Journal of Tropical Agriculture 63(4): 257-267, 2025
ISSN 0971-636X (Print), ISSN 0973-5399 (Online)
DOI: 10.63599/JTA.2025.1638

Casein based edible coating for reducing oil absorption in deep fried banana chips

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Received on 24 August 2025; received in revised form 29 October 2025, accepted 10 November 2025.

Abstract

The excessive oil absorption in banana chips during deep fat frying affects their texture, nutritional quality and consumer acceptability. To address this, an edible coating incorporating sodium caseinate and hydrocolloids was developed to minimize oil uptake while maintaining desirable sensory attributes. The edible coating solution was prepared using different proportions of sodium caseinate and hydrocolloids such as pectin, sodium alginate and carboxymethyl cellulose (CMC), where the extent of addition was determined using Central Composite Rotatable Design (CCRD) of Response Surface Methodology (RSM) and responses such as lipid/oil content, crispiness and overall acceptability score were analysed. Results showed that optimized hydrocolloid-caseinate combinations (sodium alginate-0.5%, CMC-0.5%, pectin-1.5% and sodium caseinate-4%) significantly reduced oil absorption without compromising crispiness or visual appeal. The optimum values of oil content, hardness and overall acceptability were 17.69%, 4428.85 N and 8.25, respectively, under frying conditions of 160ºC for four minutes. This approach offers a practical method for improving the health profile of fried banana chips while preserving their traditional sensory qualities.

Key words: Banana chips, Carboxymethyl cellulose, Casein, Oil absorption, Pectin, Sodium alginate

Introduction

Increasing demand for convenient and savoury food options is reflected in the market growth of oil-fried snacks. However, a high oil content in fried snacks can negatively impact product quality and pose challenges for both consumers and producers (Oginni et al., 2015). High intake of oil results increased risk of several chronic health conditions, including coronary heart disease, hypertension, diabetes and cancer (Saguy and Dana, 2003). Reduced shelf life due to oxidative changes and rising oil prices are some of issues faced by the industry. Absorbed oil can account for approximately 30% to 40% of the total weight in deep-fat fried products, with its uptake primarily due to the mechanisms such as condensation and capillary action (Mellema, 2003).

India is the largest producer of banana in the world.Kerala, a state in India, is cultivating over 20 varieties, including *Nendran*, Robusta, Red Banana, *Palayankodan* and *Poovan*. Banana chips made from sliced *Nendran* bananas fried in coconut oil are a globally recognized snack from Kerala. Banana chips are often seasoned with salt, sugar or a blend of spices to enhance their taste, making them a highly addictive snack. Converting bananas into chips can enhance their value and minimize post-harvest loss (Elkhalifa, Hassan and Zei, 2014).

Various preliminary processing methods such as osmotic dehydration, blanching, air drying and hydrocolloid coatings have been employed to produce low fat fried snacks with improved consumer demand (Ren et al., 2018). Hydrocolloids are especially beneficial in deep-fat frying processes because of their effective barrier properties against oxygen, carbon dioxide and lipids, which help reduce the uptake of oil (Rimac-Brncic et al., 2004). They alter the solution's physical characteristics through mechanisms such as gelation, thickening, coating, emulsification and stabilization (Pirsa and Hafezi, 2023). Edible films and coatings often incorporate hydrocolloids such as gums (e.g., guar and xanthan), cellulose derivatives (including methylcellulose, hydroxypropyl cellulose and carboxymethyl cellulose), as well as other polysaccharides and proteins (Sothornvit, 2011).

Carboxymethyl cellulose is a widely utilized water-soluble

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gum, particularly valued for its functional roles in the bakery industry (Sharifi and Pirsa, 2021). Among proteins and polysaccharides, casein and pectin have garnered significant research attention in recent years due to the promising functionalities of their blends across diverse food applications (Liang and Luo, 2020). Additionally, milk proteins remain a prevalent choice for the development of edible films and coatings, owing to their favourable functional properties like film-forming properties (Campos, Gerschenson and Flores, 2011) biodegradability, emulsification and moisture barrier effects (Khan et al., 2021).

The production of deep-fried products with reduced fat content is a key focus for both the food industry and health-conscious consumers (Ranasalva and Sudheer, 2017). Casein-based coatings have proven effective in lowering oil absorption during the frying process while maintaining desirable texture and flavour characteristics. However, their application in banana chips, particularly in conjunction with hydrocolloids such as sodium alginate, carboxymethyl cellulose and pectin, remains unexplored in existing literature. This study presents a novel formulation strategy to optimize casein based edible coating for banana chips and to investigate the influence of mixture of sodium caseinate and hydrocolloids (sodium alginate, carboxymethyl cellulose and pectin) on the oil absorption, texture and overall acceptability of fried banana chips, using response surface methodology.

Materials and methods

Materials

Matured unripe bananas (*Nedunendran*) and refined coconut oil (Athulya Brand-Agmark Grade 1) were purchased from local market. Casein powder was supplied by Clarion Casein Ltd, Gujarat. Edible grade pectin and carboxymethyl cellulose were procured from CK'S Products, Food ingredients company, Kochi. Edible grade sodium alginate was obtained from M/s Puramio India Pvt. Ltd., Indore, Madhya Pradesh. Food grade sodium hydroxide pellets was procured from M/s Annexe Chem Pvt. Ltd, Manjusar, Gujarat. All reagents were prepared using double distilled water.

Methods

Casein based edible coated banana chips were prepared as per the procedure outlined by Paramasivam et al. (2022). Unripened bananas were washed with clean water, peeled manually and were cut into 1.2 mm thick slices using a slicer. Refined coconut oil was used as the frying medium in the deep-fat frying process. Edible coating solution was prepared using different proportions of sodium caseinate (SC) and hydrocolloids (pectin, sodium alginate, carboxymethyl cellulose). The banana slices were subjected to blanching in hot water for one min at 90ºC. After blanching the slices were immersed in NaCl solution (2% at 60ºC) for 15 minutes. Once drained, they were soaked in the coating solutions for 10 minutes, then drained again and set aside for dryingin circulatory hot air oven at 70ºC for five minutes.

The banana slices were deep-fried in refined coconut oil at 160ºC for four minutes. After frying, the banana chips were transferred to a wire basket for two minutes to drain excess surface oil, then left to cool at room temperature (27±3ºC). The cooking oil was replaced after each treatment. Uncoated chips served as the control sample.

Determination of quality parameters

The oil/lipid content in banana chips was determined by AOAC 925.12 (2016). Chips hardness was determined using Texture profile analyzer (Stable Micro systems, TA HD Plus, UK) with following test conditions. Mode: Measure Force in Compression, Pre-Test Speed: 1.0 mm s^{-1}, Test Speed: 5.0 mm s^{-1}, Post-Test Speed: 5.0 mm s^{-1}, Strain: 40%, Probe: compression platen (P/75) with 25 kg load cell, using the Texture Exponent 32 software program. All the experiments

Table 1. The Central Composite Rotatable Design for the four factors

Standard order	Factor 1 A: Sodium Alginate (%)	Factor 2 B: Pectin (%)	Factor 3 C: CMC (%)	Factor 4 D: Sodium Caseinate (%)
1	0.5	0.5	0.5	4
2	1.5	0.5	0.5	4
3	0.5	1.5	0.5	4
4	1.5	1.5	0.5	4
5	0.5	0.5	1.5	4
6	1.5	0.5	1.5	4
7	0.5	1.5	1.5	4
8	1.5	1.5	1.5	4
9	0.5	0.5	0.5	12
10	1.5	0.5	0.5	12
11	0.5	1.5	0.5	12
12	1.5	1.5	0.5	12
13	0.5	0.5	1.5	12
14	1.5	0.5	1.5	12
15	0.5	1.5	1.5	12
16	1.5	1.5	1.5	12
17	0	1	1	8
18	2	1	1	8
19	1	0	1	8
20	1	2	1	8
21	1	1	0	8
22	1	1	2	8
23	1	1	1	0
24	1	1	1	16
25	1	1	1	8
26	1	1	1	8
27	1	1	1	8
28	1	1	1	8
29	1	1	1	8
30	1	1	1	8

were triplicated. The banana chips samples were evaluated organoleptically for different attributes like colour and appearance, crispness, flavour, oiliness and over all acceptability by a selected panel of judges comprising of five members using9-point Hedonic scale. The proximate composition (moisture, fat, protein, carbohydrate and ash) of the coated banana chips was determined according to AOAC (2016) method against control. Colour of the banana chips samples was evaluated using reflectance spectroscopy technique employing reflectance meter, known as colour flex (Hunter lab Miniscan XE plus Spectrocolorimeter, Virginia, USA). Data were received from the software in terms of L [Lightness, ranges 0 (black) to 100 (white)], a [Redness, ranges from +60 (red) to -60 (green)] and b [Yellowness, ranges from +60 (yellow) to -60 (blue)], in accordance with the international colour system (Hunter scale). Chroma value, whiteness index (WI) and yellowness index (YI), were calculated using the following equations to assess the colour changes during frying (Kumar et al., 2019).

$$\text{Chroma} = \sqrt{a^{*2} + b^{*2}}$$

$$\text{WI} = 100 - \sqrt{100 - L + a^{*2} + b^{*2}}$$

$$\text{YI} = \frac{142.86 \times b*}{L}$$

Biochemical parameters of coconut oil

The biochemical parameters of coconut oil, such as free fatty acids (FFA), peroxide value (PV) and saponification value were analyzed (AOCS, 1989).Fresh coconut oil was used for each treatment without reusing the oil.

Experimental Design:

The incorporation levels of SC, sodium alginate, pectin and carboxymethyl cellulose was determined using the Central Composite Rotatable Design of RSM. CCRD is widely preferred because it provides an efficient and statistically reliable approach for exploring the relationship between multiple independent variables and the corresponding response. Compared to full factorial or three-level factorial designs, CCRD requires fewer experimental runs while still allowing estimation of linear, quadratic and interaction effects of variables, which are essential for modeling curvature in response surfaces. SC, sodium alginate, pectin and CMC served as factors, while lipid/oil content, hardness (measured using the TA-HD Plus Texture Profile Analyzer) and overall acceptability were considered as response variables. The results were analysed statistically (Snedecor and Cochran, 1994). Details of the experimental variable levels are provided in Table 1. The responses are presented in Table 2.

Table 2. Oil content, crispiness and overall acceptability of banana chips with casein based edible coating with different levels of Sodium caseinate (SC), Sodium alginate (SA), Pectin and Carboxy Methyl Cellulose (CMC).

Standard order	Response 1 Oil Content (%)	Response 2 Hardness (N)	Response 3 Overall Acceptability
1	26.47	8463.127	7.8
2	28.04	10084.79	7.6
3	17.69	4649.88	8.3
4	21.86	4746.458	7.9
5	26.47	6983.154	7.9
6	23.23	6529.065	7.9
7	26.64	5934.955	8.25
8	27.85	9635.168	8.1
9	31.39	13812.06	7.6
10	24.4	6796.274	7.75
11	31.69	6762.524	7.7
12	27.57	14295.44	8.25
13	25.42	10686.16	8.05
14	33.02	5403.046	7.95
15	33.02	14632.1	7
16	27.61	15959.5	7.45
17	29.76	5420.619	8.05
18	25.75	9304.642	8.15
19	22.4	13209.03	6.95
20	30.35	16766.15	7.7
21	27.4	7817.696	7.9
22	30.67	6129.645	8.3
23	20.87	4413.143	8.05
24	29.56	4930.269	7.4
25	25.1	13684.04	7.5
26	27.75	21121.28	7.2
27	27.28	7834.431	7.85
28	24.39	15294.55	7.45
29	26.92	12293.6	7.9
30	25.84	13180.58	7.6

Results and discussion

Regression analysis of the experimental data was performed using Response Surface Methodology using Design-Expert software. The effects of four independent variables-sodium alginate (A), pectin (B), carboxy methyl cellulose (C) and sodium caseinate (D)- on three quality attributes of fried banana chips, namely oil content, hardness (inverse of crispiness) and overall acceptability, were investigated.

The fitted models for oil content and overall acceptability were of quadratic form, while a two-factor interaction (2FI) model was found suitable for oil content. The model F-values were statistically significant ($p < 0.05$) for all responses.

Table 3. Constraints and criteria for optimization of banana chips with casein based edible coating

Name	Goal	Lower Limit	Upper Limit
Sodium alginate (%)	In range	0.5	1.5
Pectin (%)	In range	0.5	1.5
CMC (%)	In range	0.5	1.5
Sodium caseinate (%)	In range	4	12
Oil content (%)	Minimize	17.69	33.02
Hardness (N)	Minimize	4413.14	21121.3
OA	Maximize	6.95	8.3

Table 4. Result of regression analysis of different responses of Fried banana chips

Partial Coefficients	Oil Content	Hardness	Overall Acceptability
Model	2 FI	Quadratic	Quadratic
Intercept	26.34	13901.41	7.58
A- Sodium Alginate	-1.22**	387.24 ns	0.0208 ns
B- Pectin	1.15**	623.86 ns	0.0792 ns
C- CMC	0.1894ns	115.69 ns	0.0208 ns
D- Sodium Caseinate	1.55**	1348.11 ns	-0.1375*
AB	0.8158 ns	1486.78 ns	0.0375 ns
AC	-0.6633 ns	-184.06 ns	0.0063 ns
AD	-1.80**	-525.18 ns	0.1125 ns
BC	2.16**	1578.89 ns	-0.1500*
BD	2.00**	1377.86 ns	-0.1437*
CD	-1.39**	242.28 ns	-0.0875 ns
A^2	-	-1536.87*	0.1344*
B^2	-	369.37 ns	-0.0594 ns
C^2	-	-1634.11*	0.1344*
D^2	-	-2209.60**	0.0406 ns
Lack of fit	1.98ns	0.34 ns	0.88 ns
Model F value	9.15**	2.77*	3.15*
R^2	0.8356	0.7214	0.7463
Press	136.62	5.052E+08	3.97
Adeq. Press	15.733	6.209	6.239

*- Significant at five per cent level ($p<0.05$), **- Significant at one per cent level ($p<0.01$), ns- non significant ($p>0.05$)

Importantly, all models exhibited non-significant lack-of-fit values, confirming model adequacy and robustness. Preferred goals were defined for each factor and response, with individual weights assigned to adjust the shape of their respective desirability functions. The scores for overall acceptability were kept at maximum while the values obtained for oil content and hardness were kept at minimum and the other factors were kept in range during the process of optimisation (Table 3). The outcomes of regression analysis for different responses related to fried banana chips are summarized in Table 4. Significant F-values obtained for oil content, hardness and overall acceptability confirmed the adequacy of the fitted model.

Effect of edible coating on oil content of banana chips

Oil content is one of the most important quality indicators of fried foods which influences sensory, nutritional qualities and shelf life (Santos et al., 2023). The pre-treatments given to banana chips such as blanching and coating with SC and hydrocolloids significantly lowered the oil content of the optimized, edible coated fried banana chips compared to that of the control fried chips. Oil content in the banana chips varied between 17.69% and 32.26%, with the lowest levels recorded in samples coated with SC and hydrocolloid-based solutions prior to frying (standard order 3). It is evident that the edible coating of banana chips helped to reduce the oil content of fries by approximately half of that of control (which was 33.43%). The results obtained were in agreement with Singthong and Thongkaew (2009) who observed an increased oil absorption in control banana chips (40 g/100 g) compared to hydrocolloid coated banana chips (23-38g/ 100g). The oil content of banana chips with casein based edible coating are given in Table 2 and the partial coefficient are given in Table 4. The 3-D graphs obtained for oil content are shown in Fig. 1 (a to f). The model for oil content exhibited a statistically significant F-value ($p < 0.01$), while the lack-of-fit was non-significant, indicating good model adequacy.

A response surface equation was developed to predict variations in oil content as influenced by different concentrations of sodium alginate (A), pectin (B), carboxymethyl cellulose (C) and SC (D).

$$\text{Oil content} = 26.34 - 1.22 * A + 1.15 * B + 0.1894 * C + 1.55 * D + 0.8158 * AB - 0.6633 * AC - 1.80 * AD + 2.16 * BC + 2.00 * BD - 1.39 * CD$$

Regression analysis revealed that pectin (B) and SC (D) significantly increased oil content. The interactions BC (2.16) and BD (2.00) were highly influential, reinforcing that combinations of pectin with either CMC or SC promote greater oil absorption. On the other hand, the interaction between sodium alginate and caseinate (AD = –1.80) and CMC and caseinate (CD= –1.39) showed a significant negative effect on oil uptake, indicating a potential structural synergy that enhances the barrier properties of the coating matrix and limits oil penetration. The present findings regarding reduced oil content in hydrocolloid-coated banana chips are consistent with earlier reports. Paramasivam et al. (2022) observed that coatings with CMC at concentrations of 0.5% - 1.0% were effective in reducing oil uptake ranging from 18.52% to 23.30% in *Popoulu* and 24.59% to 28.48% in *Nendran* varieties of banana. However, their study did not explore the interactive effects of multiple hydrocolloids on oil absorption, which is the focus in the present work. Aminlari, Ramezani and Khalili (2005) demonstrated that SC coatings on potato chips resulted in a 14% decrease in oil content relative to uncoated samples, highlighting the oil barrier function of milk proteins. These observations emphasise the role of hydrocolloid coatings, individually or in combination, in modulating lipid uptake during deep-fat frying.

Effect of edible coating on hardness of banana chips

Crispiness is a crucial texture attribute for snack foods like chips, significantly influencing consumer acceptance and preferences. Reduced hardness is indicative of enhanced crispiness in the product (Singthong and Thongkaew, 2009). Fig. 2 (a to f) represents the 3-D graphs obtained for hardness. To estimate changes in crispiness, a response surface equation was developed based on varying levels of sodium alginate (A), pectin (B), carboxymethyl cellulose (C) and SC (D):

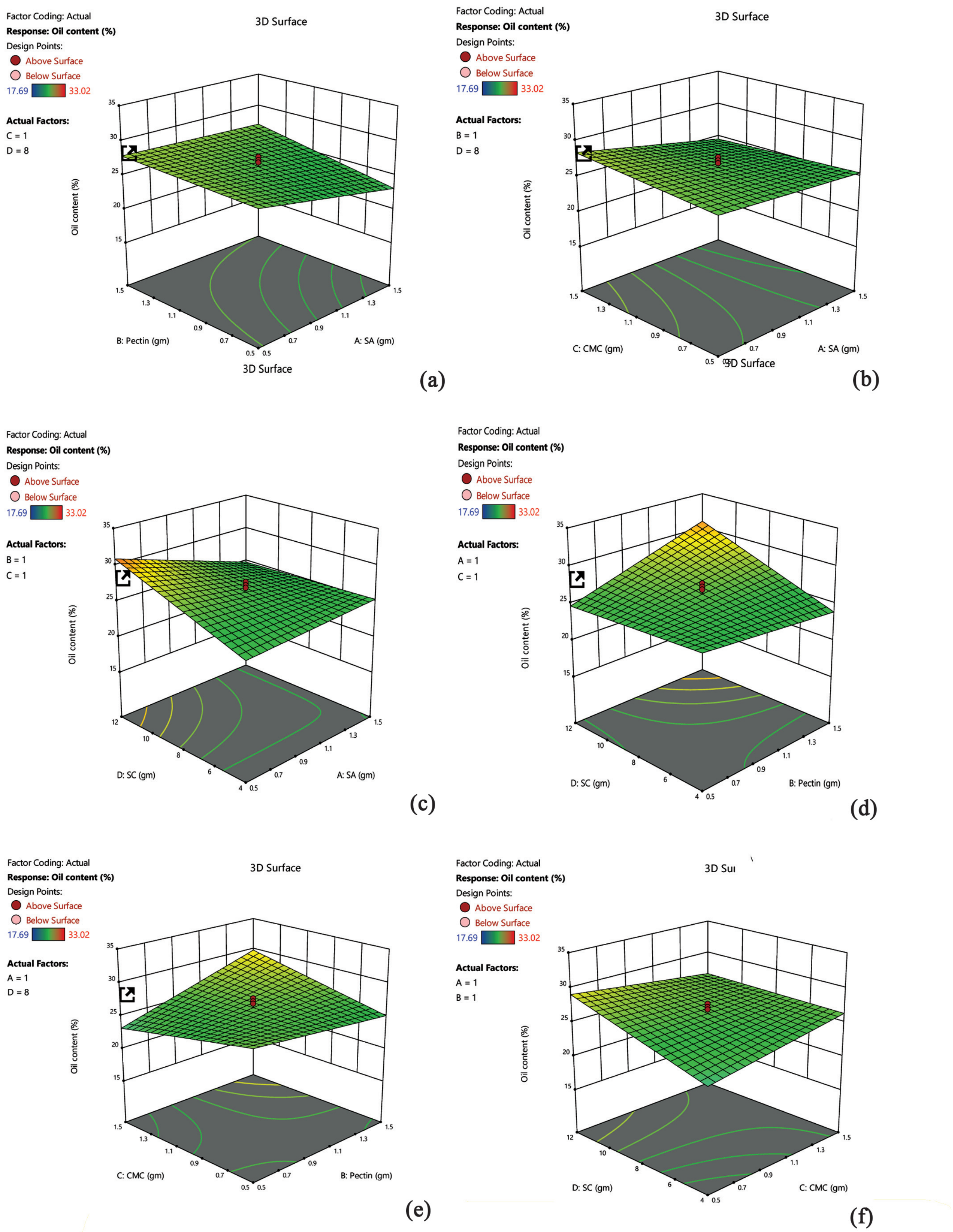

Figure 1. Response surface plot relating to oil content as influenced by level of Sodium caseinate, Sodium alginate, Pectin and CMC

$$\text{Hardness} = 13901.41 + 387.24 * A + 623.86 * B + 115.69 * C + 1348.11 * D + 1486.78 * AB - 184.06 * AC - 525.18 * AD + 1578.89 * BC + 1377.86 * BD + 242.28 * CD - 1536.87 * A^2 + 369.37 * B^2 - 1634.11 * C^2 - 2209.60 * D^2$$

The sign of partial coefficient proposed that all the factors had a significant positive effect on hardness. Table 4 shows that the interaction effects AB, BC, BD and CD had positive effect on the hardness while the other interaction factors had a negative effect on it. Hardness of fried banana chips was

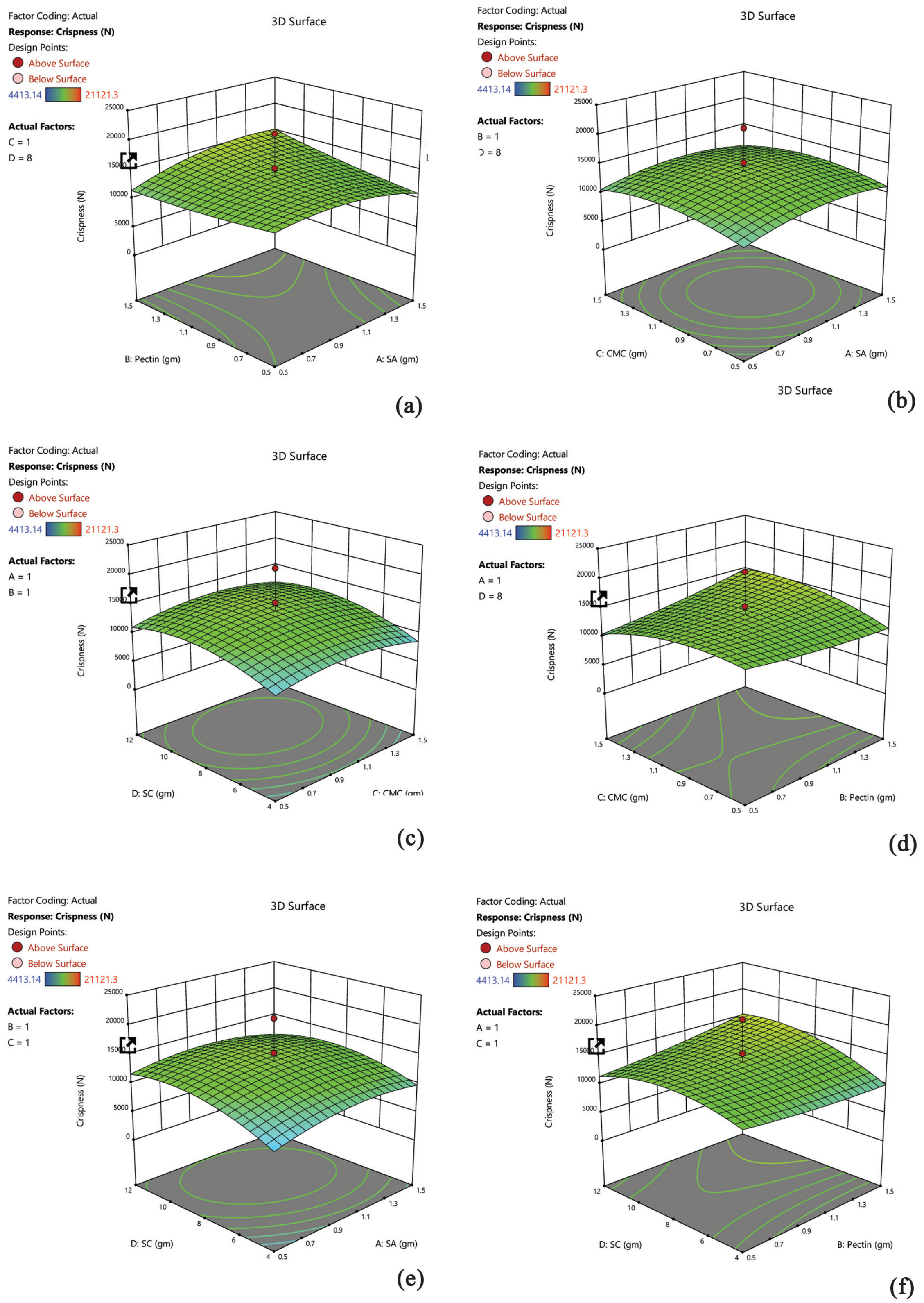

Figure 2. Response surface plot relating to hardness as influenced by level of Sodium caseinate, Sodium alginate, Pectin and C

influenced predominantly by the linear and quadratic effects of SC (D), with a positive linear coefficient (1348.11) and a significant negative quadratic effect (–2209.60). These findings suggest that while SC increased hardness at lower levels, a point of inflection exists beyond which further addition led to reduction in hardness, indicating increased crispiness. Similar curvature was observed for sodium alginate (A^2 = –1536.87) and CMC (C^2 = –1634.11), indicating optimal ranges for achieving lower hardness. Pectin (B) also contributed positively to hardness (negatively

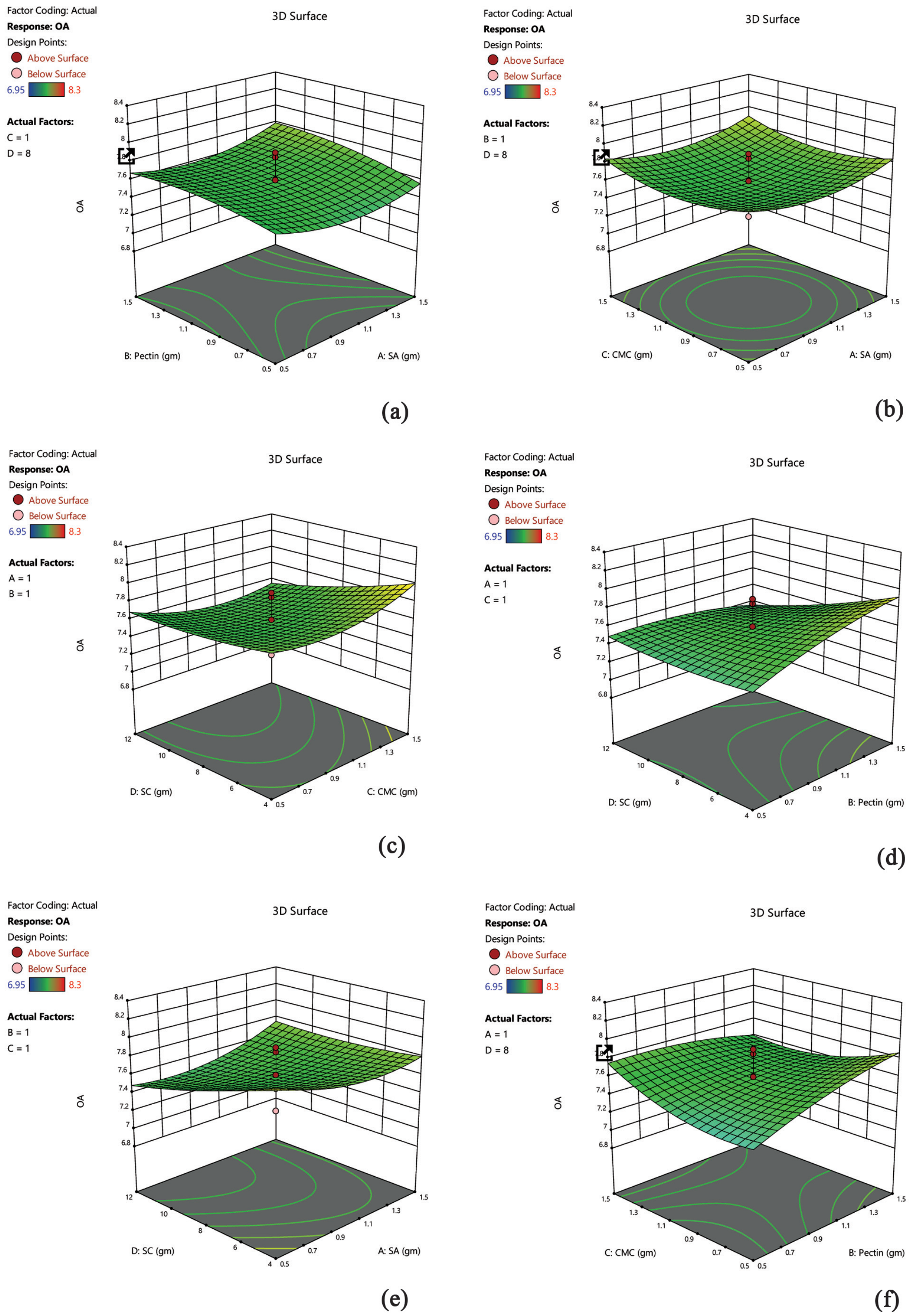

Figure 3. Response surface plot relating to overall acceptability as influenced by level of Sodium caseinate, Sodium alginate, Pectin and CMC

to crispiness), while interaction terms such as AC, AD and quadratic terms of A and D significantly reduced hardness, suggesting strong synergistic effects helps to retain crispiness. These findings are in line with the research of Paramasivam et al. (2022), who reported that the hardness of banana chips significantly decreased with hydrocolloid treatment compared to untreated controls in banana chips, indicating improved crispiness. They also observed that the hardness of banana chips increased with increasing hydrocolloid concentration, which may be due to the inherent ability of hydrocolloids which enhance the mechanical strength of banana chip tissues, thereby improving structural integrity and subsequently reducing crispiness which is contradictory to our findings. Eliminating moisture before frying contributed to increased compactness and hardness of the final product (Debnath, Bhat and Rastogi, 2003). Wani, Sharma and Kumar (2017) observed that the hardness and moisture content of fried banana chips increased with increasing thickness. The coating of banana chips before frying lead to increased thickness which may be the reason for the increased value of hardness (reduced crispiness).

Effect of edible coating on overall acceptability of banana chips

Sensory evaluation is a scientific discipline that systematically assesses and quantifies human perceptions of food and beverages, including attributes such as appearance, touch, odour, texture and taste. In this study, a nine-pointhedonic scale was used to determine any significant change in colour, crispiness, flavour, oiliness and overall acceptability of fried banana chips. The model fitted for overall acceptability exhibited a quadratic form. The model F-value for overall acceptability was found to be significant ($p < 0.05$), while the lack of fit was non-significant. The scores of overall acceptability varied between 6.95 to 8.25 on the hedonic scale (Table 2). Poor score of trial no. 19 was noted in coated banana chips without pectin due to consumer's unacceptability. Fig. 3 (a to f) represents the 3-D graphs obtained for overall acceptability. All samples exhibited overall acceptability scores exceeding the minimum limit of acceptability of more than five (Kumar and Sagar, 2016). The results of our sensory evaluation are consistent with the findings of Maity, Bawa and Raju (2015) who reported that increase in pectin and CMC concentrations (0.5 to 2.0) was accompanied by increase in overall acceptability as compared to that of control.

The response surface equation developed to predict variations in overall acceptability as influenced by different levels of sodium alginate (A), pectin (B), carboxy methyl cellulose (C) and SC (D) is:

$$\text{Overall acceptability} = 7.58 + 0.0208 * A + 0.0792 * B + 0.0208 C - 0.1375 * D + 0.0375 * AB + 0.0063 * AC + 0.1125 * AD - 0.1500 * BC - 0.1437 * BD - 0.0875 * CD + 0.1344 * A^2 - 0.0594 * B^2 + 0.1344 * C^2 + 0.0406 * D^2$$

Both the main and interaction effects had a significant influence on overall acceptability. The levels of sodium alginate (A), pectin (B) and carboxymethyl cellulose (C) exerted positive effect. SC had a small but negative effect (–0.1375), while interactions such as BD (–0.1437) and BC (–0.1500) reduced acceptability, potentially due to the combined impact on undesirable hardness or excessive oiliness. Quadratic terms for sodium alginate and CMC (A^2 and C^2 = +0.1344) had positive effects, indicating that moderate concentrations of these hydrocolloids contribute positively to the sensory profile.

Optimised solutions and their validation

The optimal formulation predicted by Design-Expert, targeting minimized hardness and oil content and maximized overall acceptability, comprised 0.5% sodium alginate, 1.5% pectin, 0.5% CMC and 4% SC, achieving a composite desirability score of 0.983. The optimised product was evaluated for oil content, hardness (inverse of crispiness) and overall acceptability and the data along with the predicted values of responses are depicted in Table 5. Figure 4 shows the optimised product and control banana chips. Statistical analysis was performed using a t-test (assuming equal variance) to compare the observed results with the corresponding predicted values. The analysis revealed no statistically significant differences between the observed and predicted values across all evaluated attributes. Responses of the optimised samples compared with control and given in the Table 6. Results revealed that the oil content of coated

Figure 4. Banana chips with casein based edible coating vs. control banana chips

Table 5. Verification of the optimum formulation

Attributes	Predicted value	Observed value	t value
Oil Content	18.148	17.69±0.352	-2.23^{ns}
Hardness	2752.525	4428.86±1493.016	-1.94^{ns}
Overall acceptability	8.296	8.25±0.216	0.36^{ns}

Figures are mean± standard error of three replications, ns-non significant (p>0.05)

Table 6. Comparison of responses of control and coated banana chips

Responses	Control	Coated chips	t value
Oil Content	33.43 ±0.533	17.69 ±0.352	-42.6233**
Hardness	6106.401 ±656.748	4428.856 ±1493.016	-1.78^{ns}
Overall acceptability	7.91 ±0.11	8.4 ±0.12	55*

*- Significant at five per cent level (p<0.05), **- Significant at one per cent level (p<0.01), ns- non significant (p>0.05)

Table 7. Proximate composition of coated chips and control (uncoated chips)

Parameter	Coated chips	Control	t value
Moisture (%)	2.5±0.017	2.76±0.204	-2.22734^{ns}
Fat (%)	17.69±0.352	33.43±0.533	-42.6233**
Protein (%)	3.48±0.20	1.81±0.85	33.89**
Carbohydrate (%)	55.88±0.441	45.51±0.640	33.06**
Dietary fibre (%)	14.91±0.095	13.17±0.211	12.94036**
Crude fibre (%)	2.62±0.043	2.45±0.085	3.02**
Ash content (%)	2.54±0.077	3.26±0.115	-9.18**

Figures are mean± standard error of three replications, **- Significant at one per cent level (p<0.01), ns- non significant

banana chips was significantly lower ($p < 0.01$) compared to the control sample indicating the effectiveness of the coating in reducing oil uptake during frying. Hardness values of coated chips were lower, which means higher crispness, however, the difference was not statistically significant ($p > 0.05$). In terms of sensory evaluation, coated chips (8.40 ± 0.12) received significantly higher ($p < 0.05$) overall acceptability scores than the control (7.91 ± 0.11), demonstrating consumer preference for the coated samples.

Proximate composition

The optimized casein based edible coated banana chips and control banana chips were subjected to proximate composition analysis which is presented in Table 7. A statistically significant difference was observed (p<0.01) in the different compositional parameters of casein based edible coated chips except moisture compared to control. There was a slight increase in the protein content and very significant reduction in the fat content in the coated banana chips when compared with control. Similar results for fat were observed by Sumonsiri, Imjaijit and Padboke (2020) in hydrocolloid coated banana chips. As moisture content increases, oil absorption rises and crispiness decreases (Santos et al., 2023). Higher carbohydrate recovery suggests reduced leaching and structural preservation. Coatings contribute positively to the nutritional profile by retaining or enhancing fiber. The increased protein and dietary fibre values in coated samples may be linked to active components in the coating material, such as casein or polysaccharides like CMC or sodium alginate. This composition highlights the role of hydrocolloid treatments in reducing oil absorption and enhancing the nutritional and textural properties of the chips.

Colour properties

Oil uptake and browning reactions may contribute significantly to the final colour development of the fried product (Baixauli et al., 2002). The L, a and b values of control and coated banana chips are given in the Table 8. The positive values for b which indicate that samples are yellow in colour. The results obtained were statistically analysed using independent t test. These findings are consistent with the observations of Ranasalva (2017), who reported b values of 37.02 and 59.84 for vacuum-fried raw and ripe banana chips, respectively, when fried in coconut oil. The chroma value, which indicates colour saturation, was higher in control chips (46.338) compared to coated chips (39.465). Similar observations were reported by Kumar et al. (2019), who noted that coatings help reduce colour degradation in fried snacks. The whiteness index (WI) was higher in coated chips (59.905) than in control chips (53.118), indicating that the coating contributed to a lighter and more appealing surface colour. The yellowness index (YI) was markedly higher in control chips (132.618) compared to coated chips (110.541). A higher YI indicates a stronger yellowish-brown appearance, which is typically associated with advanced browning reactions during frying. Similar results were reported by Paramasivam et al., 2022. This could be due to the aldehyde groups generated from triglyceride degradation reacting with amino groups to form dark-coloured compounds. Furthermore, it has been suggested that the development of a dark yellow colour in bananas is intensified when the moisture content is reduced (Wani, Sharma and Kumar, 2017).

Table 8. Colour characteristics of banana chips with edible coating and control

Parameter	Control sample	Coated banana chips	t value
L	49.38±0.84	49.95±0.30	-1.1^{ns}
a	6.78±0.30	7.98±0.18	-5.93**
b	45.84±0.95	38.65±0.65	10.73**

Figures are mean± standard error of three replications, **- Significant at one per cent level (p<0.01), ns- non significant

Biochemical parameters of coconut oil

Fresh coconut oil generally contains less than 0.5% FFA (as lauric acid), but prolonged storage, improper handling or exposure to moisture can increase FFA levels due to triglyceride hydrolysis. Also, fresh coconut oil typically has a peroxide value below 5 meq O_2 /kg oil, but the value increases with oxidation during storage or frying and it exhibits a relatively high saponification value (250–260 mg KOH/g oil) due to its higher proportion of short- and medium-chain fatty acids (particularly lauric acid) (AOCS, 1989; Marina et al., 2009; Moigradean, Poiana and Gogoasa, 2012). In the present study we used fresh coconut oil.

Conclusion

This study investigated the impact of coating on the quality attributes of fried banana chips, including oil absorption, hardness and sensory properties. A coating solution comprising 0.5% sodium alginate, 1.5% pectin, 0.5% carboxymethyl cellulose and 4% sodium caseinate was the solution formulated based on the results obtained from response surface analysis. Application of response surface methodology in optimizing analytical procedure is widespread due to its ability to generate valuable insights from fewer experiments and reveal interactions between variables. It was further noted that samples with lower oil absorption tended to possess better texture and higher sensory appeal. The optimum values of oil content, hardness and overall acceptability of coated banana chips were 17.69%, 4428.85 N and 8.25, respectively. Based on the experiment, the application of a casein-based edible coating effectively reduced oil absorption (≈48%) in banana chips during frying. This will help to enhance the consumer acceptability along with increased nutrition. Therefore, this coated banana chips serve as a healthier snack option compared to the control, particularly for individuals with cardiovascular diseases or high cholesterol, due to their significantly reduced oil content. Further analysis is needed to determine the storage period of the banana chips.

Acknowledgement

The authors acknowledge to the Kerala Veterinary and Animal Sciences University, Pookode, Kerala for providing all essential facilities and financial assistance for the research.

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