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Carboxy Methyl Cellulose, Xanthan Gum, and Carrageenan Coatings Reduced Fat Uptake, Protein Oxidation, and Improved Functionality in Deep-Fried Fish Strips: An Application of the Multiobjective Optimization (MOO) Approach

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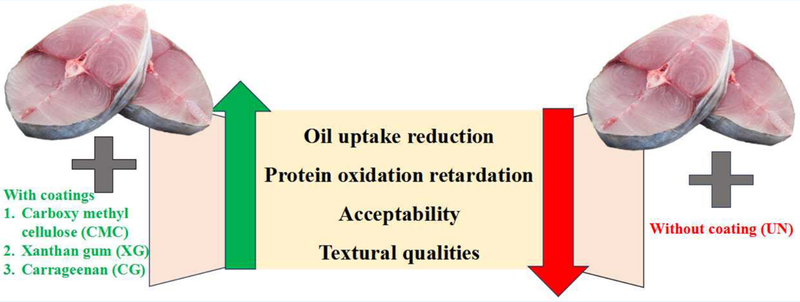

ABSTRACT: In this study, a multiobjective optimization (MOO) approach was utilized for effective decision-making when several variables were changing simultaneously during frying. Carboxy methyl cellulose (CMC), xanthan gum, and carrageenan coatings in different concentrations (0.25−1.50%, w/v) were applied on fish strips to reduce the oil uptake and protein oxidation during frying. The pickup of the strips increased significantly ($p < 0.05$) with increasing concentration. The CMC was effective in oil uptake reduction and protein oxidation, as revealed by the lower carbonyl and sulfhydryl contents in the fried strip. The hardness and chewiness of the coated fish strips were found to be declined significantly ($p < 0.05$) with increasing coating concentrations. The moisture, lipid, toughness, hardness, cutting force, oiliness, sulfhydryl content (all min), oil uptake reduction, and carbonyl content (both max) were considered as multiple criteria for the MOO technique, and fried strips coated with 1% CMC, followed by 0.75% xanthan gum and 0.75% carrageenan, emerged as the best optimal coating.

1. INTRODUCTION

Fried foods are the preferred foods of consumers worldwide. The distinctive sensory traits such as aroma, color, and texture of fried foods are the driving forces behind their wider acceptance by consumers of different ages.[1] “The national family health survey 2015−16 conducted by the Ministry of Health, Govt. of India revealed that around 10% of women consume fried foods daily and 36% weekly. Considering the population of India, these numbers are staggering and worrisome. Changing life style, urbanization, taste of fried food, and quick preparation will further enhance the consumption of fried foods.

In immersion frying, food is cooked in hot edible oil mostly at a temperature range between 160−180 °C[2] or even higher at some point of time. The high temperature causes mass transfer and heat transfer during the frying process. The mass transfer essentially corresponds to moisture evaporation and oil absorption.[3] Foods become more palatable owing to the juicy interior and crisp exterior crust.[5] Therefore, frying enhances the taste and similarly the oil content, but still remains popular. Excess fat consumption is considered to raise low-density lipoprotein (LDL), blood pressure, and thereby coronary heart disease. Contrastingly, there has been a recent surge in demand for low-fat products. In recent years, there has been a lot of research toward minimizing the oil uptake during deep-fat frying.

The growing awareness and health caution of consumers are pushing the food industry and researchers to find out new strategies for minimizing the fat absorption in fried items. On

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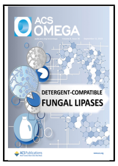

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Table 1. Effect of Carboxy Methyl Cellulose, Xanthan Gum, and Carrageenan Coating Parameters of Fish Strips after Frying[a]

	coating parameters			
treatments	Coating pickup (%)	fat uptake reduction (%)	moisture retention increment (%)	frying yield (%)
Carboxy methyl cellulose				
UN	0.00 ± 0.00^{g}			68.20 ± 0.16^{g}
CM1	2.78 ± 0.13^{f}	7.29 ± 0.79^{f}	0.22 ± 0.03^{f}	72.21 ± 0.15^{f}
CM2	3.22 ± 0.13^{e}	16.57 ± 0.78^{e}	1.14 ± 0.13^{e}	74.32 ± 0.13^{e}
CM3	4.21 ± 0.10^{d}	32.97 ± 0.83^{b}	2.93 ± 0.11^{b}	76.56 ± 0.14^{d}
CM4	5.14 ± 0.12^{c}	44.77 ± 0.91^{a}	4.32 ± 0.43^{a}	79.24 ± 0.15^{a}
CM5	6.26 ± 0.13^{b}	27.81 ± 1.11^{c}	2.48 ± 0.31^{c}	78.63 ± 0.13^{b}
CM6	7.68 ± 0.10^{a}	24.93 ± 0.74^{d}	2.00 ± 0.09^{d}	78.14 ± 0.13^{c}
Xanthan gum				
UN	0.00 ± 0.00^{g}			68.20 ± 0.16^{f}
XG1	3.22 ± 0.12^{f}	6.67 ± 1.08^{f}	0.06 ± 0.00^{f}	69.35 ± 0.14^{e}
XG2	4.25 ± 0.11^{e}	15.13 ± 0.93^{e}	0.95 ± 0.08^{e}	73.34 ± 0.17^{d}
XG3	5.22 ± 0.13^{d}	43.56 ± 0.89^{a}	4.03 ± 1.01^{a}	75.71 ± 0.17^{a}
XG4	6.31 ± 0.13^{c}	27.09 ± 0.74^{b}	2.58 ± 0.23^{b}	74.56 ± 0.17^{b}
XG5	7.42 ± 0.12^{b}	25.29 ± 0.64^{c}	2.32 ± 0.39^{c}	74.25 ± 0.17^{c}
XG6	9.16 ± 0.14^{a}	23.14 ± 1.03^{d}	1.66 ± 0.07^{d}	74.53 ± 0.19^{c}
Carrageenan				
UN	0.00 ± 0.00^{g}		-	68.20 ± 0.16^{g}
CG1	5.04 ± 0.12^{f}	7.42 ± 1.01^{e}	0.05 ± 0.00^{e}	70.32 ± 0.19^{f}
CG2	5.34 ± 0.12^{e}	15.62 ± 0.83^{d}	1.02 ± 0.01^{d}	73.49 ± 0.12^{e}
CG3	6.23 ± 0.13^{d}	44.02 ± 0.78^{a}	4.02 ± 1.19^{a}	77.54 ± 0.13^{b}
CG4	6.72 ± 0.15^{c}	28.07 ± 1.01^{b}	2.78 ± 0.08^{b}	77.75 ± 0.14^{b}
CG5	7.22 ± 0.12^{b}	27.09 ± 1.04^{b}	2.44 ± 0.4^{b}	76.23 ± 0.11^{c}
CG6	8.53 ± 0.11^{a}	24.87 ± 0.82^{c}	1.92 ± 0.03^{c}	75.21 ± 0.12^{d}

[a] Values presented in the table are means ± SD, $n = 3$. Mean values bearing different superscripts (a, b, c, etc.) in a column are significantly different ($p < 0.05$).

the other hand, reducing the oil uptake without changing the taste in fried items is a challenging task.[5] Williams and Mittal[6] indicated that the best approach to minimize the fat intake is to choose an apt food coating before frying. A suitable edible coating material may be applied as a thin layer by dipping or any other method. The hydrophilic hydrocolloids act as a coating over the products by reducing the water loss, and if water loss is reduced, oil uptake would also be reduced. The modified celluloses such as methyl cellulose, hydroxypropyl methyl cellulose, and carboxyl methyl cellulose were reported to have water-soluble and excellent coat-forming properties.[6]

In addition to the above, coating materials based on many naturally derived proteins (corn zein, soy protein, whey protein etc.) and hydrocolloids (cellulose derivatives, pectin, starch, carrageenan etc.) were also tried. The researchers have been trying several proteins and polysaccharides-based coating material especially on plant-based food items such as potato balls (HPMC),[7] dough disc (MC),[8] chickpea and green gram splits,[9] fried potato pellet chips,[10] fried breaded banana,[11] and fried potato strips.[12] In addition to this, there are few studies conducted on meat and meat products such as minced chicken meatballs (carrageenan),[13] chicken breast strips (whey protein),[14] and shrimp (gum).[15] Xavier et al.[16] concluded that addition of 1% chitosan in the batter formulation can improve the coating and oil reduction in par-fried fish fingers compared to alginate and fish gelatin individually. In another study, 6% bamboo shoot dietary fiber powder-coated fish balls were found to have maximum reduction in oil uptake.[17]

However, there is no comprehensive study on fish strips using some commercially important carbohydrates-based coating material that can substantially reduce the oil uptake along with the prevention of protein oxidation during frying. The protein oxidation is also an equally important phenomenon to be prevented during frying. In addition to this, the multiobjective optimization (MOO) approach is applied to find out the best coating using multiple variables (fat uptake, moisture, oiliness, texture, protein oxidation etc.). The majority of the researchers use a single variable for the optimization. However, the synchronized optimization of numerous variables is much more rational and enviable. In this study, a multiobjective optimization for the best coating considering several key attributes for fish strips was performed. Therefore, this investigation is aimed to study the application of edible carbohydrate coatings for oil reduction efficacy in fried fish strips with special emphasis on fish proteins' oxidation using the MOO approach.

2. RESULTS AND DISCUSSION

2.1. Effect of Different Concentrations of Polysaccharide Hydrocolloids on the Coatings Pickup of Fish Strip. Coatings are used to improve the appearance, flavor, and color, increase water retention, aid in browning, and also give a crispy texture to the fried products.[18] Coating pickup is defined as the amount of coating solution that adheres to the surface of the product when immersed in the solution[19] and changes the quality attributes of fried products.[4] In the present investigation, the coating pickup of the fish strips was found to be increased significantly ($p < 0.05$), with increase in coating concentrations of three different edible coatings (Table 1). This is possibly due to the increased viscosities of the coating solutions with increase in the concentrations. Abtahi et al.[20] also reported an increase in the CMC gum coating pickup with increase in concentration. In general, by increasing the coating concentration, more hydrocolloid solution adheres to the fish

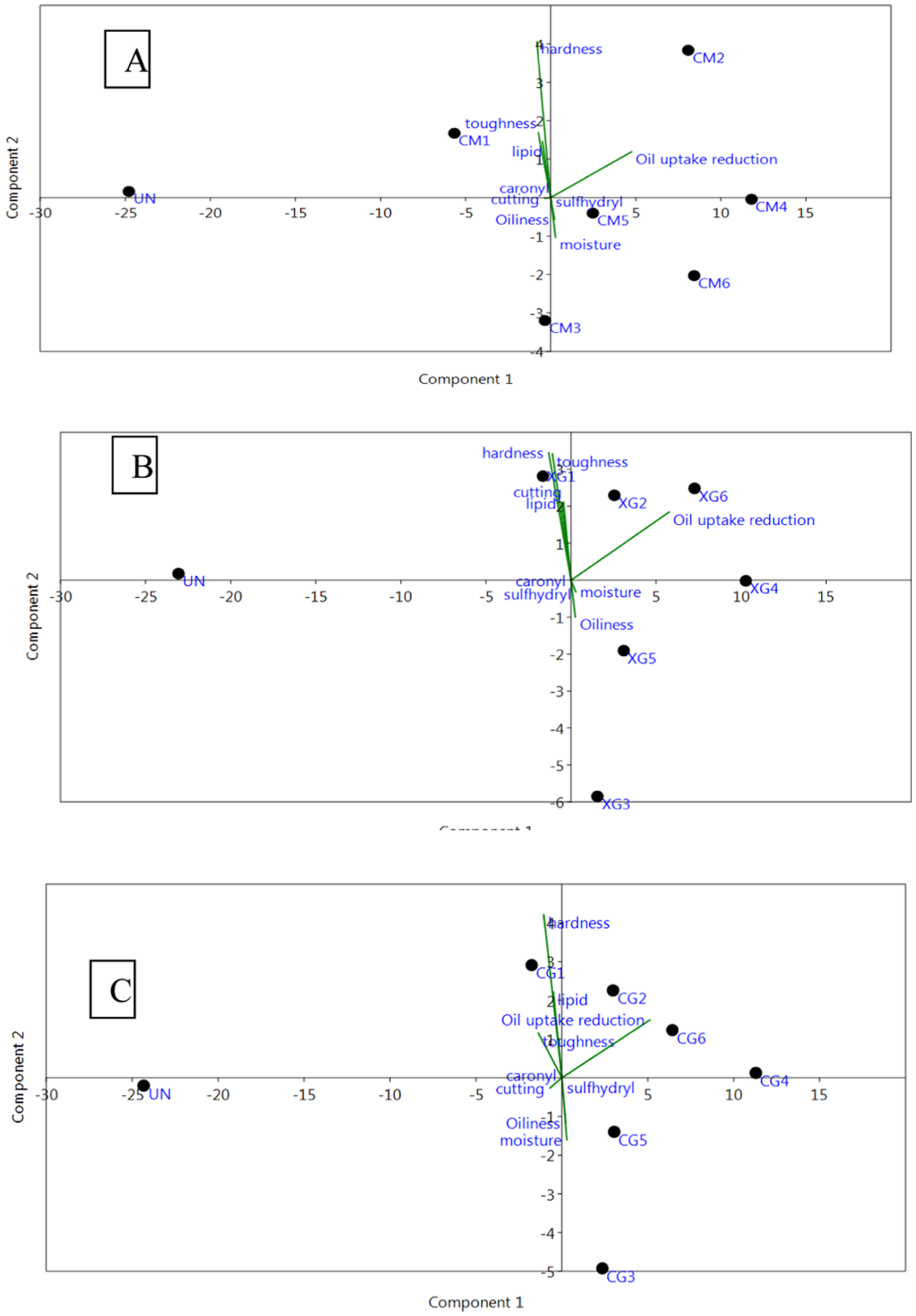

Figure 1. PCA biplot for (A) CMC, (B) xanthan gum, and (C) carrageenan.

strips and thus, coating pickup (%) is increased considerably. During dip coating, the film thickness is defined by the viscosity and density of the coating solution, and draining time.[21] The concentrations of solutions of coatings were varied from 0.25 to 1.50% (Table 1). Among various concentrations and three different carbohydrate source-coated fish strips, the maximum coating pickup was obtained for strips coated with 1.5% xanthan gum (9.16%), followed by 1.5% carrageenan (8.53%) and 1.5% CMC (7.68%) (Table 1). Since xanthan gum has a maximum viscosity of 1200 cp compared to 400–800 cp for CMC and 5 cp for CG, it exhibits the highest coating pickup. Moreover, it (xanthan gum) is soluble in both hot and cold water and imparts a high viscosity to solutions at low concentration.[22] In addition to the aforementioned, xanthan gum (XG) conferred the highest coating pickup probably due to the greater structural stability properties with the product. Higiro et al.[23] established that the xanthan gum molecule contains side chains that bind its helical structure, thus making an extraordinary stable structure.

2.2. Effect of Polysaccharide Hydrocolloid Coating on Fat Uptake Reduction. In case of all three different carbohydrate coatings, the fat uptake was found to be decreased significantly ($p < 0.05$) compared to the fish strips that remained uncoated (control) (Table 1). In view of the strips coated with CM4, CG3, and XG3, the fat absorption was reduced by 44.77, 44.02, and 43.56% respectively. In another research, it was explained that the less oil absorption in the coated products may be related to the formation of covalent links within the coatings during frying.[10] In uncoated strips, the water escape might have created pores and channels,[24] thus enhancing the oil absorption, but in the case of coated strips, these pores and channels might have been blocked to prevent moisture loss, thus eventually preventing the fat uptake into the coated product during deep-fat frying. In addition to this,[25] it was proved that the gelation of the protein depends on the structural uniqueness of the protein (e.g. charges and hydrophobicity). During gelation, the small protein aggregates group together to form large aggregates that form a void-filling setup and thus reduce the oil uptake. In a previous study, Tavera-Quiroz et al.[26] noted the oil reduction of 30% in potato chips coated with edible methyl cellulose plasticized with sorbitol. Similarly, Abtahi et al.[20] reported that CMC could lower up to 98% of oil uptake in fried items. However, the oil uptake reduction efficacy of CMC depends on the type of coated food item and nature of other ingredients. Compared to xanthan and guar gum, CMC was found to be more effective in decreasing the oil uptake in fried potato chips.[27] Coating integrity is an important parameter related to adhesion and elasticity, decreasing possible discontinuities and “brittle zones” and avoiding pores and cracks in the fried products.[28]

The correlations among the variables in the fish strips were analyzed with the variability of the components using principal components analysis (PCA). It is a multivariate data reduction technique that aims to reduce a larger set of variables into a smaller set of ‘artificial’ variables, called ‘principal components’, which account for most of the variance in the original variables. PC1 is the primary or first principal component that explains the maximum variance in the data. PC2 is the second principal component that is orthogonal to PC1. In these results (for CMC), the first two principal components have eigenvalues greater than 1 and combined, they explain 96.57% of the variation in the data. The PCA biplot showed that the first and second principal components (PC1 and PC2) account for 92.36 and 4.21% variations in the dataset (Figure 1A). The first principal component is strongly correlated with variables such as oil uptake reduction, moisture, and oiliness. The variables like hardness, lipid, toughness, and cutting contributed to PC2 and they have positive correlations among them as they have small angles between them. But, the oil uptake reduction is further away from the PC origin and has more influence (97.81%) on PC1.

Similarly, for xanthenes, PCA showed that the first and second principal components (PC1 and PC2) account for 88.78 and 8.13% variations, with 96.91% combined variations (Figure 1B). Variables such as oil uptake reduction (majorly), moisture, oiliness, and sulfhydryl contributed to PC1. Variables such as hardness, lipid, toughness, and cutting contributed to PC2 and they have positive correlations among them as they have small angles between them. The oil uptake reduction is further away from the PC origin and has more influence (94.06%) on PC1.

For carrageenan, PCA showed that first and second principal components (PC1 and PC2) account for 92.36 and 4.77% variations, with 97.08% combined variations (Figure 1C). Variables such as oil uptake reduction (majorly), moisture, and oiliness contributed to PC1. Variables like hardness, lipid, and toughness contributed to PC2 and they have positive correlations among them as they have small angles between them. The oil uptake reduction is further away from the PC origin and has more influence (93.51%) on PC1.

2.3. Effect of Polysaccharide Hydrocolloid Coating on Water Content Retention.

The water content is one of the important parts of food and affects many textural properties. The water content of the fresh fish strips was 78.46%, which reduced to 65.55% (uncoated fish strip) after deep-fat frying. The decrement in water content after frying has been reported in several fish species such as catfish strips (Hamad, 2021),[29] Asian sea bass,[30] and rainbow trout strips.[31] The decrement in water content may be attributed to the deep frying of the fish strips at high oil temperature leading to loss of water due to vaporization and then escape through their surface. As the water moved out of the pores, frying oil occupied some of the spaces. In addition to this, intensification of protein, fat, and mineral content also caused the decrease in amount of water content in food.[8,32]

Among different CMC coating concentrations, the fish strips coated with 1% aqueous CMC suspension (CM4) was found to have maximum moisture retention (4.32%). Similarly, in case of various concentrations of xanthan gum coating, the fish strips coated with 0.75% xanthan gum suspension (XG3) showed maximum moisture (4.03%). Similarly, among the different concentrations of carrageenan, the fish strips coated with 0.75% aqueous carrageenan suspension (CG3) were shown to have maximum moisture retention (4.02%) (Table 1). Among the different carbohydrate coatings and various concentrations, CMC (CM4) had better protective effect on moisture retention compared to carrageenan and xanthan gum-coated fried fish strips.

One thing that is noticeable here is that all coated fish strips had a protective effect on moisture retention in fried fish strips. This is possibly due to the continuous network shaped up by the edible coating, which thus prevented the moisture loss, and thereby retained the greater moisture content in the coated samples in comparison to the uncoated fish strips.[33] A similar protective effect on moisture retention due to 10% denatured whey protein isolate-coated chicken breast strips on deep-fat frying was observed.[14] The continuous polysaccharide film is a kind of “sacrificial moisture agent”, where water disappears from the coating instead of the interior of the food.[34]

2.4. Effect on Frying Yield.

The frying yield represents the material loss during the frying process and is calculated from the mass before and after frying.[35] Frying yield is said to be inversely proportional to the cooking loss.[33] During the frying process, the water content gets lost from the surface of the product, which affects the frying yield. Therefore, it is essential to reduce the product loss because it causes consumer dissatisfaction due to shrinkage in the product dimension and weight loss.[36] In the present investigation, the frying yield registered an increasing trend for all coated samples and thereafter a decrease was observed (Table 1). The frying yield increased significantly ($p < 0.05$) for CMC from 72.21 (CM1) to 79.24 (CM4), for xanthan gum from 69.35 (XG1) to 75.71 (XG3), and for carrageenan from 70.32 (CG1) to 77.75 (CG4) with increase in coating concentrations (Table 1). The findings of the present study were corroborated with similar studies conducted earlier.[16,33,37] The increment in frying yield values of coated fish strips might be due to the formation of films by hydrocolloid coatings, hence improving the water retention within the fried products.[15] In the present study, higher moisture retention, enhanced coating pickup (Table 1), and more water and salt-soluble proteins (data not reported)

Table 2. Effect of Carboxy Methyl Cellulose, Xanthan Gum, and Carrageenan Coatings on the Functionality and Protein Oxidation of Fish Strips after Frying[a]

	functional properties			
treatments	water-holding capacity (%)	protein solubility (%)	carbonyl content (nmol/mg protein)	sulfhydryl content (mol/10^5 g protein)
Carboxy methyl cellulose				
fresh fish	75.88 ± 0.78^{a}	75.70 ± 1.04^{a}	0.45 ± 0.02^{d}	8.36 ± 0.04^{a}
UN	69.58 ± 1.14^{e}	54.33 ± 1.33^{d}	2.26 ± 0.03^{a}	2.16 ± 0.04^{g}
CM1	71.68 ± 0.95^{d}	56.36 ± 1.09^{c}	2.24 ± 0.02^{a}	2.25 ± 0.04^{f}
CM2	72.21 ± 1.03^{cd}	57.74 ± 1.35^{c}	2.16 ± 0.02^{b}	2.31 ± 0.03^{e}
CM3	73.16 ± 0.62^{bcd}	61.31 ± 1.11^{b}	2.15 ± 0.03^{b}	2.39 ± 0.02^{d}
CM4	73.74 ± 0.80^{bc}	63.23 ± 1.01^{b}	2.05 ± 0.03^{c}	2.49 ± 0.03^{c}
CM5	73.75 ± 0.94^{bc}	62.33 ± 1.31^{b}	2.06 ± 0.03^{c}	2.41 ± 0.03^{d}
CM6	72.86 ± 1.08^{cd}	58.25 ± 1.09^{c}	2.25 ± 0.03^{a}	2.41 ± 0.04^{d}
Xanthan gum				
fresh fish	75.88 ± 0.78^{cd}	75.70 ± 1.04^{a}	0.45 ± 0.02^{d}	8.36 ± 0.04^{a}
UN	69.58 ± 1.14^{e}	54.33 ± 1.33^{e}	2.26 ± 0.03^{a}	2.16 ± 0.04^{de}
XG1	75.03 ± 0.90^{d}	56.50 ± 1.16^{d}	2.15 ± 0.04^{c}	2.14 ± 0.03^{e}
XG2	76.26 ± 0.77^{cd}	57.56 ± 1.06^{cd}	2.16 ± 0.04^{c}	2.22 ± 0.04^{cd}
XG3	81.53 ± 1.31^{a}	63.51 ± 1.42^{b}	2.20 ± 0.04^{abc}	2.35 ± 0.04^{b}
XG4	77.43 ± 1.01^{bc}	62.60 ± 1.03^{b}	2.17 ± 0.04^{bc}	2.22 ± 0.04^{cd}
XG5	78.61 ± 0.89^{b}	62.29 ± 1.11^{b}	2.16 ± 0.03^{c}	2.23 ± 0.04^{c}
XG6	81.21 ± 0.99^{a}	59.46 ± 1.15^{c}	2.23 ± 0.03^{ab}	2.26 ± 0.05^{c}
Carrageenan				
fresh fish	75.88 ± 0.78^{ab}	75.70 ± 1.04^{a}	0.45 ± 0.02^{c}	8.36 ± 0.04^{a}
UN	69.58 ± 1.14^{e}	54.33 ± 1.33^{f}	2.26 ± 0.03^{a}	2.16 ± 0.04^{e}
CG1	73.61 ± 1.07^{cd}	55.13 ± 1.01^{ef}	2.26 ± 0.04^{a}	2.15 ± 0.02^{e}
CG2	73.39 ± 0.83^{d}	56.59 ± 1.15^{de}	2.25 ± 0.03^{a}	2.19 ± 0.02^{de}
CG3	76.26 ± 1.15^{a}	61.34 ± 1.11^{b}	2.15 ± 0.04^{b}	2.25 ± 0.02^{c}
CG4	74.27 ± 1.04^{bcd}	59.22 ± 1.02^{c}	2.16 ± 0.03^{b}	2.33 ± 0.04^{b}
CG5	75.36 ± 0.98^{abc}	58.46 ± 1.22^{cd}	2.25 ± 0.04^{a}	2.22 ± 0.03^{cd}
CG6	76.11 ± 0.96^{ab}	57.65 ± 1.03^{cd}	2.26 ± 0.05^{a}	2.23 ± 0.03^{cd}

[a] Values presented in the table are means ± SD, $n = 3$. Mean values bearing different superscripts (a, b, c, etc.) in a column are significantly different ($p < 0.05$).

were observed in all coated fish strips compared to the strips that were uncoated. Because of this, the material loss in the coated strips was effectively lesser compared to uncoated fish strips. Further, Garmakhany et al.[27] also reported that during frying, formation of a uniform coating around the sample is essential to retard mass transfer. However, with further increase in coating concentrations, the value was found to be decreased; this might be due to the weaker film-forming and poor water retention ability of higher coating concentration.

2.5. Effect of Polysaccharide Hydrocolloid Coatings on the Protein Oxidation of Fish Strips after Frying.

The protein oxidation is distantly portrayed as a "poor cousin" of lipid oxidation[38] and is given low importance due to the perception that it will not affect the meat quality, the complicated mechanism, and the relative difficulty in its detection.[39] The general indexes for protein oxidation are carbonyl content and sulfhydryl contents, which have been discussed below.

2.5.1. Effect of Coatings on Carbonyl Content and Sulfhydryl Content.

The protein oxidation is a deleterious phenomenon and a major hindrance for fish quality, which depends on meat composition, processing techniques, temperature, and time.[40] Further, Estevez and Luna[39] explained that heat-induced protein oxidation leads to a surge in carbonyl products, "instability of thiol groups," loss of tryptophan fluorescence, accumulation of Schiff-base structures (SB), and formation of intermolecular cross-link. In the present investigation, the carbonyl content of fresh fish strips (uncoated) was increased nearly five times (from 0.45 to 2.26 nmol/mg) after frying. On the other hand, the sulfhydryl content of fresh fish (uncoated) was found to be declined almost four times (from 8.36 mol/10^5 g protein to 2.16 mol/10^5 g protein) after frying (Table 2). A similar increase in carbonyl content was reported in many research studies conducted earlier.[31,40,63] It is opined that the oxidative potential of the fish meat reduces due to heating (frying) and as a result cellular damage occurs, which makes it more vulnerable to oxygen and subsequently, leads to formation of the "reactive oxygen species" (ROS) that assault the stable lipid and protein. Moreover, the increase in protein oxidation (carbonyl content) in frying could be due to exposure of the proteins to the ever-oxidizing lipids-caused cleavage of porphyrin in the ring, releasing the heme iron (a pro-oxidant), which speed ups oxidative corrosion.[40−43]

Similarly, another way for detection of protein oxidation is loss of sulfhydryl groups. The fish meat is a good source of sulfur-containing amino acids. Tavares et al.[43] explained that sulfur-containing amino acids (especially cysteine) are very sensitive to almost all ROS, and their loss in meat systems may be a reflection of a specific oxidative damage to meat proteins. The decrease in the sulfhydryl content in uncoated fish strips after frying may be attributed to the formation of disulfide bonds due to cross-linking of proteins while frying. Soladoye et al.[44] reported that the free metal ions produced by myoglobin oxidation may react with sulfhydryl groups to form more stable disulfide bonds.

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Table 3. Effect of Carboxy Methyl Cellulose, Xanthan Gum, and Carrageenan Coatings on the Instrumental Textural Parameters of Fried Fish Strips[a]

	texture profile analysis (TPA)					
treatments	hardness (N)	springiness	cohesiveness	chewiness (N)	gumminess (N)	resilience
Carboxy methyl cellulose						
fresh fish	53.61 ± 2.60^{a}	0.60 ± 0.18^{c}	0.43 ± 0.08^{d}	13.96 ± 5.73^{a}	22.66 ± 3.06^{a}	0.16 ± 0.04^{e}
UN	11.26 ± 0.18^{b}	0.70 ± 0.04^{bc}	0.57 ± 0.02^{bc}	4.44 ± 0.06^{b}	6.36 ± 0.29^{b}	0.23 ± 0.01^{bcde}
CM1	9.32 ± 0.41^{c}	0.74 ± 0.04^{abc}	0.67 ± 0.05^{b}	4.59 ± 0.29^{b}	6.23 ± 0.30^{b}	0.29 ± 0.03^{bc}
CM2	8.43 ± 0.29^{cd}	0.74 ± 0.13^{abc}	$0.50 \pm 0.03c^{d}$	3.14 ± 0.49^{b}	4.23 ± 0.14^{c}	0.19 ± 0.01^{de}
CM3	4.07 ± 0.50^{fg}	0.62 ± 0.11^{c}	0.63 ± 0.09^{bc}	1.56 ± 0.27^{b}	2.54 ± 0.11^{c}	0.30 ± 0.05^{b}
CM4	5.35 ± 0.10^{ef}	0.68 ± 0.07^{bc}	0.53 ± 0.09^{bcd}	1.96 ± 0.51^{b}	2.86 ± 0.50^{c}	0.21 ± 0.05^{cde}
CM5	6.95 ± 0.22^{de}	0.84 ± 0.08^{ab}	0.63 ± 0.03^{bc}	3.65 ± 0.42^{b}	4.34 ± 0.14^{c}	0.24 ± 0.02^{bcde}
CM6	3.61 ± 0.29^{g}	0.89 ± 0.02^{a}	0.80 ± 0.05^{a}	2.56 ± 0.11^{b}	2.89 ± 0.17^{c}	0.38 ± 0.02^{a}
Xanthan gum						
fresh fish	53.61 ± 2.60^{a}	0.60 ± 0.18^{b}	0.43 ± 0.08^{b}	13.96 ± 5.73^{a}	22.66 ± 3.06^{a}	0.16 ± 0.04^{b}
UN	11.26 ± 0.18^{b}	0.70 ± 0.04^{ab}	0.57 ± 0.02^{a}	4.44 ± 0.06^{b}	6.36 ± 0.29^{b}	0.23 ± 0.01^{ab}
XG1	9.19 ± 0.28^{c}	0.76 ± 0.02^{ab}	0.62 ± 0.02^{a}	4.36 ± 0.16^{b}	5.71 ± 0.23^{b}	0.27 ± 0.01^{a}
XG2	6.62 ± 0.08^{d}	0.83 ± 0.06^{a}	0.70 ± 0.06^{a}	3.84 ± 0.49^{b}	4.60 ± 0.37^{bc}	0.32 ± 0.05^{a}
XG3	2.66 ± 0.32^{f}	0.86 ± 0.05^{a}	0.69 ± 0.11^{a}	1.56 ± 0.25^{b}	1.81 ± 0.20^{d}	0.25 ± 0.11^{ab}
XG4	4.50 ± 0.13^{e}	0.83 ± 0.08^{a}	0.69 ± 0.06^{a}	2.57 ± 0.39^{b}	3.08 ± 0.18^{cd}	0.30 ± 0.04^{a}
XG5	4.55 ± 0.03^{e}	0.76 ± 0.06^{ab}	0.61 ± 0.03^{a}	2.10 ± 0.12^{b}	2.78 ± 0.10^{cd}	0.27 ± 0.02^{a}
XG6	5.53 ± 0.07^{de}	0.74 ± 0.17^{ab}	0.66 ± 0.09^{a}	2.76 ± 0.98^{b}	3.68 ± 0.51^{cd}	0.28 ± 0.04^{a}
Carrageenan						
fresh fish	53.61 ± 2.60^{a}	0.60 ± 0.18^{b}	0.43 ± 0.08^{b}	$13.96 \pm 5.73a$	22.66 ± 3.06^{a}	0.16 ± 0.04^{b}
UN	11.26 ± 0.18^{b}	0.70 ± 0.04^{ab}	0.57 ± 0.02^{ab}	4.44 ± 0.06^{b}	6.36 ± 0.29^{b}	0.23 ± 0.01^{ab}
CG1	8.97 ± 0.01^{c}	0.72 ± 0.06^{ab}	0.56 ± 0.02^{ab}	3.60 ± 0.39^{b}	5.02 ± 0.19^{bc}	0.23 ± 0.02^{ab}
CG2	8.37 ± 0.15^{cd}	0.76 ± 0.11^{ab}	0.59 ± 0.11^{ab}	3.71 ± 0.62^{b}	4.91 ± 0.80^{bc}	0.25 ± 0.05^{ab}
CG3	2.47 ± 0.02^{h}	0.81 ± 0.07^{ab}	0.75 ± 0.06^{a}	1.50 ± 0.26^{b}	1.85 ± 0.17^{d}	0.32 ± 0.01^{a}
CG4	4.46 ± 0.21^{g}	0.81 ± 0.12^{a}	0.71 ± 0.09^{a}	2.61 ± 0.71^{b}	3.18 ± 0.39^{cd}	0.32 ± 0.07^{a}
CG5	5.22 ± 0.17^{fg}	0.74 ± 0.12^{ab}	0.61 ± 0.11^{ab}	2.39 ± 0.75^{b}	3.17 ± 0.49^{cd}	0.27 ± 0.06^{ab}
CG6	6.39 ± 0.23^{ef}	0.79 ± 0.11^{ab}	0.66 ± 0.11^{a}	3.38 ± 1.02^{b}	4.23 ± 0.79^{bc}	$0.30{\pm}0.06^{a}$

[a] Values presented in the table are means ± SD ($n = 3$). Mean values bearing different superscripts (a, b, c, etc.) in a column are significantly different $p < 0.05$ springiness, cohesiveness and resilience recorded an increase in fried fish strips compared to fresh fish strips (Table 3). A higher cohesiveness value was exhibited in all coated sample compared to the uncoated fried fish strips (Table 3). Springiness indirectly indicates elasticity hence, as the hardness is decreased with increase in coating concentration, this led to reduction in springiness value. In case of coated samples, it was noticed that; there is no significant ($p > 0.05$) difference among coated and uncoated fried fish strips.

Among coated samples, the least carbonyl content was observed to be 2.05 (CM4), 2.15 (XG2), and 2.15 nmol/mg protein (CG3) for CMC, xanthan gum, and carrageenan, respectively. Similarly, the protection of the thiol group from reduction was also observed in the same coating, as observed in the carbonyl content (Table 2). Therefore, this gave an indication that fish strips coated with the abovementioned coating concentrations are effective coatings to reduce protein oxidation significantly compared to uncoated fish strips during frying.[45]

2.6. Effect of Polysaccharide Hydrocolloid Coatings on the Functional Properties of Fried Fish Strips.

2.6.1. Effect on Protein Solubility. The solubility of proteins is a vital functionality that directly influences other functional properties of the meat proteins. The solubility is directly affected by the temperature/heat, salt concentration, and isoelectric pH. It is also an indicator of protein denaturation and is basically linked to the hydrophobicity/hydrophilicity balance.[46] In the present investigation, the value of protein solubility of fresh fish strip proteins was 75.70%, which reduced significantly to 54.33% after frying (Table 2). Similar decreases in solubility due to frying were documented in earlier studies.[47,48] During heating, the different meat proteins denature and cause structural changes in the meat,[49] such as the breakdown of cell membranes, shrinkage of meat fibers, the aggregation and gel formation of myofibrillar and sarcoplasmic proteins, and connective tissue shrinkage and solubilization.[50] Chen et al.[51] also demonstrated that as the cooking temperature rises, the protein solubility of chicken meat decreases proportionally. During protein denaturation, due to the disruption of the α helices and β sheets, proteins are uncoiled into random shape, resulting in protein-protein interactions and a loss in protein solubility.[50,51]

Further, the solubility values of carbohydrate-coated samples were found to be increased with increase in the coating concentrations from 56.36% (CM1) to 63.23% (CM4), 56.50% (XG1) to 63.51% (XG3), and 55.13% (CG1) to 61.34% (CG3) for CMC, xanthan gum, and carrageenan, respectively (Table 2). This increase in solubility values was possibly due to the protective effect rendered by the coatings over the strips, and as a result caused less denaturation and hence led to enhanced solubility. With subsequent increase in concentrations, a slight reduction in protein solubility was noticed. Moreover, the solubility values of all coated samples were still lesser than the fresh fish protein solubility, but higher than the uncoated fried fish strips' protein solubility.

2.6.2. Effect on Water-Holding Capacity. The water-holding capacity (WHC) refers to the capacity of a protein to bind water under the specified conditions. It is commonly used to determine the functional and textural quality attributes of fried products. The mouth feel of any food product may directly be related to the water-holding capacity. In the present investigation, the water-holding capacity of fresh fish meat was 75.88%, which reduced to 69.58% after frying in uncoated fried fish strips (UN) (Table 2). The decrease in the water-holding capacity may be attributed to the release of the water from protein because of the denaturation caused by the high temperature while frying. In the present study, it was observed that strips coated with all three carbohydrates with various concentrations of coating had better WHC as compared to the control (UN). This might be due to the coating entrapping the moisture inside the fried strips and preventing moisture replacement with oil. Subsequently, the WHC values of coated fish strips were found to be increased with increase of coating concentrations. In case of coated fried fish strips, with increase in coating concentrations, the WHC increased from 71.68% (CM1) to 73.75% (CM5) for CMC, 75.03% (XG1) to 81.53% (XG3) for xanthan gum, and 73.39% (CG2) to 76.26% (CG3) for carrageenan. Among all, the highest WHC was noticed in strips coated with XGP (82.51%), followed by CGP (76.57%) and CMP (74.68%) (Table 2). The fish strip coating acts as a barrier that prevents or reduces the exchange of water and oil during the frying process. In addition to the aforesaid, a continuous film also fills the spaces on the interface and due to this, the amount of water lost from the surface is also limited and so is the fat inflow.[34] The obtained result is also supported by the higher moisture retention and coating pickup (Table 1) for coated products during frying. The coating makes the surface of the product harder and more brittle, and consequently improves the water-holding capacity of the product.

2.7. Effect of Polysaccharide Hydrocolloid Coatings on the Instrumental Texture Analysis of Fried Fish Strips.

TPA is a practical method routinely practiced to evaluate food textures to assess the "mechanical properties" of foods.[52] Compression test is an often-performed test that ushers hardness, chewiness, and cohesiveness. Actually, the hardness is the force (N) required that causes deformation in a sample at a certain distance.[53] The textural parameters of the fish strips coated with carbohydrate coating are depicted in Table 3. In the present investigation, the hardness value of the fresh fish strip was 53.61 N, which reduced more or less five times (11.26 N uncoated fried fish strips) after frying. For carbohydrate-coated fried samples, the minimum hardness value was noticed for the fish strips coated with carrageenan (CG3, 2.47 N), followed by xanthan gum 2.66 (XG3) and CMC (CM6, 3.61 N). The softness of the coated samples could be due to their higher moisture retention in comparison with uncoated fried samples (control). The softness of the fried coated samples is the result of higher moisture retention in coated products[54] and development of crispy crust in fried samples due to the edible coating. In the present study, hardness values were lower (more crispiness) for both protein- and non-protein-coated strips compared with uncoated strips, which might be due to the fill-up of the void cells with edible coatings.

Chewiness refers to mastication of the food in the mouth and is normally reported for solid foods.[55] The value of chewiness for fresh fish was 13.96 N, which declined to 4.44 N after frying. Just like that described above, the value for gumminess was also found to be decreased from 22.66 to 6.36 N after frying (Table 3). However, the values for springiness, cohesiveness, and resilience recorded an increase in fried fish strips compared to fresh fish strips (Table 3). A higher cohesiveness value was exhibited in all coated samples compared to the uncoated fried fish strips (Table 3). Springiness indirectly indicates elasticity; hence, as the hardness is decreased with increase in coating concentration, this led to reduction in springiness value. In case of coated samples, it was noticed that there is no significant ($p > 0.05$) difference among coated and uncoated fried fish strips.

2.8. Effect of Polysaccharide Hydrocolloid Coatings on Sensory Parameters.

Sensory evaluation was performed to study the effect of edible coatings on the sensory attributes of deep-fried fish strips on the overall acceptance among the panelists. The sensory scores received by fish strips coated with various concentrations of coatings are given in Figure 2. The coated fried fish strips have a relatively higher value of overall acceptability followed by oiliness, crispiness, taste, and texture compared to the uncoated samples (UN). Among different carbohydrate-coated fish strips, the highest overall acceptance was recorded for fish strips coated with xanthan gum (XG3, 8.44), followed by carrageenan-coated fish strips (CG3, 8.44) and CMC-coated samples (CM4, 8.22). In case of xanthan gum and carrageenan with a coating, concentrations of 1% and above were not tested well (bitter) by the panelists. Among the coated and uncoated fried fish strips, irrespective of any type of coating, coated strips had better overall acceptability compared to uncoated fish strips, but the differences were small.

3. CONCLUSIONS

The study deduced that fish strips coated with 1% CMC, 0.75% carrageenan, and 0.75% xanthan gum reduced the fat uptake almost by half, with substantial protection of protein oxidation and improved textural properties during frying. The results obtained from this study may contribute to the production of low-fat fried fish strips with enhanced consumer acceptance. Mostly food engineering and product preparation are designed using one or two variables, but due to the complex nature of frying and food preparation, conflicts are bound to occur; therefore, MOO may be an increasingly attractive tool to get the best possible coating or solution for product engineering.

4. MATERIALS AND METHODS

4.1. Preparation of Fish Strip.

Fish weighing 2.02 ± 0.19 kg and 51.98 ± 0.92 cm in length were purchased from a fish market, Agartala, India, in live condition. This experiment was conducted between August, 2021- September, 2021. The fish were stunned and packed in a thermocol box (fish/ice ratio of 1:1, w/w) and were transported to the Dept. of Fish Processing Technology and Engineering laboratory. On arrival, fishes were washed, beheaded, descaled, and double-filleted and cut into meat strips with a size of 4 cm × 2 cm × 1.5 cm (40 ± 1 g weight); all visible fat portions were removed and the narrow tips were discarded to make the pieces as uniform as possible.

4.2. Preparation of Coating Solutions and Application to Fish Strips.

Fish strips were coated with three carbohydrate coatings, viz., carboxy methyl cellulose (CMC, viscosity: 400−800 cp), xanthan gum (XG, viscosity: 1200 cp), and carrageenan (CG, viscosity ≥ 5 cp) were procured from HIMEDIA (Mumbai, India). The fish strips were dipped into the coating solution for 10 s and allowed to drip for 12 s before frying. Three carbohydrate coatings with different concen-

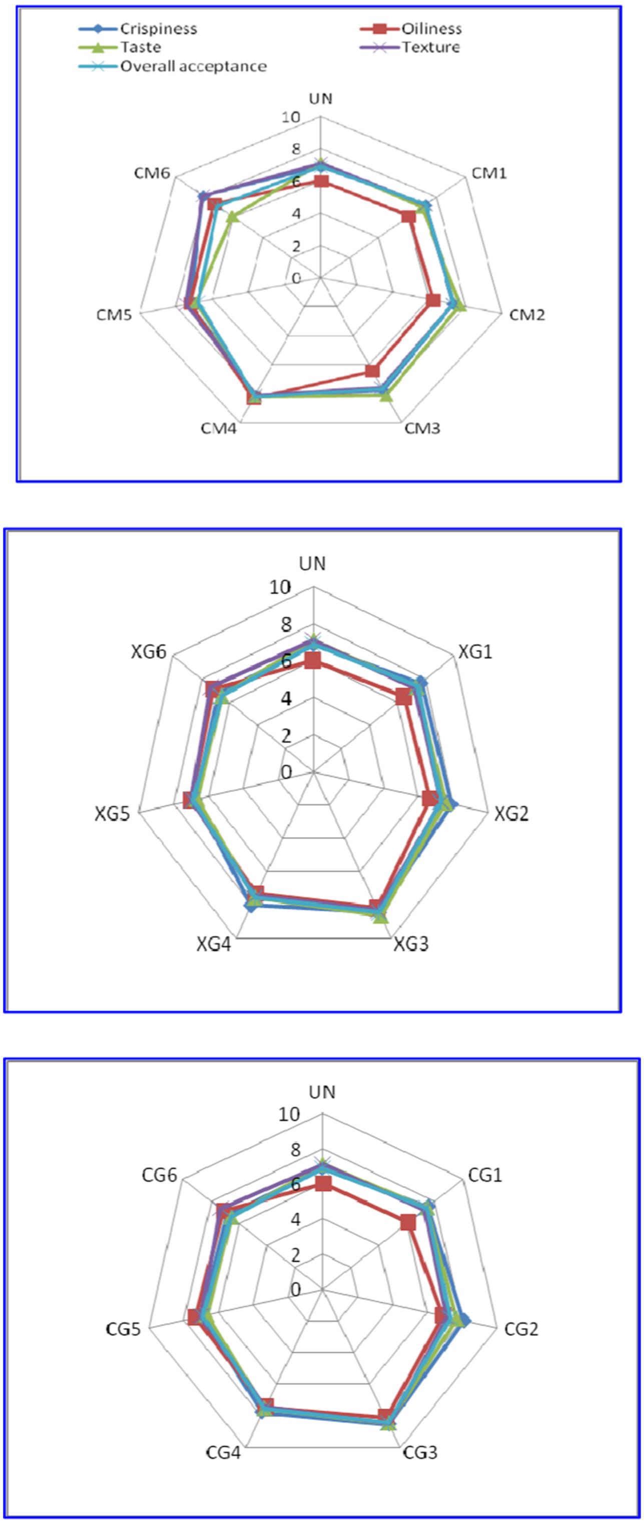

Figure 2. Spider Chart depiction of the sensory analysis of CMC, xanthan gum, and carrageenan-coated fried fish strips.

trations of 0.25, 0.5, 0.75, 1.0, 1.25, and 1.50% (w/v) were formulated with water. The codes assigned for different concentrations of three different carbohydrate sources are given in Table 4.

4.3. Frying Procedure. Coated fish strips (*Labeo rohita*) were fried at 180 °C for 5 min in a deep fryer (Inalsa Professional 2 L Electric Deep Fryer/1700 W, China). Fortune refined soybean oil (Adani Wilmar Limited) was used as the "frying medium". Intermittently, the frying temperature was checked using metal thermometer (multi-thermometer 9283B, Mextech). After frying each batch, the oil was changed. The fried strips were removed from the oil using prongs and kept on a tissue paper until cooling to ambient temperature. Analysis of the samples was performed immediately.

4.4. Coating Pickup. The "coating pickup" was calculated to assess the amount of coating that glued to the fish strips.[4] The edible coating pickup was calculated as follows

$$\text{coating pickup (\%)} = [(\text{CW} - \text{IW})/\text{IW}] \times 100$$

where CW is the weight of the coated sample after dipping, and IW is the initial weight of the uncoated sample.

4.5. Fat Reduction and Moisture Retention Analysis. The moisture and fat content were determined using a Sartorius moisture analyzer and Soxhlet apparatus, respectively. The fat extraction was performed using petroleum ether (BP 60–80 °C) as a solvent. The fat uptake reduction (FUR) pertaining to uncoated samples (control) was estimated as the percent of oil content difference between uncoated and coated fried samples as shown in the following formula

$$\begin{aligned}\text{FUR(\%)} &= (\text{oil content in fried coated fish strips}\\ &\quad - \text{oil content in fried uncoated fish strips})\\ &\quad /(\text{oil content in fried uncoated fish strips}) \times 100\end{aligned}$$

The % of moisture retention (MR) was calculated using the moisture content of the uncoated sample (control) and the moisture content of the coated sample was calculated as follows

$$\begin{aligned}\text{MR(\%)} &= (\text{moisture content in fried coated sample}\\ &\quad - \text{moisture content in fried uncoated sample})\\ &\quad /(\text{moisture content in fried uncoated sample}) \times 100\end{aligned}$$

4.6. Frying Yield. The frying yield of the fish strips after frying was calculated as the difference between the "fried fish strip weight" and the "raw fish strip weight (after coating)," multiplied by 100.[56]

4.7. Protein Solubility. The protein solubility of coated and uncoated fish strips was determined according to the method described by Benjakul and Bauer.[57] A 2 g sample was homogenized with 18 mL of 0.6 M KCl for 30 s, then stirred at 25–27 °C for 4 h, followed by centrifugation at 12,000*g* for 20 min at 4 °C. To 10 mL of the supernatant, cold 50% (w/v) TCA was added to obtain the final concentration of 10%. The precipitate was washed with 10% TCA and solubilized in 0.5 M NaOH. The sample was completely dissolved in 0.5 M NaOH in order to estimate the total protein content, which was determined by Biuret method.[58] The following formula was used to calculate the total protein solubility:

$$\begin{aligned}&\text{protein solubility(\%)}\\ &\quad = (\text{protein Concentration in supernatant/totalprotein})\\ &\quad \times 100\end{aligned}$$

4.8. Water-Holding Capacity. The water-holding capacity was determined using the technique outlined by Barrera et al.[59] The values of WHC were arrived at by finding the difference

Table 4. Codes Assigned for Carboxy Methyl Cellulose, Xanthan Gum, and Carrageenan Coatings

code	treatment	code	treatment	code	treatment
UN	uncoated sample	UN	uncoated sample	UN	uncoated sample
CM1	0.25% aqueous CMC suspension	XG1	0.25% aqueous xanthan gum suspension	CG1	0.25% aqueous carrageenan suspension
CM2	0.50% aqueous CMC suspension	XG2	0.50% aqueous xanthan gum suspension	CG2	0.50% aqueous carrageenan suspension
CM3	0.75% aqueous CMC suspension	XG3	0.75% aqueous xanthan gum suspension	CG3	0.75% aqueous carrageenan suspension
CM4	1% aqueous CMC suspension	XG4	1% aqueous xanthan gum suspension	CG4	1% aqueous carrageenan suspension
CM5	1.25% aqueous CMC suspension	XG5	1.25% aqueous xanthan gum suspension	CG5	1.25% aqueous carrageenan suspension
CM6	1.50% aqueous CMC suspension	XG6	1.50% aqueous xanthan gum suspension	CG6	1.50% aqueous carrageenan suspension

between the weights before and after the experiment as a percentage of the retained water.

4.9. Protein Oxidation Indices. In order to study the protein quality, protein oxidation, carbonyl content, and sulfhydryl content were analyzed. The methodology in detail is given below.

4.9.1. Carbonyl Content. To measure the carbonyl content in the fish strips, exactly 2 g of meat was taken and macerated with phosphate buffer (0.02 M, pH 6.5) and centrifuged at 15,000*g* for 10 min. Thereafter, equal volumes (0.4 mL) of supernatant and 2,4-dinitrophenylhydrazine (DNPH, 10 mM) were added into 2 M HCl and along with it, a control was run (taking 2 M HCl buffer without DNPH). The mixture was placed in dark condition for 1 h, vortexed every 10 min, and then precipitated with 0.5 mL of 20% (w/v) TCA. The precipitate was washed with ethanol-ethyl acetate (1:1, v/v) three times, and dissolved in 6 M guanidine hydrochloride (GH) at 30 °C for 15 min. The absorbance of the GH supernatant was measured at 370 nm and a molar extinction coefficient of 22,000 M^{-1} cm^{-1} was used for calculating the total carbonyl content of the sample.[60] The carbonyl content was expressed as nmol carbonyls/mg protein and calculated using the following formula

$$\begin{aligned}&\text{total carbonyl content}\\&\quad= [10^6 \times (\text{Abs } 370\text{ nm}/22.000\text{ M}^{-1}\text{cm}^{-1})]\\&\qquad/\text{protein}(\text{mg/mL})\end{aligned}$$

4.9.2. Sulfhydryl Content. The "sulfhydryl content" was measured according to the method described by Eymard et al.[61] 2 mL of myofibrillar solution (2 mg/mL) was taken and 8 mL of Tris-glycine solution (pH 8) was added. The homogenization and centrifugation were performed at the speed of 6000*g* under 4 °C for 15 min. The insoluble protein was discarded, and 0.5 mL of 10 mM Ellman reagent was added into 4.5 mL of the sample. The absorbance at 412 nm was recorded after 30 min. The sulfhydryl content was calculated as follows

$$\begin{aligned}&\text{total sulfhydryl content}(\mu\text{mol/g})\\&\quad= A_{412} \times D \times 10^6/C \times 13,600\end{aligned}$$

where "A_{412}" represents the absorbance at 412 nm; "C" is the concentration of MP (mg/mL); "D" is the dilution of MP; and "13,600" is the molar extinction coefficient (M^{-1} cm^{-1}).

4.10. Texture Profile Analysis. Textural analysis of the fried fish strips (uncoated + coated) was performed using a texture analyzer (TA-XT PLUS Stable Micro Systems, Surrey, England). The fish strip was sliced into standard size (2 cm × 2 cm) for studying texture profile. To measure the textural parameters (hardness, springiness, cohesiveness, chewiness, gumminess, and resilience), the compression of 40% of the original height of the sample with the pretest speed and load cell was set as per our previous work.[62] The average of three close values was reported as the final value of each parameter.

4.11. Sensory Analysis. A panel comprising 10 members (7 males and 3 females), "post-graduate students" and "doctoral fellows" of the department, performed the sensory evaluation test. The panelists were detailed about the sensory parameters to be adjudged and provided with two to three pieces of fried fish strips. After each test, panelists were asked to rinse their mouth with potable water. The panelists were told to follow a 9-point hedonic scale.

4.12. Statistical Analysis. Statistical analysis was performed using SPSS version 22.0 (IBM SPSS for Windows, Chicago, IL). All data were subjected to one-way analysis of variance (ANOVA) and represented as ± standard deviation (SD). The correlations among the variables in the products were analyzed with the variability of the components using principal component analysis.

4.12.1. Multiobjective Optimization (MOO) Approach. For finding the optimal solution/treatment, different criteria such as moisture (max), hardness (min), lipid (min), toughness (min), cutting (min), oil uptake reduction (max), oiliness (min), carbonyl (max), and sulfhydryl (min) were taken together using the multiobjective optimization (MOO) technique. Multiobjective optimization is a novel technique consisting of a set of methods to structure and formalize decision-making processes in a transparent and consistent manner.[63] There are many methods that can be used for solving problems and they can be arranged according to different parameters. The "MOO formulation" is given by more than one objective function such as F1(x), F2(x), and F3(x) and so on. In these, F1 may be minimized or maximized, F2 minimized or maximized, and so on. MOO often yields a series of values for each component of x^* (the optimal values of x are denoted by x^*), which are referred to as a set of nondominated solutions or Pareto optimal solutions. Corresponding to each of these solutions, there will be one set of values for objectives such as F1(x^*), F2(x^*), and F3(x^*).[64] MOO gives an explanation of the steps to create, solve, and then select the optimum result. Firstly, the number of objectives/criteria and number of solutions were assigned for the MOO problem. Then, the types of objectives/criteria were fixed and weights were given to each objective. MOO methods[65] like COPRAS, ELECTRE, FUCA, GRA, PROBID, MOORA, TOPSIS, VIKOR etc. were selected and employed for solving the formulated problem and selecting one optimal solution. In the given problem, there are 9 objectives like moisture (max), hardness (min), lipid (Min), toughness (min), cutting (min), Oil uptake reduction (max), Oiliness (min), carbonyl (max), and sulfhydryl (min) with the mentioned types of criteria i.e., maximum or minimum (under parenthesis) were assigned for 8 different solutions or

Table 5. Statistical Variance Methods for Allocating Weights to Various Objectives under CMC, Xanthan ± Gum, and Carrageenan

objectives	moisture	hardness	lipid	toughness	cutting	oil uptake reduction	oiliness	caronyl	sulfhydryl
For CMC									
types (max or min)	max	min	min	min	min	max	min	max	min
weightage used (StatVar)	0.000497	0.256481	0.085248	0.074213	0.160587	0.38027	0.034469	0.003271	0.004964
For Xanthan gum									
types (max or min)	max	min	min	min	min	max	min	max	min
weightage used (StatVar)	0.000267	0.287334	0.058372	0.112643	0.248292	0.271983	0.018205	0.000459	0.002444
For Carrageenan									
types (max or min)	max	min	min	min	min	max	min	max	min
weightage used (StatVar)	0.00031	0.203731	0.053524	0.148166	0.342625	0.23508	0.014924	0.000615	0.001025

Table 6. Results of Multicriteria Decision Methods for Finding the Optimal Solution (Bold) under CMC, Xanthan Gum, and Carrageenan

treatment/solution	COPRAS Q	ELECTRE 2	FUCA final rank	GRC	PROBID	MOORA	VIKOR
UN	0.049150825	0	7.701072	0.666666667	0.232687762	−0.31391228	1
CM1	0.10092432	0.003156917	6.30799	0.732311852	0.35643092	−0.14276601	0.442975194
CM2	0.126893669	0.006313835	4.734349	0.714806814	0.835878426	−0.07630685	0.316974858
CM3	0.128946131	0.012627669	4.721078	0.75022532	0.769283059	−0.06738361	0.239500628
CM4	0.156418617	**0.066295265**	**2.398744**	0.785306413	**1.03295934**	**0.001989669**	**0.031223328**
CM5	0.129614764	0.034726091	4.131716	0.729961234	0.764983808	−0.06318957	0.199661094
CM6	**0.15911827**	0.037883008	3.32161	**0.814510339**	1.026613037	0.000327862	0.03231064
Xanthan gum							
UN	0	0.99380805	7.854413	0.660917634	−0.53936968	−0.38785232	0.010128005
XG1	−1.87308113	0.321981424	6.398446	0.660105455	−0.13848717	−0.22220791	0.442543547
XG2	−1.31150676	0.205366357	5.644817	0.658560647	−0.08138187	−0.193791	0.52796929
XG3	1.295550453	0.311661507	2.905101	0.761745917	0.282254833	−0.0566046	0.807798415
XG4	0.731159214	**0.068210526**	2.471796	0.75705505	0.236536323	−0.06911439	0.804803313
XG5	−0.23192877	0.228070175	3.738989	0.730095843	0.169568487	−0.09876415	0.752800661
XG6	−0.52461997	0.155052632	4.705121	0.70707071	0.016361863	−0.1525941	0.611235647
Carrageenan							
UN	0.046250343	0	7.885382	0.659381955	−0.61287164	−0.47013886	0.006558083
CG1	0.100381511	0.003320312	6.91708	0.742002833	−0.09800556	−0.22713273	0.588441516
CG2	0.129470328	0.0265625	3.977636	0.751152777	0.084424948	−0.14151783	0.749182597
CG3	0.140371348	0.063085938	4.500755	0.777684413	0.165773522	−0.11923001	0.756376622
CG4	0.158739167	0.043164063	2.2303	0.750534445	**0.239874634**	**−0.07823391**	**0.874187569**
CG5	0.132898905	0.03984375	4.240732	0.770006819	0.123914316	−0.13305775	0.764676644
CG6	0.132592097	0.024902344	4.099342	0.773834719	0.118851993	−0.13216598	0.774180778

treatments. Then, weights were given to each objective using statistical variance methods, which are shown in Table 5. After that, the different MOO methods such as Complex Proportional Assessment (COPRAS), Elimination and Choice Translating Priority (ELECTRE), Faire Un Choix Adéquat (FUCA), Gray Relational Analysis (GRA), Preference Ranking on the Basis of Ideal-Average Distance (PROBID), Multi-objective Optimization on the basis of Ratio Analysis (MOORA), Technique for Order Preference by Similarity to Ideal Solutions (TOPSIS), and Viekriterijumsko Kompromisno Rangiranje (VIKOR) etc., were employed for solving the formulated problem and selecting one optimal solution, which are presented in Table 6.

■ ASSOCIATED CONTENT

Data Availability Statement

Data sets generated during the research are available from the corresponding author on reasonable request.

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K.G.: Investigation, formal analysis; N.K.M.: Conceptualization, writing original draft, supervision, and visualization; R.K.M.: Manuscript editing and validation; M.B.P.: Review correction and supervision; P.P.: Formal analysis, manuscript review; K.A.M.X.: Writing, manuscript review; S.S.: Manuscript editing and review.

Notes

The authors declare no competing financial interest.

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