nutritionally enriched fish-based snack chips.

Sago flour is a traditional starch source widely used in food products due to its high carbohydrate content and excellent gelatinization properties. It also contains resistant starch, which provides dietary fiber-like benefits and supports digestive health. However, sago flour is low in protein, fat, and minerals, limiting its nutritional value when used alone (Suparmi et al., 2022). This limitation can be effectively addressed by fortifying sago-based formulations with high-quality animal protein derived from fish meat, thereby improving overall nutritional quality (Litaay et al., 2021).

Potato (*Solanum tuberosum*), the world's third most important food crop after rice and wheat, is extensively used in snack production due to the functional properties of potato starch (Camire et al., 2009; Izci et al., 2011). Potato starch is characterized by large granule size, long amylose and amylopectin chains, and phosphate ester groups, which enable the formation of thick visco-elastic gels and contribute to desirable textural properties such as expansion and crispiness (Yusuph et al., 2003; Alvani et al., 2011).

Response Surface Methodology (RSM) is a widely used statistical tool for optimizing ingredient levels and evaluating the interactive effects of multiple variables on product quality using fewer experimental trials (Sharma et al., 2016). RSM has been successfully applied in optimizing composite flour formulations for products such as seaweed-based edible ice cream (Sravani et al., 2023), fish crackers (Ramesh et al., 2018), and fish nuggets (Omidiran et al., 2024). Therefore, the present study aimed to optimize composite flour levels using RSM to develop a nutritionally improved fish-based snack with desirable overall acceptability and linear expansion.

2. MATERIALS AND METHODS

The experiment was conducted during the months of May to August in the year 2025 at the Department of Fish Processing Technology Laboratory, to study the optimization of fish-based snack chips through Response Surface Methodology (RSM) at College of Fishery Science, Muthukur.

Freshwater Fish (*Oreochromis niloticus*) was purchased from the local fish market of Nellore, India and brought to the fish processing laboratory in an iced condition for processing. Fish was semi-dressed by removing the head, viscera, fins and tail. Potato starch, sago flour, and other ingredients like salt, pepper, garam masala and refined sunflower oil were obtained from the local supermarket.

2.1. Standardization

Different combinations of ingredients (Table 1) were used for the initial standardization recipe for fish chips preparation. Based on the overall acceptability, the recipe "B" was selected for ingredients and then the initial levels of independent variables were taken for optimizing the final recipe for formulating the fish chips through RSM.

2.2. Response surface methodology-experimental design

Response Surface Methodology (RSM) was employed to

Table 1: Different ingredient concentrations for initial standardization of fish chips recipe

Ingredients	Recipe concentrations (%)				
	A	B	C	D	E
Fish meat	20%	25%	30%	35%	40%
Sago flour	35%	30%	25%	20%	15%
Potato starch	35%	35%	35%	35%	35%
Garam masala	4%	4%	4%	4%	4%
Pepper	3.5%	3.5%	3.5%	3.5%	3.5%
Salt	2.5%	2.5%	2.5%	2.5%	2.5%

optimize the formulation of fish-based chips with enhanced overall acceptability (OAA) and linear expansion (LE). A Box-Behnken Design (BBD) (Ferreira et al., 2007) was used to evaluate the effects of composite flour components, namely fish meat (20–30%), sago flour (25–35%), and potato starch (30–40%), as independent variables. 17 experimental runs, including 5 centre points and 12 true and axial points, were conducted to assess model adequacy and experimental reproducibility. OAA was evaluated in ten replicates, while LE was measured in three triplicate, and mean values were used for RSM analysis. A quadratic model was fitted and analyzed using analysis of variance (ANOVA) to assess the significance of model terms and interactions at a 5% significance level. Numerical optimization was applied to maximize OAA and LE, and model adequacy was confirmed through p-values, lack-of-fit tests, and coefficient of determination (R^2). Statistical analysis and graphical interpretation, including contour and three-dimensional response surface plots, were performed using Design-Expert software, and results were expressed as mean±SD with $p<0.05$ considered statistically significant.

2.3. Preparation of fish chips

Based on the results of RSM, the optimized composite flour levels and process factors were used for the formulation of fish chips. Other ingredients/seasonings used for fish chips preparation were salt (3%), garam masala (4%), and pepper (3%), to improve the taste and flavour. All the ingredients were mixed and blended well in a food processor for 2-3 min until the dough was formed. The dough was then rolled manually into a cylindrical shape and steamed. The steamed roll was then cooled to room temperature and kept in the refrigerator (4°C) in order to harden the roll. Later, it was cut into round slices of 2–3 mm thickness using a hand slicer and dried in an oven. After cooling to room temperature under a fan, the dried slices were packed in Ziplock pouches. The packed chips were fried using sunflower oil in a shallow pan for 2 min at 180±2°C.

2.4. Optimization of composite flour levels by RSM

The optimization process of composite flour levels by following the Box-Behnken experimental design for three independent variables and 17 sample runs was furnished in Tables 2 and 3, respectively.

Table 2: Box-Behnken experimental design with three independent variables for composite flour levels of fish chips

Variables/Response	Units	Codes		
		Low	Medium	High
A. Fish meat	%	20	25	30
B. Sago flour	%	25	30	35
C. Potato starch	%	30	35	40

Table 3: 17 sample runs of BBD matrix designs for coded composite flour levels

Standard	Run	Factor 1 A: Fish meat (%)	Factor 2 B: Sago flour (%)	Factor 3 C: Potato starch (%)
12	1	25	22	28
15	2	25	24	23
11	3	20	24	28
17	4	15	24	23
9	5	20	26	23
6	6	20	24	28
14	7	20	26	33
7	8	25	26	28
5	9	20	24	28
13	10	20	22	33
4	11	20	22	23
8	12	25	24	33
2	13	15	24	33
1	14	20	24	28
16	15	15	22	28
3	16	15	26	28
10	17	20	24	28

2.5. Determination of overall acceptability

A semi-trained judges group (n=30) was selected out of the Fish Processing Technology Department, College of Fishery Science, Andhra Pradesh Fisheries University (APFU), Muthukur, Nellore. The fish-based snack chips were provided to the panelists for evaluation of organoleptic properties viz., Appearance, taste, flavour, texture, odour, colour, crispiness, and overall acceptability. A 9-Point Hedonic scale method was used for rating the product where 9-Like extremely, 8-Like very much, 7-Like moderately, 6-Like slightly, 5-Neither like nor dislike, 4-Dislike, 3-Dislike moderately, 2-Dislike very much, 1-Dislike extremely (Peryam, 1989).

2.6. Determination of linear expansion

Fish chips expand into a porous snack product during frying and the degree of expansion is measured as linear expansion (Ramesh et al., 2018). Linear expansion was measured by drawing a line across for both dried and fried samples with a permanent marker pen. Then the lines were measured before and after frying in oil at 180°C–200°C. The percentage of linear expansion was calculated as follows:

Linear expansion (%)=(Length after frying-Length before frying)/Length before frying)×100

2.7. Statistical analysis

The analytical and quantitative data are presented as mean±standard deviation (SD) of three replicates. Statistical analysis was performed using one-way analysis of variance (ANOVA), followed by Duncan's post-hoc test. A significance level of $p<0.05$ was used to determine statistical significance. Data analysis was conducted using SPSS software, version 22.

3. RESULTS AND DISCUSSION

3.1. Optimizing ingredients ratio for fish chips

To optimize the composite flour levels for fish-based snack chips, 17 RSM combinations were formulated with three independent variables. OAA and LE were the primary output parameters considered for the preparation of fish chips (Ramesh et al., 2018). Tables 4 and 5 represent the statistical analysis and inter-relation between the independent (fish meat, sago flour and potato starch), and dependent (OAA, LE) variables. The model demonstrated significance in both cases, with a P-value less than 0.0001.

3.2. Optimization of three independent ingredient levels

Among the three independent variables, the *p*-value of all three ingredients showed a high and equal influence ($p<0.0001$) on both OAA and LE. To assess the adequacy of the selected model in describing the observed data, the lack-of-fit test was used. A P-value less than 0.05 indicates the adequacy of the model (Ganesan et al., 2021). The lack-of-fit test yielded a *p*-value of 0.0194 for OAA and 0.0025 for LE. In this study, a notably high coefficient of determination (R^2) was observed for LE (0.9989) and OAA (0.9995), indicating a strong model-data fit. Additionally, the adjusted coefficient of determination was considered as a measure of the significance of the model (Osman et al., 2017). The adjusted coefficient of determination for OAA and LE was calculated as 0.9988 and 0.9974, respectively. Furthermore, the predicted R^2 values closely matched the adjusted R^2 values for both response variables. Consequently, the model was deemed appropriate for optimizing the production of fish-based snack chips, with OAA and LE as the desired parameters. The optimal explanatory model equations for OAA and LE are as follows

Table 4: Analysis of variance (ANOVA) for the quadratic model of OAA

Source	Sum of Squares	df	Mean square	F-value	*p*-value
Model	9.75	9	1.08	1511.29	< 0.0001
A-fish meat	0.0648	1	0.0648	90.36	< 0.0001
B-sago	0.4608	1	0.4608	642.55	< 0.0001
C-starch	0.2965	1	0.2965	413.38	< 0.0001
AB	0.5256	1	0.5256	732.94	< 0.0001
AC	1.03	1	1.03	1436.57	< 0.0001
BC	1.24	1	1.24	1733.58	< 0.0001
A^2	2.06	1	2.06	2870.75	< 0.0001
B^2	1.46	1	1.46	2038.59	< 0.0001
C^2	1.97	1	1.97	2748.91	< 0.0001
Residual	0.0050	7	0.0007		
Lack of fit	0.0045	3	0.0015	11.54	0.0194
Pure error	0.0005	4	0.0001		
Correlation total	9.76	16			
R^2	0.9995				
Adjusted R^2	0.9988				
Predicted R^2	0.9925				
Adequate precision	105.8233				

$$OAA=+8.30-0.0900A-0.2400B+0.1925C+0.3625AB+0.5075AC-0.5575BC-0.6993A^2-0.5892B^2-0.6843C^2$$

$$LE\ (\%)=+42.88+1.02A+1.39B-0.7638C-0.1425AB+0.6675AC+0.2600BC-1.38A-2.41B^2-1.60C^2$$

Where A=Fish meat, B=Sago flour, C=Potato starch

Two-dimensional (2D) contour plots and three-dimensional (3D) response surface plots were employed to elucidate the interactive effects of formulation variables on overall acceptability (OAA) and linear expansion (LE) of fish-based snack chips (Figures 1 and 2). These graphical tools provide a visual interpretation of the combined influence of independent variables and the nature of their interactions (Kamble et al., 2023). According to established methodology, circular contour plots indicate negligible interaction between variables, whereas elliptical contour plots signify significant interaction effects (Anandito et al., 2024).

With respect to overall acceptability, the 2D contour plots (Figures 1a–c) and corresponding 3D response surface plots

Table 5: Analysis of variance (ANOVA) for quadratic model of LE

Source	Sum of squares	df	Mean square	F-value	*p*-value
Model	78.52	9	8.72	678.52	< 0.0001
A-fish meat	8.36	1	8.36	650.50	< 0.0001
B-sago	15.43	1	15.43	1199.97	< 0.0001
C-starch	4.67	1	4.67	362.93	< 0.0001
AB	0.0812	1	0.0812	6.32	0.0402
AC	1.78	1	1.78	138.61	< 0.0001
BC	0.2704	1	0.2704	21.03	0.0025
A^2	7.97	1	7.97	620.02	< 0.0001
B^2	24.53	1	24.53	1907.49	< 0.0001
C^2	10.76	1	10.76	836.74	< 0.0001
Residual	0.0900	7	0.0129		
Lack-of- Fit	0.0867	3	0.0289	35.25	0.0025
Pure error	0.0033	4	0.0008		
Correlation total	78.61	16			
R^2	0.9989				
Adjusted R^2	0.9974				
Predicted R^2	0.9823				
Adequate precision	73.8719				

(Figures 1d–f) illustrate the interactive effects of fish meat, sago flour, and potato starch on sensory quality. The circular contour patterns observed in Figures 1a and 1c suggest a relatively weak interaction between fish meat and potato starch, as well as between sago flour and potato starch (Gedam et al., 2024). In contrast, the convex nature of the 3D response surface plots (Figures 1d and 1f) indicates the presence of well-defined optimum regions, reflecting the suitability of the fitted quadratic model and the reliability of the experimental data in predicting maximum OAA.

In terms of linear expansion, the 2D contour plots (Figures 2a–c) and 3D response surface plots (Figures 2d–f) reveal more pronounced interaction effects among formulation variables. Elliptical contour plots observed in (Figures

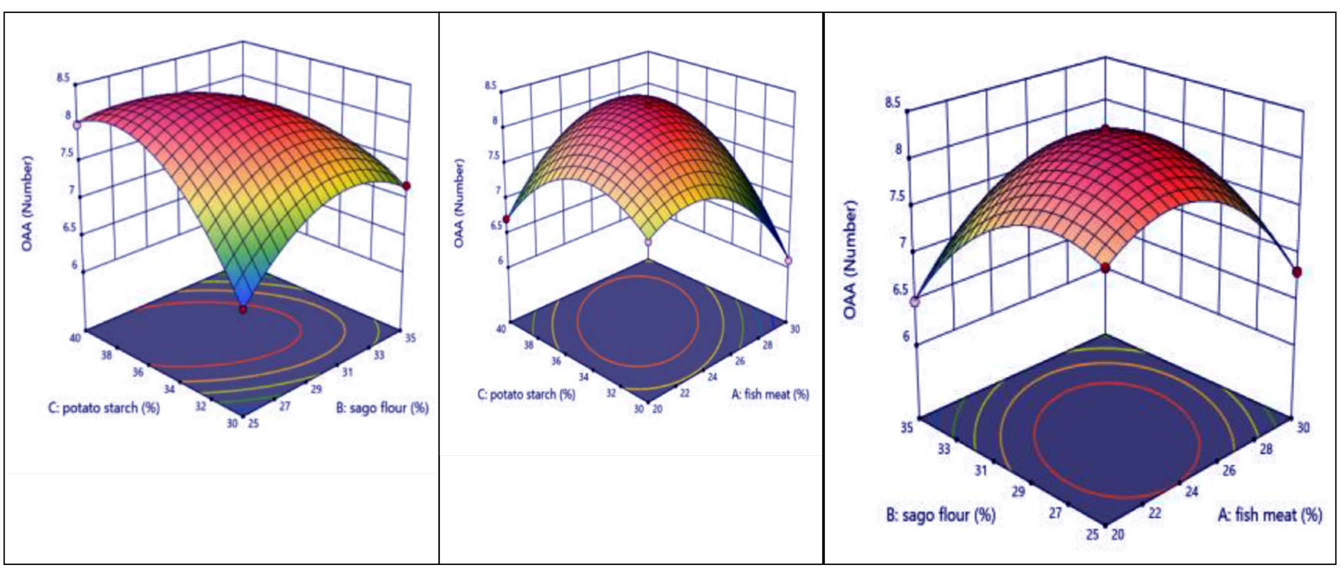

Figure 1 (a-c): Response surface graphs showing the effect of fish meat (A), sago flour (B), and potato starch (C) on OAA of fish chips

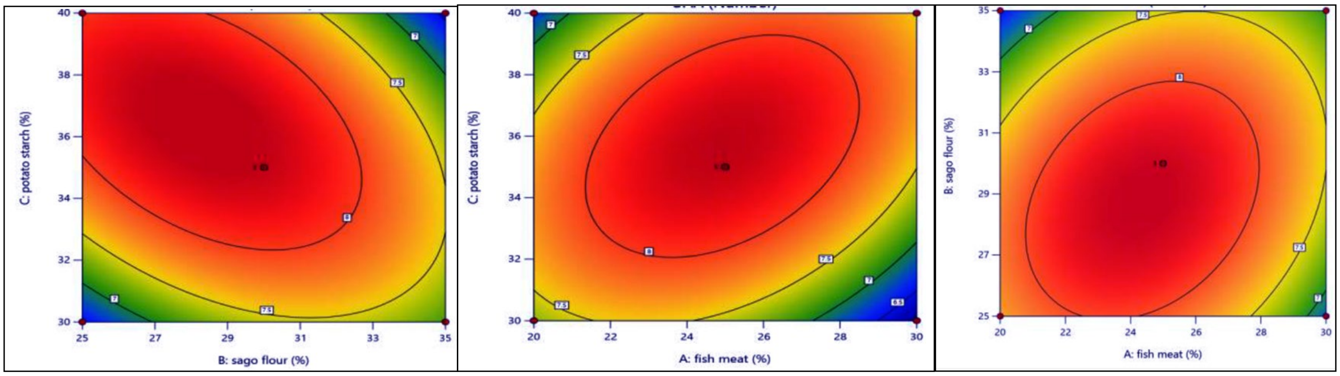

Figure 1 (d-f): Contour surface plots showing the effect of fish meat (A), sago flour (B), and potato starch (C) on OAA of fish chips

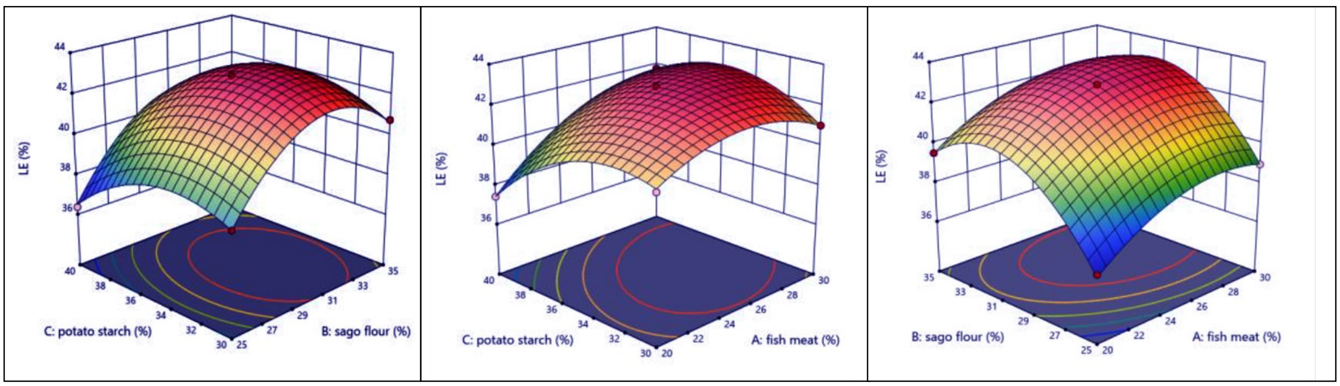

Figure 2 (a-c): Response surface graphs showing the effect of fish meat (A), sago flour (B), and potato starch (C) on LE of fish chips

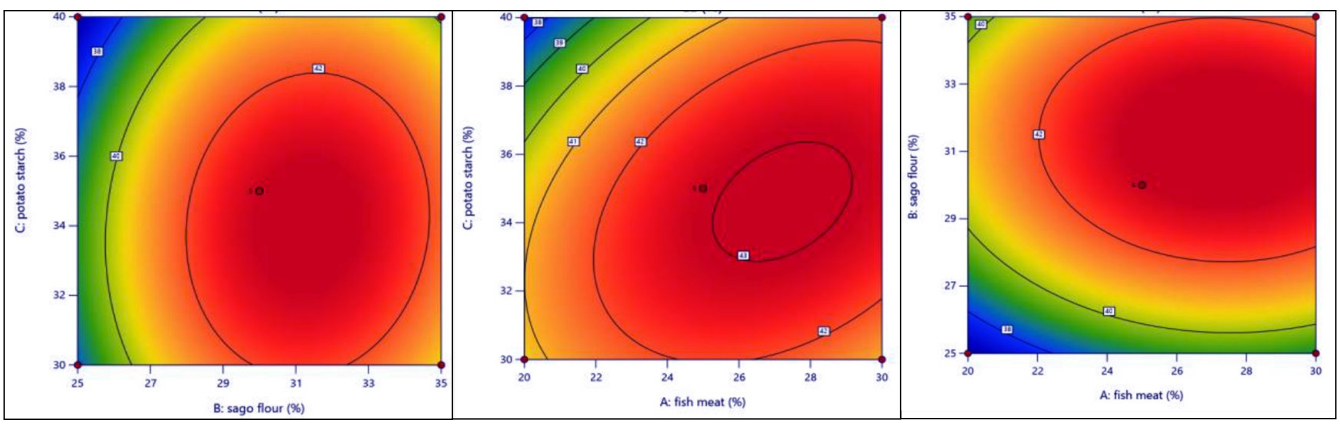

Figure 2 (d-f): Contour surface plots showing the effect of fish meat (A), sago flour (B), and potato starch (C) on LE of fish chips

2a and 2c), along with the corresponding 3D surfaces in (Figures 2d and 2f), clearly indicate significant interactions between fish meat and potato starch, and between sago flour and potato starch, respectively (Choi et al., 2023). Conversely, the nearly circular contour plot in (Figure 2b) and the corresponding 3D plot in (Figure 2e) indicate that the interaction between fish meat and sago flour had a negligible effect on linear expansion. These interaction patterns demonstrate that potato starch plays a dominant role in influencing the expansion characteristics of fish-based snack chips (Charthad et al., 2023).

4. CONCLUSION

The present study demonstrated the successful application of Response Surface Methodology using a Box–Behnken Design for optimizing the composite flour formulation of fish-based snack chips. The effects of fish meat, sago flour, and potato starch on overall acceptability and linear expansion were effectively modelled using a statistically significant quadratic polynomial equation. The optimized formulation, comprising 25% fish meat, 30% sago flour, and 35% potato starch, resulted in high overall acceptability and desirable expansion characteristics, confirming the suitability of the model for formulation optimization.

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