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Development of Banana Pseudostem Incorporated Nuggets from Threadfin Bream *(Nemipterus japonicus)* Surimi and its Quality Evaluation During Frozen Storage

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Abstract

The objective of this study was to evaluate the effect of banana (*Musa acuminata* cv. Palayam Codan, AAB group) pseudostem flour (BP) on enhancing the nutritional, biochemical, organoleptic, and microbial quality of surimi nuggets during frozen storage. Surimi nuggets were prepared from threadfin bream by incorporating BP at varying concentrations (0%, 1%, 2.5%, and 5%). The nugget formulation with the highest dietary fibre content and acceptable sensory score was identified using Response Surface Methodology (RSM). The inclusion of 5% BP in surimi nuggets (SNBP) resulted in a 2.57% increase in total dietary fibre (TDF) compared to control surimi nuggets (SN) without BP. The nuggets were subjected to quality assessments over 240 days of storage at -18 ± 2°C. The thiobarbituric acid value, peroxide value, and free fatty acid value of both SN and SNBP increased significantly ($P<0.05$) during frozen storage but remained within permissible limits. Sensory evaluation showed that SNBP scored higher for flavour, taste, and texture compared to SN. Microbiological analysis confirmed that both nugget samples were microbiologically safe for consumption throughout the storage period. In conclusion, incorporating banana pseudostem, a secondary agricultural by-product, into surimi nuggets made from threadfin bream can enhance nutritional content while maintaining quality during frozen storage.

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Introduction

Surimi is composed of refined myofibrillar proteins obtained after washing and dewatering of fish mince. It serves as an excellent raw material for shaping and forming various convenience food items such as sausages, patties, nuggets, and many seafood analogues. Traditionally, surimi has been used by the Japanese to produce kamaboko, chikuwa and hampen. One of the important characteristics of surimi is its gel-forming ability and its ability to readily absorb and blend with other flavours and seasonings. This contributes to the desired texture and mouthfeel of surimi-based products. Earlier research in this field focussed on improving gel strength, enhancing colour and flavour, increasing water-holding capacity, enhancing mechanical properties by introducing cross-linking enzymes and improving the protein gel network by calcium compounds, chitosan, and oxidizing agents (Martín Sánchez, Navarro, Perez-Alvarez, & Kuri, 2009). However, recent research is more focused on methods to preserve the nutritional and functional properties of surimi, by incorporating naturally occurring digestible fibres from inulin (Huang, Tsai, & Chen, 2011), okara (Yin et al., 2019), pectin (Buda et al., 2021), psyllium husk (Zhu, Ye, Jiang, Lin, & Lu, 2022), oat bran (Alakhrash, Anyanwu, & Tahergorabi, 2016) and wheat bran (Lin et al., 2019).

Dietary fibre plays a pivotal role in supporting overall health and well-being. It has a positive impact on gastrointestinal digestion, controls blood glucose levels (Bhaskar, Shobha, Sambaiah, & Salimath, 2011), promotes healthy bowel movements (Anderson et al., 2009), lowers blood cholesterol and body weight (Galisteo, Duarte, & Zarzuelo, 2008) and prevents the conditions like colon cancer, cardiovascular disease (CVD), and type 2 diabetes (Singh, Banerjee, & Arora, 2015). In a cohort study conducted in the United States, it was observed that despite the recognized health benefits, most people consume less than half of the daily recommended level of dietary fibre (Korczak & Slavin, 2020). Based on the ICMR guidelines for the management of type 2 diabetes, the recommended fibre intake for the general population is 40 g/day for a 2000 kcal diet (ICMR, 2018). However, the disparity continues, and reports pointed out that 10 million deaths were caused by cancer and about 20% of cases are related to colon and rectum cancer (Ferlay et al., 2020). Thus, more focused research on including high-fibre food products in diet is inevitable.

There has been a growing demand to find potential sources of dietary fibre from underutilized resources. This has led to the extraction of dietary fibre from cereals, fruits and vegetables including husks, seeds, and peels. The utilization of the core of fresh banana pseudostem (BP) as a fibre source has been a long-standing practice in South Indian culinary tradition. This traditional approach has sparked the interest of researchers in exploring BP as an alternative source of fibre. After harvesting bananas, approximately 88% by weight in terms of pseudostem and leaf is discarded as agro waste in the plantation (Elanthikkal, Gopalakrishnapanicker, Varghese, & Guthrie, 2010). The BP is rich in fibre (lignin, hemicellulose, cellulose) and contains numerous beneficial compounds, including alkaloids, flavonoids, phenolic acids, amino acids, organic acids, coumarins, tannins, and terpenes (Deng et al., 2020). The consumption of BP is beneficial for weight loss, detoxification, and kidney stone treatment (Thorat & Bobade, 2018). By converting the BP into flour, it can become a valuable raw material for extracting functional ingredients like fibre and other bioactive compounds. However, incorporating dietary fibre into fish-based products, such as those made with surimi, presents various processing challenges. These challenges include the potential effects on water holding capacity, gel strength, emulsion stability, cooking loss, taste, and colour of the final product (Borderías, Pérez-Mateos, & Sánchez-Alonso, 2013; Buda et al., 2021). Therefore, careful consideration and optimization of processing methods are necessary for maintaining their desired quality attributes. Hence, the objective of this study was to develop surimi-based nuggets incorporated with BP flour and to evaluate their quality during frozen storage, with a particular focus on sensory characteristics and shelf stability.

Materials and Methods

Frozen surimi blocks of *Nemipterus japonicus* (threadfin bream) purchased from Shree Ulka -LLP, (Mangalore, Karnataka, India) were kept under frozen (-18±2 ºC) storage until required. The pseudostem cores of the South Indian banana variety, *Musa acuminata* cv. Palayam codan AAB group collected from local farmers were washed, shredded and dried (55±5 ºC for about 5 h) in a cabinet drier. The dried material was powdered using a kitchen blender, packed in polyethylene-polypropylene laminated pouch and stored at room temperature (27±2 ºC). Analytical grade chemicals purchased from Sigma-Aldrich (India) and Merck (India) were used for biochemical analysis. For microbiological analysis, media bought from Oxoid (UK), Difco (USA), and Himedia (India) were used.

Single factorial experimental design with D-optimality criteria was formulated to optimize the dietary fibre concentration and sensory attributes of surimi nuggets. The second-order regression model given below was used to fit the experimental data.

$$Y = \beta_0 + \beta_1 X + B_{11} X^2 + e$$

Where Y is the dependent variable (yield), X is the concentration of banana pseudostem (BP) β_0 is the intercept, $\beta_1 X$ is the linear regression coefficient, $\beta_{11} X^2$ is the quadratic regression coefficient and e is the error term. The coefficient of determination (R^2) was used to assess the goodness of fit of the model. Multivariate optimization was done using the desirability function and the combination with the highest desirability score was selected as the optimum dietary fibre concentration for further storage study.

Surimi nuggets (SN) were prepared by seasoning surimi with salt and spices. The frozen surimi block was initially thawed under chilled storage (4±2 ºC) for 18h, ground in a silent cutter for 3-5 min, along with 2.5% (w/w) salt, and 12% (w/w) spice mix (3% garlic powder, 3% onion powder, 2% sunflower oil, 1.5% garam masala, 1.5% chilli flakes, and 1% lemon juice). These were then weighed into 30 g portions and formed into nuggets with 1 cm thickness, subjected to flash frying in sunflower oil (180±10 °C for 30s) after pre-dusting, battering, and breading of the nuggets. These nuggets were then equilibrated to room temperature and packed into a polyethylene-polypropylene laminated pouch. After blast freezing at -18 °C for about 2h, the nuggets were stored at -18±2 °C. For the preparation of BP flour incorporated surimi nuggets, 1%, 2.5% and 5% surimi were replaced with BP flour along with the same amount of salt and spices. The percentage of BP to be incorporated into surimi was finalized as 5% based on the sensory acceptability and intake of dietary fibre per 100 g of nuggets consumption. The samples were drawn at two-month intervals for analysing biochemical, microbiological, and sensorial properties.

Proximate composition was determined by AOAC (2019) based on the wet weight of the surimi nugget. The moisture content was determined by the hot air oven method (AOAC 950.46), while crude fat content was estimated by the Soxhlet method using petroleum ether as a solvent (AOAC 991.36). The crude protein was analysed by the Kjeldahl method (AOAC 2001.11), whereas dietary fibre was quantified by the enzymatic gravimetric method (AOAC 991.43) and ash was analysed by dry ashing method using a muffle furnace (AOAC 942.05).

The digital pH meter (Cyberscan pH 510, Thermo Fisher Scientific Inc., Singapore) was used to determine the pH of the sample (Moosavi Nasab, Asgari, & Oliyaei, 2019). The free fatty acid (FFA) value and peroxide value (PV) value of nuggets were calculated as per AOAC (2019). For the estimation of PV, 30 ml acetic acid and pinch of potassium iodide was added to 20 ml of chloroform extract and titrated against 0.01N sodium thiosulfate. For free fatty acid value (FFA), 10 ml neutralised ethyl alcohol was added after evaporating 20 ml chloroform extract and titrated against 0.01N sodium hydroxide. For the estimation of oxidative rancidity, 5 ml of thiobarbituric acid (TBA) reagent was added to 5 ml of sample distillate prepared in 2% (v/v) hydrochloric acid and absorbance was taken at 538 nm in UV-Visible spectrophotometer (Shimadzu-UV 2600) after 30 minutes incubation in boiling water bath (Tarladgis, Watts, Younathan, & Dungan, 1960).

The colour parameters of nuggets were measured using a Hunter lab colour analyser (Colour Flex- EZ s/n CFEZ 0257, Reston, Virginia). The values of L* (lightness), a* (redness), and b* (yellowness) were determined (Sreelakshmi, Manjusha, Nagalakshmi, Chouksey, & Venkateshwarlu, 2015).

For sensory evaluation, the samples were subjected to deep frying at 180±10 °C for 3 min without thawing. The randomly coded samples were served to sensory panellists and the samples were evaluated by using a 9-point hedonic scale. Both SN and SNBP (surimi nuggets incorporated with 5% banana pseudostem flour) were evaluated for appearance, taste, texture, flavour and overall acceptability by 10 semi-trained panellists. The score for dislike to like was set from 1 to 9, with 5 as the rejection threshold.

The microbiological quality analysis was carried out based on the method described by Abid, Ali, Hussain, and ur-Rehman (2010). Frozen nuggets (25g) were taken under aseptic conditions and homogenized in 225 ml of sterile 0.85% (w/v) saline solution at 230 rpm using a stomacher blender (Seward Stomacher 400 Circulator, England). For enumeration, appropriate serial dilutions were made. Similarly, sampling was carried out every two months. The total mesophilic and psychrotrophic bacterial counts were determined using plate count agar (Oxoid, UK). For mesophilic counts, plates were incubated at 37°C for 48h, whereas plates were incubated at 7°C for 7 days for total psychrotrophic counts in a refrigerator. The microbial counts were presented as log cfu/g. The count of total Enterobacteriaceae including total Coliforms *and Escherichia coli*, *Staphylococcus aureus*, *Salmonella spp.,* and Yeast and mould were checked only on the 0^{th} day.

The effect of incorporating BP into SN during frozen storage was analysed using a two-way analysis of variance (ANOVA), considering the influences of treatment, storage time, and their interaction in the generalized linear model. All the statistical analysis was carried out by using statistical software SAS 9.3 (SAS Institute Inc., Cary, NC, USA). The means (n=3) were compared by Tukey's post hoc analysis at a 5% level of significance ($p<0.05$).

Results and Discussion

In this study, Response Surface Methodology (RSM) was used to analyse the relationships between BP and various sensory attributes (appearance, flavour, taste, and texture) and to optimize the dietary fibre concentration in the product. The regression coefficients (β_0, $\beta_1 X$ and $\beta_{11} X^2$) of the fitted model along with the coefficient of determination (R^2) are given

Table 1. Estimated regression coefficients with R^2

Dependentvariable	Regression coefficients			R^2
	β_0	β_1	β_{11}	
Dietary fibre	-0.026	0.6274	-0.021	0.996
Appearance	8.566	-0.150	0.007	0.762
Flavour	7.374	0.354	-0.029	0.646
Taste	7.078	0.539	-0.053	0.816
Texture	7.435	0.426	-0.014	0.863

in Table 1. The results revealed that significant relationship between response variables and the concentration of the dietary fibre. It was observed that the linear effect of dietary fibre was positive on most of the response variables except for appearance, which indicated that increasing the concentration of dietary fibre has a significant effect on appearance, flavour, taste and texture. The optimum concentration of dietary fibre was found to be 5%, which gave the highest desirability score of 0.834 and was selected for the development of surimi nuggets.

Proximate analysis of SN and SNBP showed significant differences in the moisture content ($P < 0.05$). The moisture content of SN was 59.5% and that of SNBP was 52.38% (Fig. 1). Similar results were noticed by Huang et al. (2011), who reported that based on the type of fibre and percentage composition, the moisture percentage shows variation. Likewise, Kaur, Kumar, and Bhat (2015) reported that the chicken nuggets incorporated with tomato powder resulted in a 3.6% reduction in moisture percentage. Compared to SN, fat content was higher in SNBP. Medina, Antequera, Ruiz, Jiménez-Martín, and Pérez-Palacios (2015) reported that while frying the surface, temperature of the food rises quickly and causes evaporation of the surface water. This evaporation creates voids in the food product, which are replaced by the surrounding hot oil. A study by Rukundo, Dass, and Nkafamiya (2024) reported that banana pseudostem fibres exhibited an oil absorption capacity of 59%. Also, the addition of BP resulted in a decrease in the protein content of the surimi nuggets. This was earlier identified by Cardoso, Mendes, Vaz-Pires, and Nunes (2009), that this decrease may be attributed to the dilution effect caused by the incorporation of fibre or due to the denaturation of protein during frying.

The ash content of the surimi nuggets significantly increased by 66.59% after the incorporation of BP. This increase can be attributed to the mineral composition of BP. Li, Fu, Zhan, Zhan, and Lucia (2010) reported that the banana pseudostem had higher ash content compared to other wood fibres. Similarly, Yilmaz and Daðlýoðlu (2003) observed an increase in ash content when oat bran (20g/100g) was incorporated into meatballs. For optimization of

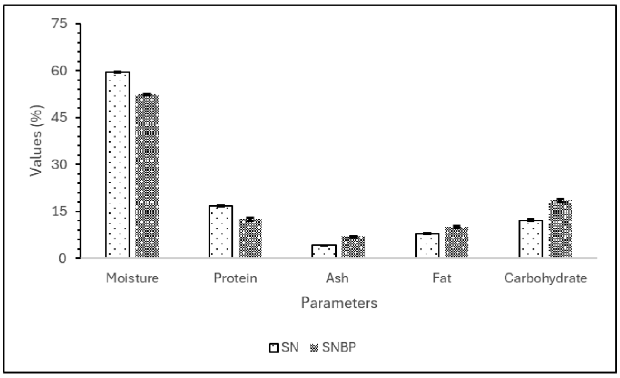

Fig. 1. Proximate composition of surimi nuggets (SN) and surimi nuggets incorporated with 5% banana pseudostem flour (SNBP)

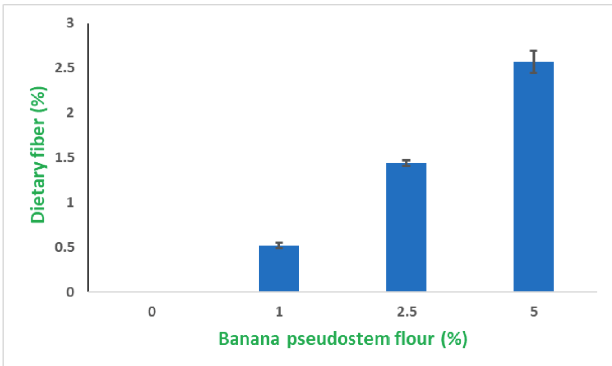

Fig. 2a. Percentage of dietary fibre in surimi nuggets with different concentrations of BP flour

surimi nuggets, different concentrations of BP were used. The incorporation of BP at a 5% level resulted in a 2.57% increase in the total dietary fibre (TDF) content of the surimi nuggets as mentioned in Fig. 2a. This addition contributed to an intake of 2.57g of dietary fibre per 186.54 Kcal consumption. Hence 5% BP incorporated nuggets (SNBP) was considered for storage study. These findings aligned with the results of a cohort study carried out in the United States by Korczak and Slavin (2020) and suggested that an intake of 14 g dietary fibre per 1000 kcal has a beneficial effect in preventing cardiovascular diseases (CVD). Similarly, Verma, Rajkumar, Banerjee, Biswas, and Das (2013) indicated that the addition of guava powder significantly improved the TDF content of meat nuggets by 43.21%. Incorporating dietary fibre in meat-based products not only provides nutritional and health benefits, but also helps in improving textural properties, reducing cooking loss, and lowering formulation costs. A daily intake of 3-6% dietary fibre can be beneficial in lowering cholesterol, reducing the risk of CVDs, cancer, and diabetes, as well as improving gastrointestinal health in humans (Mehta, Ahlawat, Sharma, & Dabur, 2015).

The TBA value is an indicator of secondary lipid oxidation and the production of volatile metabolites during storage. During frozen storage, the TBA value of SN significantly ($P < 0.05$) increased from 0.23 to 0.31 mg MDA/ kg (Table 2). However, the TBA value of SNBP increased from 0.14 to 0.27 mg MDA/ kg. The variation of TBA values between SN and SNBP could potentially be attributed to the

Table 2. Biochemical characteristics of SNBP and SN during frozen storage

Analysis	Samples	Storage days 0	60	120	180	240	Mean
[1]TBA	SN	0.23	0.27	0.27	0.28	0.31	0.27^{A}
	SNBP	0.14	0.19	0.21	0.24	0.27	0.21^{B}
	Mean	0.18^{a}	0.23^{b}	0.24^{b}	0.26^{c}	0.29^{d}	
[2]PV	SN	0.94	2.19	3.74	4.34	4.56	3.15^{A}
	SNBP	0.99	3.21	4.44	5.33	6.50	4.09^{B}
	Mean	0.97^{a}	2.70^{b}	4.09^{c}	4.83^{d}	5.53^{e}	
[3]FFA	SN	2.10	2.57	2.64	2.79	3.07	2.63^{A}
	SNBP	0.96	1.72	2.19	2.37	2.46	1.94^{B}
	Mean	1.53^{a}	2.15^{b}	2.42^{c}	2.58^{d}	2.76^{e}	
pH	SN	5.77	5.86	5.88	5.98	5.99	5.90^{A}
	SNBP	6.10	6.16	6.23	6.22	6.27	6.20^{B}
	Mean	5.94^{a}	6.01^{b}	6.06^{c}	$6.10^{c,d}$	6.13^{d}	
L*	SN	53.21	50.68	51.58	50.63	50.20	51.26^{A}
	SNBP	48.48	48.35	47.54	47.31	46.86	46.86^{B}
	Mean	50.85^{a}	49.52^{b}	49.56^{b}	$48.97^{b,c}$	48.53^{c}	
a*	SN	12.01	11.17	10.86	10.66	10.28	10.99^{A}
	SNBP	8.15	8.60	8.39	8.18	8.45	8.35^{B}
	Mean	10.18^{a}	$9.88^{a,b}$	$9.62^{a,b}$	$9.42^{a,b}$	9.36^{b}	
b*	SN	32.89	33.45	33.21	32.17	32.01	32.75^{A}
	SNBP	28.53	27.33	26.79	26.74	26.90	27.25^{B}
	Mean	30.71^{a}	30.39^{a}	$30.00^{a,b}$	29.45^{b}	29.45^{b}	

[1] TBA in mg MDA/kg [2] PV in mEq/kg fat [3] FFA in % oleic acid
Mean (n=3) with different letters on the superscript indicates statistical difference ($p < 0.05$) at 5% level of significance. Uppercase superscript letters (A and B) compare the marginal means between SN and SNBP. Lowercase superscript letters (a, b, c, d and e) compare the marginal means between storage days.

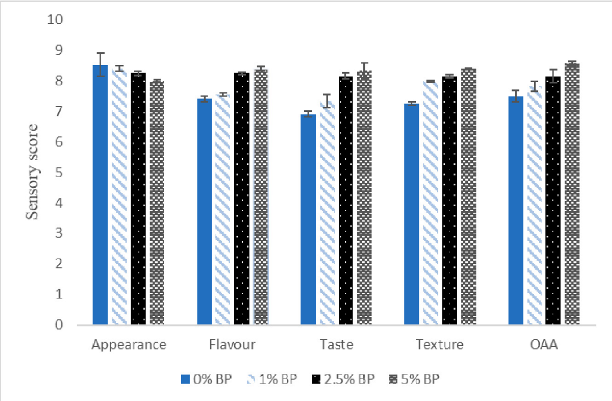

Fig. 2b. Sensory acceptability score of banana pseudostem (BP) incorporated surimi nuggets

antioxidant properties of BP in SNBP. As previously reported by Bhaskar, Mahadevamma, Chilkunda, and Salimath (2012), dietary fibre is recognized for its ability to carry antioxidants such as polyphenols. Similar findings were documented by Carballo et al. (2021), and they stated that 4.5g/kg BP showed a significant reduction in TBA value compared to control. TBA values of the surimi nuggets in the present study were within the threshold limit of 2 mg MDA/kg to negatively affect the sensory attributes of surimi nuggets (Sallam, Ishioroshi & Samejima, 2004).

The peroxide value (PV) measures the rate of oxidative rancidity at the primary level. Table 2 shows the PV of frozen-stored nuggets over 240 days. During storage, a significant increase (P<0.05) was observed in the PV of SN from 0.94 to 4.56 mEq/kg fat, while SNBP showed an increase from 0.99 to 6.50 mEq/kg fat. Both values remained well below the threshold limit of 10 to 20 mEq/kg fat (Kong & Singh, 2016). According to Ninan, Bindu, and Joseph (2010), the PV of fish balls reached 16.29 mEq/kg fat after 15 weeks of frozen storage. In comparison, surimi nuggets typically exhibit a lower PV (2.50 mEq/kg fat after 90 days of storage), which could be attributed to the lower lipid content of the raw material (Moosavi Nasab et al., 2019). Similarly, Oppong, Panpipat, Cheong, and Chaijan (2021) reported that the PV of fish nuggets increased up to 4.03 mEq/kg fat after 90 days of frozen storage. In our study, the fat content in SNBP was found to be higher than in SN, possibly due to the oil absorbed by banana pseudostem during the processing of SNBP. Although the antioxidant properties of banana pseudostem flour are beneficial, they are not sufficient to fully prevent the oxidative degradation of lipids, especially in the presence of factors such as temperature and pro-oxidants like transition metals (Kuruta, 2015). SNBP showed lower TBA values, indicating that the banana pseudostem fiber might be more effective in reducing secondary lipid oxidation products, even if it cannot completely prevent primary lipid oxidation.

Hydrolytic rancidity in fried foods occurs when triglycerides in oil break down into free fatty acids, di- and monoglycerides, and glycerol. The FFAs (free fatty acid) formed by the degradation and breakdown of lipids indicate fat instability during storage. The FFA value of SNBP showed a significant increase (P<0.05) from 0.96 to 2.46% during frozen storage (Table 2). Oppong et al. (2021) suggested that the higher FFA value on storage might be due to lipid hydrolysis or because of lipase/phospholipase activity. On comparing the SN, SNBP showed a lower FFA value, despite its higher PV, which can be attributed to the protective antioxidant effects of

Table 3. Mesophilic and psychrotrophic bacterial count of SN and SNBP stored at -18±2 ºC

Bacterial count (log cfu/g)	Samples	Storage days 0	60	120	180	240	Mean
Mesophilic	SN	4.58	5.34	4.51	4.15	3.85	4.48^{A}
	SNBP	4.61	3.95	3.60	3.49	2.60	3.65^{B}
	Mean	4.60^{a}	4.65^{a}	4.05^{b}	3.82^{c}	3.22^{d}	
Psychrotrophic	SN	2.45	3.90	2.86	2.78	2.49	2.89^{A}
	SNBP	2.32	2.30	2.13	1.89	1.71	2.08^{B}
	Mean	2.38^{a}	3.10^{b}	2.49^{c}	2.34^{d}	2.11^{e}	

Mean (n=3) with different letters on the superscript indicates statistical difference (P< 0.05) at 5% level of significance. Uppercase superscript letters (A and B) compare the marginal means between SN and SNBP. Lowercase superscript letters (a, b, c, d and e) compare the marginal means between storage days.

Table 4. Sensorial characteristics of SNBP and SN during frozen storage

Sensory attributes	Samples	Storage days 0	60	120	180	240	Mean
Appearance	SN	9.00	8.68	8.40	8.40	8.34	8.56^{A}
	SNBP	8.28	8.23	8.10	7.95	7.68	8.04^{B}
	Mean	8.64^{a}	8.45^{a,b}	8.25^{b,c}	8.18^{b,c}	8.00^{c}	
Flavour	SN	8.18	8.13	8.13	7.88	7.82	8.02^{A}
	SNBP	8.33	8.28	8.23	8.10	7.93	8.17^{A}
	Mean	8.25^{a}	8.20^{a}	8.18^{a}	7.99^{a}	7.88^{a}	
Taste	SN	8.15	8.13	8.05	8.05	7.78	8.03^{A}
	SNBP	8.43	8.32	8.18	8.05	8.02	8.20^{A}
	Mean	8.29^{a}	8.22^{a}	8.11^{a}	8.05^{a}	7.90^{a}	
Texture	SN	8.10	7.95	7.88	7.75	7.73	7.88^{A}
	SNBP	8.50	8.40	8.10	8.05	7.32	8.07^{A}
	Mean	8.30^{a}	8.18^{a}	7.99^{a}	7.90^{a,b}	7.52^{b}	
OAA	SN	8.15	8.00	8.02	8.00	7.95	8.02^{A}
	SNBP	8.55	8.38	8.32	8.10	7.45	8.16^{B}
	Mean	8.35^{a}	8.19^{a}	8.18^{a}	8.05^{a,b}	7.70^{b}	

Mean (n=3) with different letters on the superscript indicates statistical difference (P< 0.05) at 5% level of significance. Uppercase superscript letters (A and B) compare the marginal means between SN and SNBP. Lowercase superscript letters (a, b, c, d and e) compare the marginal means between storage days.

polyphenolic compounds in banana pseudostem flour, which inhibit lipid hydrolysis. In addition, Mitcham, Adkison, Lingga, and Bikoba (2022) stated that FFA was not correlated with lipid oxidation or rancidity, and it is more correlated with the bitterness of the product during sensory evaluation. The significant decrease (P<0.05) in the FFA value of SNBP might be due to polyphenolic extracts present in BP. The study conducted by Anusuya, Gomathi, Tharani, and Murugesan (2013) reported that the polyphenolic extract of BP can delay the rate of rancidity in sunflower oil and extend the shelf-life of the product.

The study conducted by Kim et al. (2015) reported that pH value is an important criterion for assessing meat quality as it influences the shelf life, colour, water-holding capacity, and textural properties of the products. The initial pH of SN was 5.77±0.03 and SNBP was 6.10±0.02. The nuggets showed a significant increase (p<0.05) in pH values with increasing time of storage (Table 2). Conversely, Huda, Leng, and Nopianti (2011) reported that the pH of the surimi sample showed a tendency to decrease the pH during frozen storage. During storage, the SNBP showed a gradual increase in pH compared to SN, which might be due to the presence of BP in nuggets. Similar results were observed by Saranya and Sudheer (2016) and they stated that the characteristic pH of fresh pseudostem was in the range of 6.4-6.6, which may influence the pH of nuggets.

The L*, a* and b* values of surimi nuggets with and without BP are shown in Table 2. Significant differences (P < 0.05) in L*, a*, and b* values were noticed between SN and SNBP during storage. The higher L*, a*, and b* values observed for SN compared to SNBP might be attributed to the greater whiteness of surimi. Additionally, the incorporation of banana pseudostem in SNBP might have introduced natural pigments in the fibre, slightly reducing the lightness (L*) and altering the redness (a*) and yellowness (b*) values compared to SN. In the case of SN, there was a significant decrease (P<0.05) in colour values during storage, which could be due to freezing conditions and the leaching of coloured pigments from spices. In another study, Benjakul, Visessanguan, Phongkanpai, and Tanaka (2005) reported that non-enzymatic browning reactions also contribute to colour change in heat-treated fish mince. The redness (a*) value showed a slight decrease, but no significant difference was noticed between 60 and 180 days of storage. A similar effect was noticed by Madane et al. (2020) in dragon fruit peel-incorporated chicken nuggets. Bonato et al. (2016) reported that changes in L*, a*, and b* values correlated with the product's pH values, as an increase in pH darkened surimi nuggets.

Sensory evaluation is an important criterion for evaluating consumer acceptability of a product. The surimi nuggets were optimized based on sensory acceptability score using RSM as shown in Table 1. The sensory property of surimi nuggets incorporated with different concentrations of BP is given in Fig. 2b. The 5% BP incorporated surimi nuggets (SNBP) were more acceptable compared to 0, 1 and 2.5% BP incorporated nuggets. So, SNBP was selected for storage study along with SN. The SNBP had more acceptable flavour, taste, and texture compared to SN (Table 4). The factors contributing to the overall acceptability of a product are the interaction of secondary metabolites and bioactive compounds such as flavonoids, lipids, lignan, coumarins, alkaloids, organic acids, amino acids, and its derivatives present in BP (Deng et al., 2020) with spices and meat. The study conducted by Golge, Kilinççeker, and Koluman (2018) reported that up to 9% fibre can be incorporated into meatballs without affecting the sensory attributes. Mansour and Khalil (1997) reported that fibre type was an important factor in determining the sensory property. During storage, the sensory attributes and overall acceptability of SNBP declined, but it had an acceptable shelf life of up to 180 days.

Pawar, Pagarkar, Rathod, Patil, and Mahakal (2013) reported that a decrease in overall acceptability at the end of storage may be because of protein denaturation and lipid oxidation during frozen storage. Similar findings were observed by Kaur et al. (2015) in their study of fibre-enriched chicken nuggets.

The total bacterial count of nuggets during frozen storage is given in Table 3, which showed a significant decrease. The initial mesophilic and psychrotrophic bacterial counts for SN were 4.58 log cfu/g and 2.45 log cfu/g, respectively. However, for SNBP the counts were 4.61 log cfu/g and 2.32 log cfu/g, respectively. The reduction in the bacterial count may be due to the effect of air blast freezing employed before frozen storage. Oppong et al. (2021) stated that blast freezing technique can help to maintain the quality and safety of the food by retarding the growth of bacteria and other microorganisms. The addition of BP resulted in a significant ($P<0.05$) reduction in mesophilic and psychrotrophic bacterial count of SNBP. This might be due to the antibacterial effect of banana pseudostem against bacteria like *E. coli, Klebsiella sp., Pseudomonas aeruginosa* and *Streptococcus faecalis* (Onyema, Ofor, Okudo, & Ogbuagu, 2016). Similarly, Madane et al. (2020) found that the antimicrobial properties of dragon fruit peel powder caused a reduction in the bacterial count of chicken nuggets. In our study, the initial sampling revealed the absence of gram-negative pathogenic bacteria like *E. coli,* Enterobacteriacea, *Salmonella spp.*, gram-positive pathogens like *S. aureus*, and *Streptococcus* and also yeast and mould in both SN and SNBP indicating the hygienic production and safety of the surimi nuggets with and without BP.

The addition of banana pseudostem in surimi nuggets as a functional ingredient enhanced the nutritional and sensory properties. The study concluded that 5% BP-incorporated surimi nuggets yielded the highest sensory acceptance compared to 0%, 1%, and 2.5% BP-incorporated surimi nuggets. Incorporating 5% BP into surimi nuggets increased the total dietary fibre content by 2.57%, by providing 2.57g of dietary fibre per 186.54 Kcal serving, making them a healthier choice. This augmentation is particularly evident in the improved texture, flavour and increased dietary fibre content of the nuggets. The nuggets had very good acceptability and a shelf life of 180 days under frozen storage. This study underscores the need to explore the latent benefits of underutilized plant-based constituents.

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