Fishery Technology 62 (2025) : 474 - 481

Healthy Coating for Fish Nuggets: Effects of Millet Batter on Coating Performance and Nutritional Composition

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Abstract

The present study investigated the effects of substituting refined wheat flour (RFW) in conventional batter with different millet flours on the coating performance and nutritional quality of fish nuggets. Among the different millets used (pearl millet, sorghum and little millet), substitution of RWF with pearl millet flour significantly ($p < 0.05$) reduced the lightness (L^*) and yellowness score (b^*) of batter. At 20% substitution, the coating pick-up of millet batters was comparable (40.62 to 43.82%) to that of conventional batter (43.90%), but the pick-up ratio decreased as the level of substitution increased up to 50%, regardless of the millets used (38.76-41.54%). The cooking yield of coated nuggets increased proportionally with the addition of millet flour in the batter. Substitution of maida with millet flour in the batter significantly enhanced the nutritional components, including protein and fat. However, the oil absorption by millet batters (285 to 667%) was significantly ($p < 0.05$) higher than that of the conventional batter (334%). Overall, the results of the study revealed that maida in conventional batter can be substituted with millet flour to enhance the coating performance and the nutritional quality of coated products.

Keywords: Coated nuggets, batter, pearl millet, sorghum, coating performance, protein

Introduction

Millets, classified under cereal and popularly known as poor man's crop/nutricereals, is a well-liked traditional food item in many parts of the Indian subcontinent. Millets are nutritionally and functionally rich, containing significant amounts of protein, minerals, vitamins, dietary fibre, and antioxidants (Mehta, Vyas, Dudhagara, Patel, & Parmar, 2024). Millets have the potential to emerge as a super food as they are gluten-free and are highly nutritious, meeting the requirements of a health-conscious diet. Like rice and wheat, millets are consumed in a diversified preparation (boiling whole grain, preparations with flour, etc.). To increase the global productivity and production of millets, the Food and Agriculture Organisation (FAO) declared 2023 as the "International Year of Millets" (Kheya et al., 2023). This initiative has considerably enhanced the research and developmental activities in millet processing and value addition. Seafood is a nutritious food commodity that goes well with cereal-based products. Combining seafood with millet is a great choice for a balanced diet because of the complementary nutritional benefits of each. Seafood-based millet products can have the advantage of nutrition from seafood, such as protein and lipids, and those from millets, such as minerals, vitamins, dietary fibre and carbohydrates, which are otherwise undersupplied in seafood.

Battered and breaded seafood products are popular all over the world because of their delicious taste, aesthetic appeal and the crunchiness of their coating. Battering and breading are also considered as tools for the value addition of low-cost resources. Batter typically consists of flour mixed with water and seasonings (optional). The primary function of batter is to act as an adhesive base for the bread crumbs and also to act as a moisture barrier to the product during frying, making it juicy inside and crispy outside (Ninan, Joseph, Zynudheen, Abbas, & Ravishankar, 2010). As batter coating modifies the

Received 19 July 2025; Revised 25 October 2025; Accepted 27 October 2025

Handling Editor: Dr. Remya S.

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outer surface of the food, the oil absorption by the product during frying is also reduced.

Refined wheat flour (Maida) is the most commonly used ingredient for making batter bases (Bhuiyan & Ngadi, 2024). The popular use of wheat flour for batter formulation is driven by its unique visco-elastic properties, such as lower moisture loss and fat absorption, and a smoother crust after frying (Okonkwo, Mba, Kwofie, & Ngadi, 2021). Nevertheless, wheat flour has a few drawbacks, such as its high gluten content and low nutritional value, particularly when refined wheat flour (RWF) is used. As a result, researchers are now paying more attention to modifying the wheat-based batter formulation using rice, corn, soy or a flour blend. A recent review by Bhuiyan and Ngadi (2024) proposes the use of alternative flour or flour blends to wheat flour in the batter, as the latter has gluten-related health issues. Although numerous studies have been conducted to reduce fat absorption in battered and breaded products by incorporating suitable ingredients into the batter formulation, attempts to enhance the nutritional value of the coating remain limited. So, the present work aimed to enhance the nutritional value of batter used for coating fish nuggets by incorporating different kinds of millet flour in the batter formulation. The effects of millet incorporation on the coating performance and proximate composition of fish nuggets were investigated in this study.

Materials and Methods

Fresh tilapia fish (670 ± 35 g) was procured from a retail fish market, and the mince was prepared after filleting under chilled conditions. Pearl millet (*Cenchrus americanus*), little millet (*Panicum sumatrense*) and sorghum (*Sorghum bicolor*) were purchased from a grocery shop in Visakhapatnam and were ground into flour in a commercial mill. The other ingredients used for fish nuggets (corn starch, ginger, garlic, salt) and batter (refined wheat flour/maida, bengal gram powder, guar gum) were purchased from a departmental store. The chemicals and glassware were procured from the local dealers of Borosil, Merck and Qualigens.

The batter used for coating of nuggets was prepared by following the standard recipe developed by ICAR-Central Institute of Fisheries Technology, Kochi. The composition of different batter formulas is given in Table 1. The millet flours used were those of pearl millet (Bajra), sorghum millet (Jowar) and little millet. Each millet flour was used at three different levels as shown in Table 1. In total, 9 batter formulations were made by replacing RWF with different millet flours and a conventional batter (control) was prepared only with refined wheat flour.

Hunter colour parameters (L^*, a^* and b^*) of the batters were determined by the Hunter colour analyser. A total of 6 readings were taken, and the mean values were compared. The nuggets from tilapia fish mince were prepared as follows. To 100 g of fish mince, 5 g corn starch, 5 g ginger-garlic paste, and 3 g salt were added and blended in a mixer grinder. The ground mass was moulded into a ball and beaten to remove the entrapped air. It was then spread on an aluminum tray at a thickness of 1 cm and steamed for 15 min using a domestic food steamer. After cooling, nuggets of 2.5 x 1 cm were cut from the cooked mince and battered and breaded. The nuggets were uniformly coated with batter, excess batter was drained off, coated with

Table 1. Composition of batter formulations

	20% replacement	30% replacement	50% replacement	Control
Millet flour (pearl millet/ sorghum/little millet) g	16.5	24.75	41.25	0.00
Refined wheat flour (g)	66.00	57.75	41.25	82.50
Corn flour (g)	8.5	8.5	8.5	8.5
Bengal gram powder (g)	8.5	8.5	8.5	8.5
Turmeric powder (g)	0.25	0.25	0.25	0.25
Gum acacia (g)	0.25	0.25	0.25	0.25
Salt (g)	1	1	1	1
Chilled Water (ml)	140	140	140	140

breadcrumbs and fried in refined sunflower oil (180 °C for 120 sec).

The coating characteristics, such as coating pick-up, cooking yield and frying loss, were determined as given in the equations below (Hsia, Smith, & Steffe, 1992).

$$\text{Coating pick-up} = \frac{(\text{Weight of nugget after coating} - \text{Weight of nugget before coating})}{\text{Weight of nugget before coating}} \times 100$$

$$\text{Cooking yield} = \frac{(\text{Weight of nugget after frying} - \text{Weight of nugget before coating})}{\text{Weight of nugget before coating}} \times 100$$

$$\text{Frying loss} = \frac{(\text{Weight of nugget after frying} - \text{Weight of nugget after coating})}{\text{Weight of nugget after coating}} \times 100$$

Moisture, protein, fat and ash contents of the fried nuggets were determined as per the AOAC (2016) method. The carbohydrate content of the nuggets was calculated by the difference method by deducting the sum (%) of moisture content, crude protein, crude fat, and ash from 100.

Oil absorption was calculated from the difference in the fat content of coated nuggets before and after frying, expressed as a percentage using the following equation (Tamsen, Shekarchizadeh, & Soltanizadeh, 2018)

$$\text{Oil absorption} = \frac{(\text{Fat content after frying} - \text{Fat content before frying})}{\text{Fat content before frying}} \times 100$$

The data derived from the study were subjected to ANOVA using SPSS software (SPSS 16.0). For evaluating the coating performance, the number of samples (n) was 7, and for other parameters, n was 3. Statistical significance was determined at a 95% confidence level ($p < 0.05$).

Results and Discussion

Colour is an important physical property of batter that contributes to the aesthetic attribute of fried coated products. The colour of the batter and breadcrumbs contributes to the typical golden yellow colour of coated food products after frying. Even though the colour of batter is dominated by turmeric powder, the Hunter colour values of MF batters were compared to the RWF batter to understand the influence of millet flour on the lightness and yellowness of batter. The addition of millet flour to the batter did not cause any obvious colour difference by the human eye, but there were significant differences in Hunter values. As Fig. 1a depicts, the highest lightness score (L^*) was displayed by the RWF batter (84.14). Among all millets, substitution of RWF with pearl millet flour significantly ($p < 0.05$) reduced the lightness (L^*) and yellowness score (b^*) of batter. On the other hand, even though the lightness score reduced, increasing levels of little millet and sorghum significantly ($p < 0.05$) increased the yellowness score (41.3 to 50.97) of batter compared to the control (40.57). The difference in colour attributes exhibited by different millet flours could be due to the difference in their chemical composition. Millets have carotenoids, flavonoids, lipids and free sugars that decide the colour (Choudhary, Vignesh, Chidanand, & Baskaran, 2025) along with the colour of their bran. Most species of pearl millet have a slate grey colored bran that impairs the colour of food products, and in the present study, the addition of pearl millet flour resulted in a significant reduction of the lightness value of its batter.

The yield and quality of coated fried food product is dependent on the amount of coating adhered to the surface of the product, i.e., the coating pick-up. Generally, coating pick-up of battered and breaded products varies from 30-50% (Loewe, 1993). As seen in Fig. 2a, the coating pick-up of millet batters at 20% inclusion (40.62 to 43.82%) was comparable to that of RWFB (43.90%). However, replacement of RWF with 50% millet flour resulted in a modest reduction in coating pick-up of pearl millet (38.76%) and sorghum (41.54%), while a significant reduction ($p < 0.05$) in coating pick-up was noticed with 50% little millet (40.28%). This indicates that the viscosity characteristics of the batter were negatively influenced when the amount of millet flour was increased up to 50% in the batter. Among the different millet flours used, the coating pick-up of pearl millet batter was slightly lower compared to little millet and sorghum millet batters. The batter pick-up is related to the viscosity of the batter system. Since wheat flour has a high gluten protein content, it can contribute more elasticity and

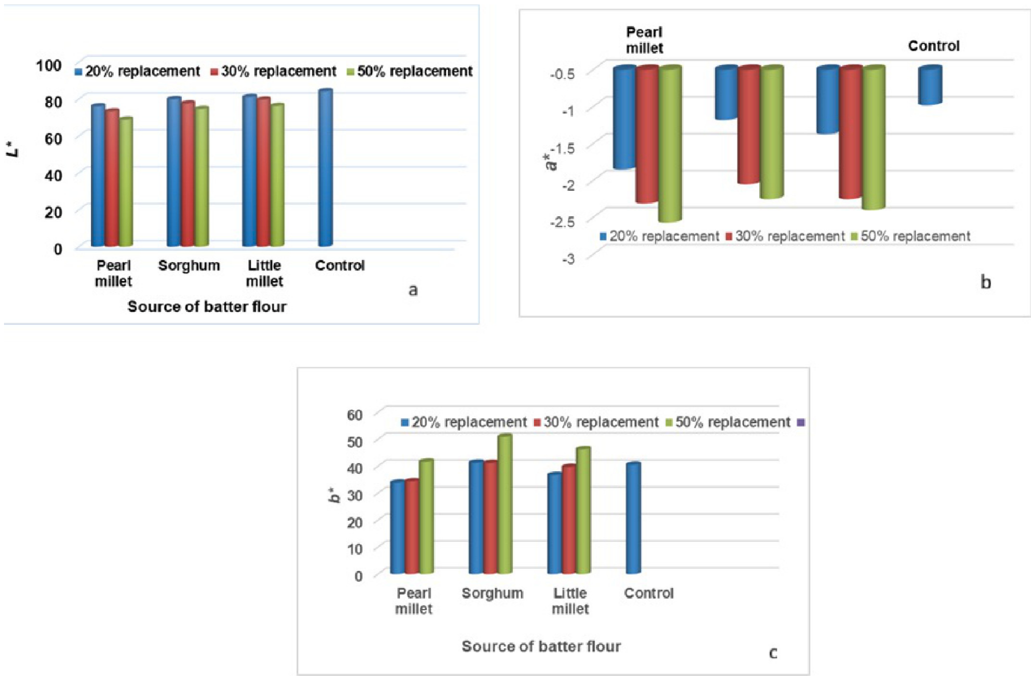

Fig. 1. Hunter colour values (a-L*, b-a* and c-b*) of batter containing different millets

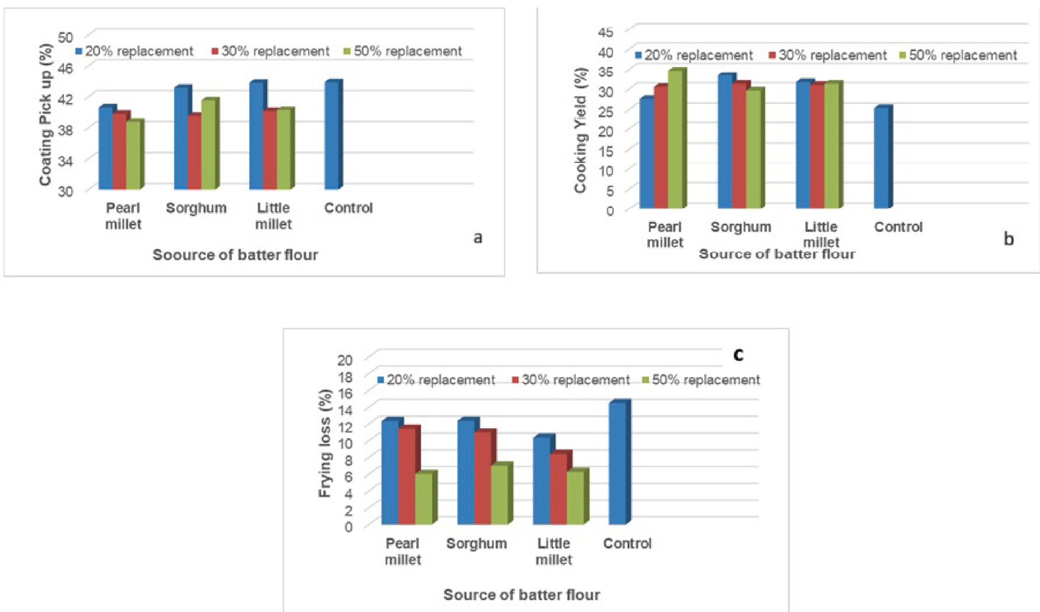

Fig. 2. Coating performance, a-coating pick up, b-cooking yield and c-frying loss of fish nuggets coated with millet flour batter (n=7)

cohesiveness in food formulations compared to millet flour, which is a non-gluten product. Sharma, Gujral, and Solah (2017) observed a low visco-elastic nature of millet flour due to the lack of gluten, which hinders its applications for making chapati/ bread. Pearl millet is reported to have a high fibre content (Munshi & Dashora, 2024), contributing to poor viscoelastic behaviour in the batter, resulting in a lower coating pick-up.

Cooking yield represents the weight gain of the coated product after frying. Cooking yield of nuggets coated with wheat flour batter and millet batter was significantly different (Fig. 2b). Millet battered nuggets yielded significantly higher ($p < 0.05$) weight after cooking compared to conventional batter. Further, the cooking yield increased proportionally with the addition of millet flour in the batter. One of the reasons for the higher yield of millet battered nuggets after frying could be attributed to its oil binding properties. Millet flours have high oil binding capacity compared to wheat flour and hence result in more weight gain after frying in oil. The high starch and fibre content of millet flour aids in the creation of pores on the coating during frying, which allows it to absorb more oil. This finding aligns with the results of fat uptake given in Fig. 3. Additionally, the millet flour coating retained moisture within the fried nuggets compared to the conventional coating, as shown by the proximate composition results (Table 2). This improved moisture retention also contributed to the higher cooking yield observed in millet battered nuggets. The differences noticed among the three millet flour coatings could be attributed to their compositional variations.

The frying loss represents the weight loss of nuggets after cooking. Frying loss of millet flour battered nuggets varied from 6-12% (Fig. 2c) and was significantly lower ($p < 0.05$) than that of the control sample (14.49%). Frying loss was inversely proportional to the quantity of millet flour in the batter. During the frying process, the batter coating (starch) gelatinizes and forms a network structure, acting as a barrier to the loss of moisture and other juices from the product. It is assumed that the coating based on millet starch had higher barrier properties than that of wheat flour and hence reduced the frying loss significantly.

Proximate composition indicates the nutritional value of food products. The results of proximate composition analysis of coated nuggets after frying are presented in Table 2. The results indicate that the moisture, protein, fat and ash content of MF battered nuggets were significantly ($p < 0.05$) higher than that of RWF battered nuggets. As explained previously, millet batter might have controlled the release of moisture and exudate coming out from the product during frying. As a result, the moisture was trapped within the nuggets/coating, leading to a higher moisture content. This result suggests superior barrier properties (one of the functional properties required for coating) of MF coating compared to RWF coating.

Refined wheat flour is a poor source of protein and cannot contribute to the protein content of coated fish products. In the present work, RWF coated

Table 2. Proximate composition of nuggets coated with millet batter at different replacement levels (n=3).

Source of batter	Moisture (%)	Protein (%)	Fat (%)	Ash (%)	Carbohydrate (%)
Pearl millet					
20%	44.34 ± 0.76^{b}	15.62 ± 0.46^{b}	5.80 ± 0.43^{a}	1.20 ± 0.10^{a}	33.91 ± 0.90^{c}
30%	46.57 ± 0.37^{b}	16.49 ± 0.41^{c}	5.65 ± 0.38^{bc}	1.83 ± 0.34^{bc}	26.92 ± 0.76^{b}
50%	50.28 ± 0.57^{d}	18.18 ± 0.42^{d}	7.02 ± 0.18^{c}	1.98 ± 0.13^{c}	23.09 ± 1.47^{a}
Sorghum					
20%	45.62 ± 0.55^{b}	14.81 ± 0.57^{ab}	6.51 ± 0.39^{b}	1.51 ± 0.37^{b}	33.24 ± 1.27^{c}
30%	47.60 ± 0.53^{c}	16.44 ± 0.73^{c}	7.70 ± 0.45^{c}	1.60 ± 0.19^{b}	26.02 ± 1.05^{b}
50%	48.27 ± 0.44^{c}	19.95 ± 0.75^{d}	8.38 ± 0.39^{d}	1.81 ± 0.27^{bc}	21.22 ± 0.92^{a}
Little millet					
20%	46.45 ± 0.42^{b}	14.77 ± 0.43^{ab}	5.30 ± 0.34^{a}	1.81 ± 0.12^{bc}	33.08 ± 1.25^{c}
30%	45.13 ± 0.73^{b}	15.48 ± 0.39^{b}	5.20 ± 0.34^{a}	1.65 ± 0.23^{b}	28.04 ± 0.34^{b}
50%	49.71 ± 0.72^{d}	18.82 ± 0.53^{d}	7.73 ± 0.38^{c}	1.88 ± 0.22^{cd}	21.86 ± 0.98^{a}
Control	41.90 ± 0.40^{a}	13.44 ± 0.54^{a}	5.53 ± 0.31^{a}	1.13 ± 0.14^{a}	37.91 ± 0.74^{d}

The different letters given as superscripts in each column represent the statistical difference between the samples nuggets had 13.44% protein, but substitution of RWF in batter formulation significantly increased the protein content of fried fish nuggets (14.77 to 20.17%). A proportional increase in protein content with the addition of millet flour was observed. Among the different millet flour coated nuggets, pearl millet and sorghum resulted in a significant increase in protein content compared to little millet. In general, the protein content of Indian millets varies from 6-13% (Jacob et al., 2024). Pearl millet, sorghum and little millets are reported to contain 11.6, 10.4 and 8.7% protein, respectively (Gowda et al., 2022), whereas that of refined wheat flour is nearly 10% (Marpalle, Sonawane, & Arya, 2014). The higher protein in MF-coated nuggets could be associated with the rich protein content in millet flour compared to refined wheat flour. Similar findings were reported by Akhila et al. (2023) in chicken nuggets prepared by substituting refined wheat flour with different millet flours. Ash content indicates the amount of minerals and salts present in the sample. Millet flour battered products showed slightly higher ash content than RWF coated samples, which could be due to the presence of more minerals in millet flour. Munshi and Dashora (2024) compared the composition of different millet flours to that of wheat flour and noticed that the millet flours are highly enriched with essential minerals compared to wheat flour. Regarding the fat content of fried nuggets, a similar trend to that of protein was noticed. At a 20% inclusion level, the fat content of MF battered nuggets was comparable (5.30 to 6.51%) to that of control nuggets (5.53%), whereas the addition of MF up to 50% significantly increased the fat content of fried nuggets (7.02 to 8.38%). A higher fat content, in parallel with increasing levels of millet flour in the batter formula, is due to the higher absorption of oil by millet starch during the frying process. Elavarasan, Malini, Ninan, Ravishankar, and Dayakar (2024) reported a significantly higher fat content in fish sausages prepared by replacing corn starch with different varieties of millet flour.

Carbohydrate is the major component in millet flours, with the concentration varying from 60-75% depending on the species of millet (Munshi & Dashora, 2024). In the present study, the quantity of CHO in coated nuggets reduced significantly with increasing levels of millet flour in the batter. Nuggets coated with RWF batter had the highest amount of CHO (37.91%), whereas those in MF battered products varied from 21 to 33%, depending on the variety and quantity of millet flours added to the batter. Within the MF battered nuggets, the CHO content of pearl millet and sorghum added nuggets was comparable, but the CHO content of little millet battered nuggets was the lowest.

Oil absorbed during the frying of nuggets was determined to evaluate the oil absorption properties of millet flours. As seen in Fig. 3, at 20% substitution, the OA of MF battered nuggets was comparable to that of RWF nuggets (334%), but significantly ($p < 0.05$) higher OA was noticed at 50% substitution. Sorghum battered nuggets displayed the highest OA (351-667%) than those of little millet (341 to 621%) and pearl millet (285 to 618%). In the process of frying, oil is absorbed by the food products and can be explained by two mechanisms. As the water replacement theory suggests, water evaporates from the food's surface during frying, leaving pores and subsequently, oil is absorbed by the pores (Ching et al., 2021). Another theory, known as the surface interaction mechanism, suggests that various chemical reactions occur on the food surface during frying, leading to the formation of surface-active compounds that promote oil absorption by increasing the contact between the food and the oil (Jeong et al., 2021). Rahimi and Ngadi (2014) compared the fat absorption of wheat flour and rice batter, and they noticed a lower oil absorption property by wheat flour than rice flour batter. This finding can be related to the formation of smaller holes/cracks in wheat flour during frying compared to rice flour, which showed larger holes/cracks on the surface. Another theory can elucidate the underlying mechanism of oil absorption by cereals. The gluten protein content of starch has a significant role in oil absorption characteristics. Studies suggest that a compact gluten network

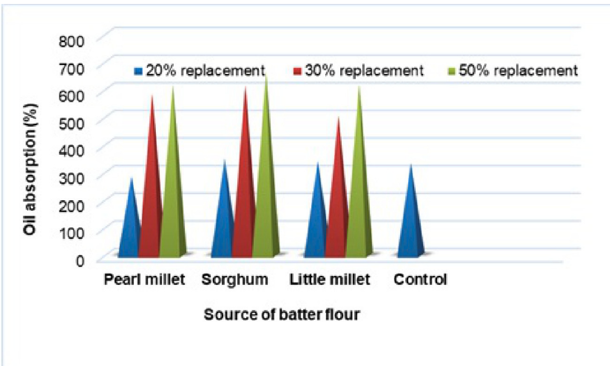

Fig. 3. Oil absorption in fried nuggets coated with millet flour batter

structure created during deep frying prevents the penetration of oil into the food matrix (Wang, Wen, Fan, & Zheng, 2024; Li et al., 2025). Accordingly, RWF batter with a higher gluten content than MF batter might have reduced oil uptake during frying of nuggets.

The present study investigated the effects of the substitution of refined wheat flour in batter formulation by different millet flours at varying concentrations on coating parameters and nutritional value of fish nuggets. The results revealed that at a 20% substitution level, the coating pick-up of millet flour batter was comparable to that of conventional batter prepared with refined wheat flour, but the pick-up ratio slightly reduced with increasing levels of substitution. Nuggets coated with millet flour batter showed a significantly higher ($p < 0.05$) cooking yield than those coated with wheat flour batter. Additionally, the nutritional components such as protein, fat and ash (mineral) content of the fried nuggets were enhanced with an increasing proportion of millet flour in the batter. Nevertheless, substituting wheat flour with millet flour up to 50% has significantly increased the oil absorption in fried nuggets compared to conventional batter. The sensory evaluation (data not presented here) indicated no major changes in acceptability between the RWF battered nuggets and the MF battered nuggets. Also, nuggets prepared with MF batter were crispier compared to those of RWF nuggets. In brief, findings of the study suggest that millet flours can be effectively incorporated into batter formulations to enhance the nutritional value and cooking performance of coated products. However, increased oil absorption by millet flour is a health concern, and hence, future research should focus on developing strategies to reduce the increased oil uptake associated with millet flour during frying.

Acknowledgement

The authors would like to thank the Indian Council of Agricultural Research, New Delhi for its guidance and support in the Research and development activities of ICAR-Central Institute of Fisheries Technology and the Director, ICAR-CIFT for granting permission to carryout the study.

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