

RESPONSE SURFACE METHODOLOGY BASED OPTIMIZATION AND QUALITY EVALUATION OF ORANGE PEEL POWDER-ENRICHED *KULFI*

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ABSTRACT

This study aimed to optimize the incorporation of orange peel powder (OPP) and mix concentration in kulfi using response surface methodology (RSM) and evaluate the quality characteristics of the optimized product. A central composite rotatable design was employed with OPP concentration (2.0–3.0%, w/v) and mix concentration (1.0–1.75-fold) as the independent variables. Color and appearance, taste/texture, sweetness, and overall acceptability were evaluated using a 9-point hedonic scale, while sugar and stabilizer-emulsifier levels were kept constant based on preliminary trials. Quadratic models adequately described the sensory responses, with R^2 values ranging from 0.8375 to 0.9231 and a non-significant lack of fit for all responses. Numerical optimization, based on maximizing color, flavor, and overall acceptability while maintaining the other sensory responses within the experimental range, yielded an optimum formulation containing 3.0% OPP and 1.75-fold mix concentration, with a desirability of 0.88. Validation of the optimized formulation showed no significant difference ($p > 0.05$) between the predicted and observed values for the sensory responses. Compared with the control, the optimized kulfi showed no significant differences in fat, protein, and total sugar contents, whereas carbohydrate, ash, total solids, and energy values differed significantly ($p < 0.05$). The findings demonstrate that OPP can be incorporated into kulfi at an optimized level while maintaining acceptable sensory characteristics and modifying its compatibility.

Industrial relevance

Orange processing generates large volumes of peel waste which has substantial disposal and environmental costs. This study provides dairy and frozen-dessert manufacturers with a validated RSM-based formulation and process window (OPP concentration and mix concentration) for converting orange peel into a value-added functional ingredient in *kulfi*, a widely consumed traditional Indian frozen dessert. The optimized formulation offers a scalable route to reduce citrus by-product waste while diversifying functional frozen-dessert product lines for health-conscious consumers.

KEYWORDS: *Kulfi*; Orange peel powder; Response surface methodology; Sensory evaluation; Functional dairy dessert; Citrus by-product valorization

Highlights

- *Kulfi* enriched with orange peel powder (OPP) was optimized using RSM-CCRD.
- OPP at 3.0% with a 1.75-fold mix gave the highest desirability (0.88).
- Quadratic models showed high adequacy ($R^2 > 0.85$) for sensory responses.
- OPP addition altered ash, total solids and carbohydrate, not fat or protein.
- Findings support valorization of citrus peel in functional dairy desserts.

1. INTRODUCTION

As per the official reports of the Department of Animal Husbandry and Dairying, Govt. of India (2024), nearly, 4.0% of Indian milk production is converted to western dairy products such as cheese, milk powder and ice cream. The ice cream market in India has increased four times in the past decade and is projected to reach INR 45,000 crore by 2029 (IMARC Group, 2026). *Kulfi* is an indigenous counterpart to ice cream (Aneja, Mathur, Chandan, & Banerjee, 2007) with denser texture and distinctive flavour relative to conventional ice cream. *Kulfi* manufacturers are looking to exploit the ice cream market through technological improvements in *Kulfi*. As a result, several *kulfi* variants with special ingredients such as cardamom, saffron, pistachio, tomato (Chaturvedi et al., 2022), amaranthus (Patel et al., 2020), and wood apple pulp (Singh et al., 2017) have emerged to entice the traditionalists and health-conscious modern consumers (Tharun, 2024). *Kulfi* formulations with fruit pomace, pulp, peel, peel extracts with anti-oxidant properties, natural sweeteners (e.g., stevia) and natural colorants are rising in the market (Chaouch & Benvenuti, 2020; Rafiq et al., 2016, Tharun, 2024). The fruits parts such as banana peel, citrus peel/seed/pomace (Adil et al., 2023), avocado seed, pomegranate peel (Sandhya, Khamrui, Prasad, & Kumar, 2018), and potato peel (Javed, Ahmad, Tahir, & Shabbir, 2019) have been used for valorization

of dairy products as functional foods. They offer health-benefits through their fiber, minerals, and vitamins contents (Figueroa, Hurtado, Estévez, Chiffelle, & Asenjo, 2005). They can also extend the shelf life of food products owing to their antibacterial (Abdelmigid et al., 2022) and antioxidant properties (García-Alonso, de Pascual-Teresa, Santos-Buelga, & Rivas-Gonzalo, 2004).

Orange peel is a citrus fruits processing by-product known to contain dietary fibre and structural polysaccharides, including pectin, cellulose, hemicellulose, and lignin, along with phenolic and other bioactive constituents (Rafiq et al., 2016; Sayah et al., 2016). These characteristics have encouraged investigations into the use of orange peel powder (OPP) as an ingredient in bakery products, ice cream, frozen yoghurt, and other food systems. Previous studies have reported that the incorporation of OPP can influence colour, flavour, texture, and other quality characteristics depending on the level of addition (Ananthakumar et al., 2019; Kohajdová et al., 2011; Adil et al., 2023).

Although OPP has been investigated in ice cream, frozen yoghurt, and other food products, comparatively limited information is available regarding its incorporation into kulfi. Kulfi differs from conventional ice cream in its concentrated milk base, dense body, and characteristic sensory properties. Consequently, the effects observed with OPP in other frozen dairy products cannot necessarily be directly applied to kulfi. In particular, information is limited on the combined effects of OPP concentration and mix concentration on the sensory quality of kulfi.

Response surface methodology (RSM) provides an effective approach for evaluating the effects of multiple formulation variables and identifying optimum processing conditions with a limited number of experimental runs. Therefore, the present study was undertaken to optimize OPP concentration and mix concentration for kulfi using a central composite rotatable design and RSM. There is also a lack of published data on an optimized formulation that jointly ensures OPP functionality, appropriate mix concentration, and consumer acceptability. The present investigation was therefore undertaken to develop kulfi incorporating orange peel powder as a natural functional ingredient, combining the traditional appeal of kulfi with the functional and nutritional benefits of orange peel, and to identify the optimum OPP and mix concentration levels using response surface methodology (RSM). The study further aimed to evaluate the sensory characteristics of the experimental formulations, validate the optimized formulation, and compare selected compositional characteristics of the optimized OPP-added kulfi with those of a control.

2. MATERIALS AND METHODS

2.1 Materials and equipment

Milk, unsalted butter, ripe oranges, granular sugar, stabilizer, and emulsifier were procured from the local market of Pusad, Maharashtra, India. *Kulfi* was prepared at the Dairy Technology Department, College of Dairy Technology, Warud (Pusad), Maharashtra Animal and Fishery Sciences University, Nagpur. Equipment used included a stainless-steel (SS) pan with stirrer, an SS basket of *kulfi* moulds, a candy-freezing machine (Ice Make Refrigeration Ltd., Ahmedabad, India), a hardening-tunnel deep freezer (Ice Make Refrigeration Pvt. Ltd., Ahmedabad, India), and a vacuum tray dryer.

2.2 Preparation of orange peel powder

Orange peel powder (OPP) was prepared following the method described by Adil et al. (2025), with slight modifications to optimize drying efficiency and powder uniformity (Fig. 1). Fresh oranges (*Citrus sinensis* cv. Valencia) were washed, and peels were removed and cut into strips (approximately 4 × 1 cm). The peels were blanched at 77 °C for 5 min (peel: water = 1:2, w/v) and de-bittered in 2.0% (w/v) sodium bicarbonate solution at 95 °C for 3 min. The treated peels were immersed in sugar syrup (≈50 °Brix) at 50 ± 2 °C for 5 h and then vacuum tray-dried at 50 ± 2 °C for 8 h (vacuum of 670 ± 20 mm Hg) to a final moisture content of ≤10%. Dried peels were ground and sieved through a 500-µm SS mesh to obtain a uniform powder, which was packaged in plastic jars and stored at 4 ± 2 °C.

Selecting oranges (*Citrus sinensis* cv. Valencia)

↓

Washing fruit with water

↓

Removing peels

↓

Cutting peels (size: 4 × 1 cm)

↓

Blanching (77 °C for 5 min; peel: water = 1:2, w/v)

↓

De-bittering of peels (2.0% NaHCO₃ solution, 95 °C, 3 min)

↓

Treatment of peels with sugar syrup (50 °Brix, 50 ± 2 °C, 5 h)

↓

Vacuum tray drying of processed peels (50 ± 2 °C, 8 h, vacuum 670 ± 20 mm Hg)

↓

Grinding of dried orange peel (moisture ≤ 10.0%)

↓

Sieving of powder (size 500 μm)
 ↓
 Packaging of powder (plastic jar)
 ↓
 Storage ($4 \pm 2^\circ\text{C}$)

Fig. 1. Flow chart for the manufacture of orange peel powder.

2.3 Preparation of control and experimental kulfi samples

Standardized buffalo milk (6.3% fat, 7.0% milk-solids-not-fat) was heated to 40°C , followed by addition of sugar, OPP, and a stabilizer-emulsifier blend at 15.0%, 3.0%, and 0.3%, respectively. The mix was stirred continuously and concentrated to the target mix concentration (1.0-1.75 fold, per the experimental design). The concentrated mix was cooled, aged at 4°C , filled into moulds, frozen at $-18 \pm 2^\circ\text{C}$ for 25 min, hardened, packaged, and stored at $-10 \pm 1^\circ\text{C}$ until analysis. The detailed preparation flow for OPP-added kulfi is shown in Fig. 2.

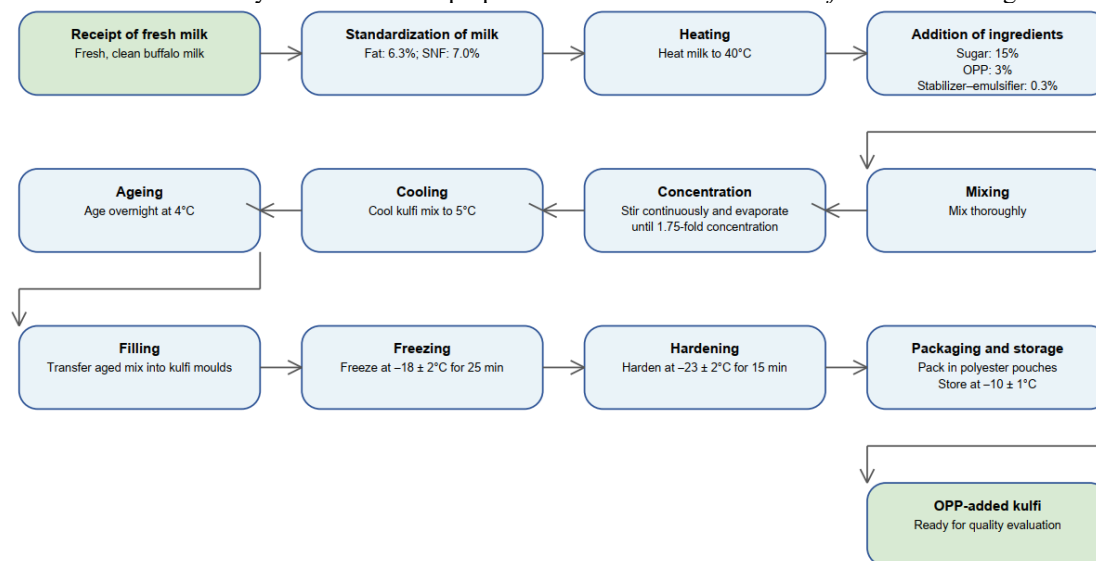


Fig. 2. Preparation of OPP-added kulfi.

2.4 Physicochemical properties of orange peel powder

Crude fibre content was determined by AOAC Official Method 978.10 (AOAC, 2004). Moisture content was determined per AOAC (2000). Crude protein was quantified by the micro-Kjeldahl method using an Automatic KEL-PLUS CLASSIC-DX apparatus (Pelican Equipment's, Chennai, India), following AOAC (2000). Total sugar content was estimated by the Lane-Eynon titrimetric method (BIS, 1981), and ash content was determined per AOAC Official Method 942.05 (AOAC, 2005). Antioxidant activity of OPP was determined by the 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical-scavenging assay; aqueous extracts were prepared following Friedman, Levin, and McDonald (2002) and Arora and Kaur (2013), and DPPH scavenging activity was measured according to Brand-Williams, Cuvelier, and Berset (1995). All analyses were performed in triplicate and results expressed as mean $\pm$ standard deviation. The proximate composition and antioxidant activity of OPP are presented in Table 1.

Table 1. Proximate composition and antioxidant activity of orange peel powder

Parameter	Value
Protein (%)	3.97 ± 0.02
Moisture (%)	4.29 ± 0.56
Total sugar (%)	64.90 ± 0.04
Crude fibre (%)	3.99 ± 0.02
Ash (%)	3.31 ± 0.01
Antioxidant activity (% DPPH inhibition)	70.05 ± 0.05

Values are expressed as mean $\pm$ SD of triplicate determinations ($n=3n=3$). DPPH = 2,2-diphenyl-1-picrylhydrazyl.

2.5 Experimental design

A central composite rotatable design (CCRD) of RSM was used to optimize the OPP-containing kulfi formulation. Preliminary trials were conducted to fix the ranges of the two independent variables, OPP concentration (2.0-3.0% w/v) and mix concentration (1.0-1.75 fold); the resulting design comprised 13 runs (4 factorial points, 4 axial points, and 5 center-point replicates). Colour/appearance, taste/flavour, sweetness, texture, and overall

acceptability were evaluated as sensory responses. The complete design matrix, together with the corresponding sensory responses, is presented in Table 2.

Table 2. CCRD experimental design matrix and sensory scores* of *kulfi* with different levels of OPP and mix concentration.

Run	OPP (%)	Mix conc. (fold)	Colour & appearance	Taste/flavour	Sweetness	Texture	Overall acceptability
1	2.50	1.69	7.1	7	7	7.6	7
2	3.00	1.75	8	8.1	8	8.2	8.6
3	3.21	1.88	8.1	8.1	7.8	7.9	7.5
4	2.00	2.00	7	7.6	8	7.2	7.8
5	2.50	1.88	7.2	7.3	7.8	7.25	7.5
6	2.50	1.88	7.2	7.4	7.3	7.3	7
7	1.79	1.88	7	6.6	7.8	7.2	7.2
8	2.50	2.05	7.1	7.6	7.5	7.1	7.5
9	2.50	1.88	7.2	7.4	7.5	7.3	7.5
10	3.00	2.00	7.6	8.5	8.2	8.0	8
11	2.50	1.88	7.2	7.5	7.8	7.3	7.5
12	2.00	1.75	7.3	7.6	7.9	7.5	7.6
13	2.50	1.88	7.4	7.7	7.5	7.7	7

*Score on a 9-point hedonic scale. OPP: orange peel powder.

2.6 Sensory evaluation

Kulfi samples corresponding to each formulation were evaluated by a semi-trained panel of five judges from the College of Dairy Technology, Warud (Pusad). Panelists scored colour and appearance, flavour, sweetness, texture, and overall acceptability using a 9-point hedonic scale, following the method of Raju (2004).

2.7 Statistical analysis

Response surface regression and analysis of variance (ANOVA) were performed using Design-Expert® software (version 13.0; Stat-Ease Inc., Minneapolis, MN, USA). Second-order polynomial (quadratic) models were fitted to each response, and model adequacy was assessed using the coefficient of determination (R^2), adequate precision, the model F-value, and the lack-of-fit test. Numerical optimization was performed using the software's built-in desirability function to identify the OPP and mix-concentration combination that maximized colour, flavour, and overall acceptability while keeping the remaining responses within an acceptable range. Compositional data for the optimized and control *kulfi* (Table 5) were compared by one-way ANOVA, and means were separated using Duncan's multiple range test at a 5% significance level ($p < 0.05$); results are reported as mean $\pm$ standard error of the mean ($n = 3$).

3. RESULTS AND DISCUSSION

3.1 Optimization of OPP and mix concentration for *kulfi* formulation

The experimental data for the 13 treatment combinations and their effects on the five measured sensory responses are presented in Table 2. Regression coefficients, p-values, adequate precision, and model-fit statistics for the fitted quadratic models obtained for all five responses are listed in Table 3. Model adequacy was assessed using the F-ratio and the coefficient of determination (R^2). As shown in Table 3, R^2 values for all sensory responses (colour & appearance, taste/flavour, texture, and overall acceptability) exceeded 0.85, indicating a good model fit, and the lack-of-fit test was non-significant for all responses, confirming that the quadratic models adequately described the experimental data.

3.2 Effect of OPP and mix concentration on colour and appearance

Colour and appearance are key attributes of food products, closely linked to overall quality perception (Fergus, 1991). Mean scores for colour and appearance ranged from 7.0 to 8.1 across treatments (Table 2). The highest sensory score of *kulfi* was perceived 8.1 by treatment number 3 followed by treatment numbers 2 (8), 10 (7.6) and treatment numbers 4 and 7 secured the lowest (7) sensory score. As shown in Table 3 and illustrated in Fig. 3(a), OPP level (A) had a significant ($p \leq 0.01$) positive effect on colour and appearance, while mix concentration (B) had a significant ($p \leq 0.05$) negative effect at the quadratic level; the interaction ($A \times B$) was negative. A similar trend was reported by Raj and Masih (2014), who found that incorporating 5% dried orange peel into wheat flour buns improved texture, flavour, colour, and overall acceptability. Zaker et al. (2017a, 2017b) likewise observed enhanced appearance, colour, taste, and texture in cakes and biscuits with OPP addition up to 10%, although a further increase reduced appearance due to a grainy texture. In the present study, the higher colour and appearance scores at intermediate-to-higher OPP levels may be associated with the natural colour imparted by orange peel powder. Although carotenoids and phenolic compounds have been reported in orange peel, these compounds were not quantified in the present study. The highest observed colour and appearance score was 8.1 at the formulation containing 3.21% OPP and 1.88-fold mix concentration; however, the selected optimum formulation was based on simultaneous optimization of all sensory responses.

3.3 Effect of OPP and mix concentration on taste and flavour

Flavour scores ranged from 7.0 to 8.5 (Table 2). The highest sensory score of *kulfi* was received (8.5) by treatment number 10, followed by treatment numbers 2 and 3 (8.1) and treatment number 7 secured the lowest (6.6) flavor score. Based on the response-surface plot (Fig. 3b) and ANOVA results (Table 3), both OPP level (A) and mix concentration (B) had a significant ($p \leq 0.05$) positive effect on flavour. However, at higher OPP levels (A^2) a significant ($p \leq 0.05$) negative effect on taste was observed, whereas higher mix concentration (B^2) had a significant positive effect ($p \leq 0.05$); the OPP $\times$ mix-concentration interaction ($A \times B$) was significantly positive ($p \leq 0.05$). The reduction in flavour score at higher OPP levels may be related to the characteristic bitter notes associated with citrus peel. Naringin has been reported as a bitterness-associated compound in citrus peel; however, it was not quantified in the present study (Pinzon et al., 2013). These results are consistent with Kohajdová, Karovičová, Jurasová, and Kukurová (2011), who reported that OPP incorporation in biscuits improved flavour at moderate levels due to flavonoid content, but reduced taste scores at higher levels because of bitterness. Similarly, Ananthakumar et al. (2019) found that, among ice creams formulated with 1.5-5.0% OPP, the 2.5% sample scored highest for flavour.

3.4 Effect of OPP and mix concentration on sweetness

Sweetness is the sensation perceived upon contact of a food with taste receptors (Chen et al., 2023). Sweetness scores ranged from 7.0 to 8.2 (Table 2). The highest sensory score of *kulfi* was perceived (8.2) by treatment number 10, followed by treatment numbers 2 and 4 (8.0), 12 (7.9), 3, 5, 7, 11 (7.8) and treatment number 1 secured the lowest (7.0) sweetness score. Based on the response-surface plot (Fig. 3c) and ANOVA results (Table 3), mix concentration (B) had a significant ($p \leq 0.05$) positive effect on sweetness, whereas higher levels of OPP (A^2) and mix concentration (B^2) had a significant ($p \leq 0.05$) negative effect; neither the OPP $\times$ mix-concentration interaction ($A \times B$) nor OPP alone (A) significantly affected sweetness. These findings are consistent with Ojha and Thapa (2017), who found that biscuits containing 6% mandarin peel powder had the highest sweetness scores, whereas 9% inclusion produced slight bitterness attributable to polyphenols and limonene (Ojha, Karki, & Sitaula, 2016). Haghani et al. (2021) similarly reported that Cornelian cherry peel above 6% reduced taste and sweetness scores in probiotic ice cream due to intense sourness; in the present study, higher OPP levels may have influenced the perceived sweetness because citrus peel can contribute bitter or astringent notes. The presence and concentration of naringin or other bitterness-related compounds were not determined (Pinzon et al., 2013).

3.5 Effect of OPP and mix concentration on texture

Texture, an important determinant of consumer acceptability, scored between 7.1 and 8.2 (Table 2). The highest sensory score of *kulfi* was secured 8.2 by treatment number 2 followed by treatment number 10 (8.0), 3 (7.9), 13 (7.7), 1 (7.6), 12 (7.5) and treatment number 8 secured the lowest (7.1) texture score. The response-surface plots (Fig. 3d) and ANOVA results (Table 3) showed that both OPP level (A) and mix concentration (B) had a significant ($p \leq 0.05$) positive effect on texture, whereas the $A \times B$ interaction was non-significant. Higher levels of OPP (A^2) and mix concentration (B^2) had a significant ($p \leq 0.05$) negative effect on texture. The texture changes at higher OPP levels may be related to the fibre-rich composition and water-binding behavior of orange peel powder. Pectin has been reported as a constituent of orange peel; however, pectin content and water-holding capacity were not measured in the present study (Asati et al., 2019). Gurram and Sharma (2019) similarly reported improved crispness in bajra-based biscuits with OPP incorporation, with texture scores declining above 5% OPP, while Asati et al. (2019) reported that orange rind addition enhanced the texture score of burfi.

Table 3. Regression coefficients and ANOVA of the quadratic models for sensory characteristics of OPP-added *kulfi*.

Factor	Appearance & colour	Taste/flavour	Sweetness	Texture	Overall acceptability
Intercept	7.24	7.46	7.58	7.37	7.30
OPP (A)	0.3570**	0.2643*	0.0375	0.3112*	0.2030*
Mix concentration (B)	-0.0875*	0.0936*	0.1259*	0.1509*	0.0384*
A^2	-0.1925**	-0.1512*	0.2350	-0.1587*	-0.2000*
B^2	0.0325	0.0012*	-0.0400*	-0.0587*	-0.1500*
AB	-0.0250	0.0250*	0.0250	0.0250	0.2000*
R^2	0.9031	0.9231	0.8375	0.8778	0.8707
Adequate precision	11.6968	5.0988	3.5849	6.9949	2.5560
Model F-value	13.05	2.31	1.09	4.90	0.8246
Lack of fit	NS	NS	NS	NS	NS

OPP = orange peel powder; A = OPP concentration; B = mix concentration; AB = interaction between OPP concentration and mix concentration; NS = non-significant. * $p < 0.05$, ** $p < 0.01$

3.6 Effect of OPP and mix concentration on overall acceptability

Overall acceptability, influenced jointly by colour/appearance, taste, flavour, texture, and sweetness, ranged from 7.0 to 8.6 across treatments (Table 2). The highest sensory score was secured by treatment number 2 (8.6) followed by treatment no. 10 (8), 4 (7.8), 12(7.6), 3, 5, 8, 9 and 11 (7.5) and treatment number 1 secured the lowest score of 7.0. The response-surface plot (Fig. 3e) and ANOVA results (Table 3) indicated that OPP level (A) and mix concentration (B) each had a significant ($p \leq 0.05$) positive effect, and their interaction ($A \times B$) also had a significant ($p \leq 0.05$) positive effect on overall acceptability. However, higher levels of OPP (A^2) and mix concentration (B^2) had a significant ($p \leq 0.05$) negative effect, indicating that increasing OPP and mix concentration beyond the optimum adversely affected individual sensory attributes and, consequently, overall acceptability. The maximum overall acceptability score was obtained with 3.0% OPP and a 1.75-fold mix concentration. These findings agree with Dias, Sajiwanie, Rathnayaka, and Awolu (2021), who reported reduced overall acceptability of sugar-free probiotic yoghurt enriched with passion fruit, pineapple, and orange peel powder (0.5-1.0%) as inclusion levels increased, and with Ismail, Hameed, Refaey, Sayqal, and Aly (2020), who reported favourable overall acceptability for ice cream formulated with 0.25% pomegranate peel powder and 2.5% doum fruit syrup. In the present study, OPP addition significantly affected overall acceptability, with scores declining at higher inclusion levels, likely owing to OPP-associated bitterness.

3.7 Numerical optimization of OPP and mix concentration

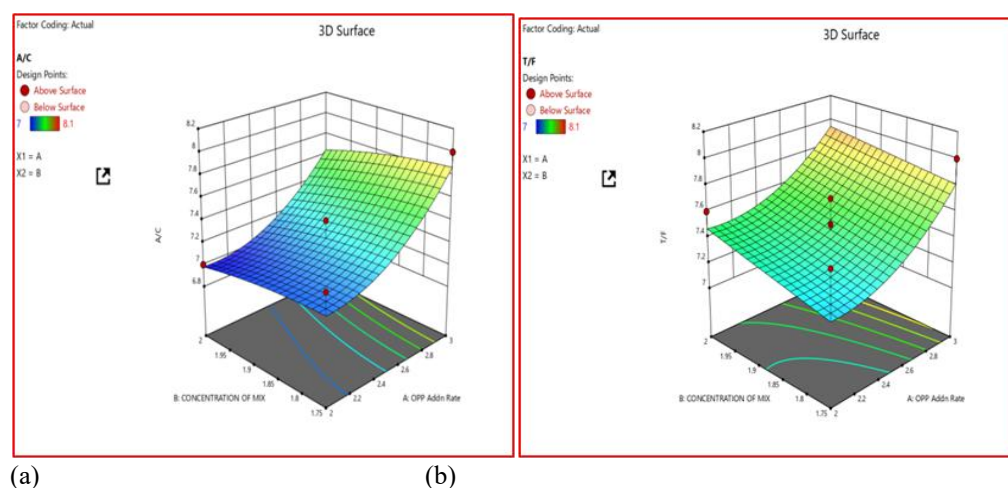
OPP and mix-concentration levels were optimized using the built-in numerical-optimization module of Design-Expert® 13.0 to identify the best combination of process variables. Target values for colour, flavour, and overall acceptability were maximized, while the remaining responses were constrained within their observed ranges. Among the solutions proposed, the most suitable combination had a desirability of 0.88, corresponding to 3.00% (w/v) OPP and a 1.75-fold mix concentration as the optimum formulation for OPP-added *kulfi* (Table 4.).

Table 4. Suggested solutions for OPP added *kulfi* given by RSM

Solution	OPP (%)	Mix concentration (fold)	Colour and appearance	Taste and flavour	Sweetness	Texture	Overall acceptability	Desirability
Predicted	33.00	1.75	7.97	77.91	7.96	8.13	8.52	0.88
Observed	33.00	1.75	8.00	8.10	8.00	8.20	8.60	-
Difference	-	-	0.03	0.19	0.04	0.07	0.08	
P value			> 0.05	> 0.05	> 0.05	> 0.05	> 0.05	

Note: OPP = orange peel powder. Sensory scores were measured using a 9-point hedonic scale. The observed values correspond to the formulation containing 3.0% OPP and 1.75-fold mix concentration.

Table 4. depicts the sensory responses predicted and observed for the best formulation of *kulfi* with optimum OPP obtained from the numerical optimization. The results of the optimization process were 3.0% OPP and 1.75-fold mix concentration with an overall desirability of 0.88. Colour and appearance, taste and flavour, sweetness, texture, and overall acceptability ratings were observed and predicted sensory scores, all of which were found to be very close, thus indicating the suitability of the formulation selected.



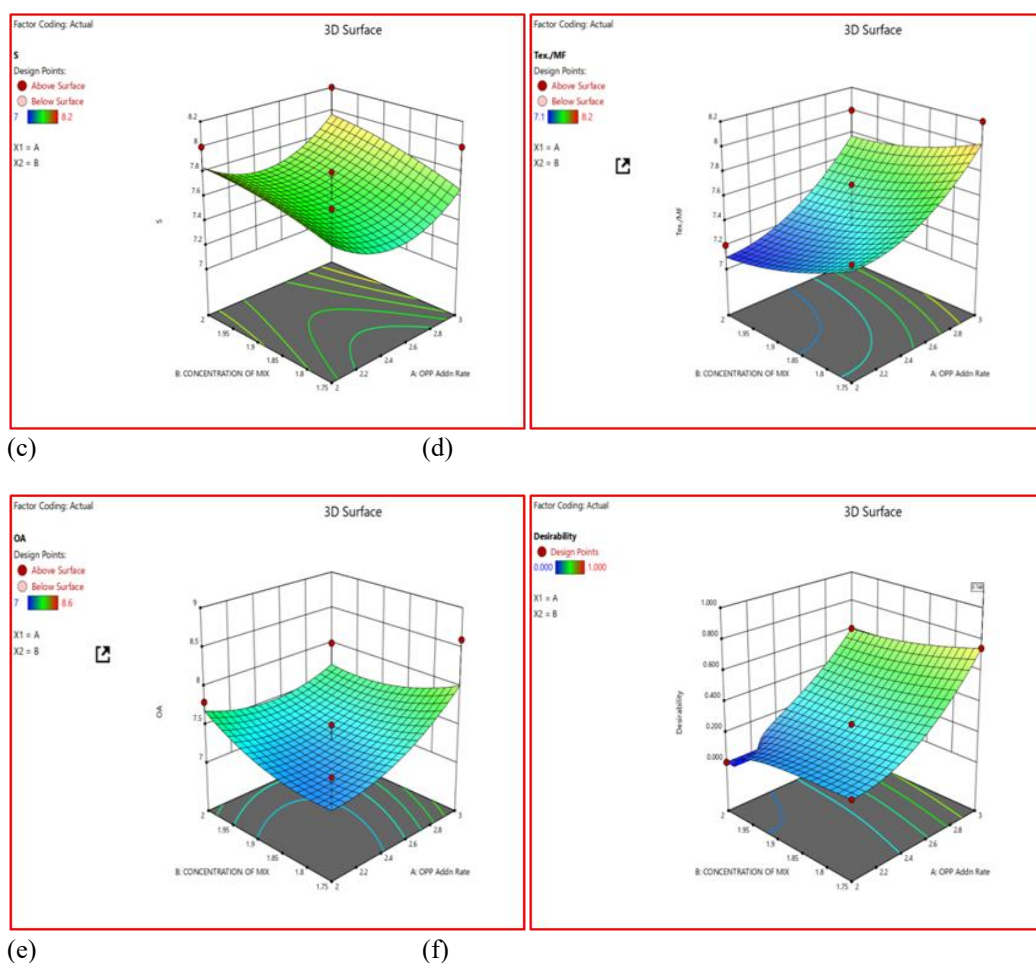


Fig. 3. Response-surface plots of sensory score as a function of OPP and mix concentration: (a) colour and appearance, (b) taste/flavour, (c) sweetness, (d) texture, (e) overall acceptability, (f) Desirability

3.8 Validation of the optimized process conditions

The optimized formulation with 3.0% OPP and a 1.75-fold concentration of the mix was chemically formulated under the recommended process conditions. The sensory responses obtained were tested and compared to the values predicted by the Design-expert software. The values obtained for colour and appearance, taste and flavor, sweetness, texture and overall acceptability were not far off from that predicted as presented in Table 4.7. The results of the statistical comparison between predicted and observed values for all the sensory responses did not show any significant difference ($p > 0.05$), indicating that the selected optimum formulation was suitable. The compositional characteristics of the optimized OPP-added *kulfi* were subsequently compared with those of the control sample (Table 5). Fat, protein, and total sugar contents did not differ significantly ($p > 0.05$) between the samples, whereas carbohydrate, ash, total solids, and energy value differed significantly ($p < 0.05$).

Table 5. Compositional parameters of control and OPP-added *kulfi*.

Parameter (%)	Control	OPP-added <i>kulfi</i>
Fat	10.20 ^a ± 0.18	10.18 ^a ± 0.13
Protein	5.17 ^a ± 0.16	5.14 ^a ± 0.08
Total sugar	22.39 ^a ± 0.89	21.34 ^a ± 1.90
Carbohydrate	25.41 ^a ± 0.64	22.92 ^b ± 0.08
Ash	0.71 ^b ± 0.02	0.78 ^a ± 0.01
Total solids	41.33 ^a ± 0.48	38.95 ^b ± 0.10
Energy value (kcal/100 g)	212.65 ^a ± 3.25	203.02 ^b ± 1.74

Data are mean ± SEM ($n = 3$). Means in a row with different superscripts (a, b) differ significantly ($p < 0.05$), by one-way ANOVA with Duncan's multiple range test.

One of the limitations in this work is the absence of quantification of individual orange-peel bioactive constituents such as pectin, carotenoids, flavonoids and naringin. Hence, their potential for colour, flavour, texture and antioxidants should be viewed with caution. These constituents could be quantified and their association with quality parameters of OPP added *kulfi* could be studied in the future.

4. CONCLUSION

Response surface methodology using a central composite rotatable design was successfully applied to optimize orange peel powder (OPP) concentration and mix concentration for *kulfi*. The optimized formulation consisted of 3.0% (w/v) OPP and a 1.75-fold mix concentration, with a desirability value of 0.88. Validation of the optimized formulation showed good agreement between the predicted and experimentally observed sensory responses, supporting the adequacy of the developed models within the experimental conditions studied. The optimized OPP-added *kulfi* had fat, protein, and total sugar contents comparable to the control, while carbohydrate, ash, total solids, and energy value differed significantly. Thus, OPP can be incorporated into *kulfi* at the optimized level while maintaining acceptable sensory quality and producing measurable changes in its compositional characteristics. Further studies on melting behavior, storage stability, and consumer acceptance are required before assessing the suitability of the optimized formulation for commercial application.

CRediT authorship contribution statement

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Ethics approval

This study was conducted in accordance with institutional ethical principles and was approved by the Research Committee, Maharashtra Animal and Fishery Sciences University, Nagpur, and the Advisory Committee of the College of Dairy Technology, Warud (Pusad), Maharashtra.

Informed consent

Written informed consent was obtained from all sensory panel participants prior to inclusion in the study. Participants were assured that their data would remain confidential and used solely for research purposes.

Data availability

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request, subject to participant privacy and ethical considerations.

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