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Research Article

Evaluating the synergistic effect of emulsifiers on the quality characteristics of ready-to-eat chapati (*Indian flatbread*)

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Abstract

Chapati is an unleavened flatbread precisely consumed as a staple food across India and the Middle East. The staling limits the shelf life of the sensory qualities of chapati. Emulsifiers act as antistaling agents due to their structural interaction with starch and water in food. Hence, an optimal combination of emulsifiers, namely diacetyl tartaric acid esters of monoglycerides (DATEM), sodium stearoyl-2 lactylate (SSL), and glycerol monostearate (GMS), was formulated using response surface modelling to study their synergistic action in improving the quality of RTE chapaties. The responses were water activity, soluble starch, hardness, lightness, and sensory characteristics. The optimized combination of emulsifiers was 0.26% DATEM, 0.5% SSL, and 1% GMS. Emulsifiers in chapati increased the moisture and soluble starch percentage. The reduction in hardness value suggests the softness effect of emulsifiers with increased sensory acceptability. A lower enthalpy value (479.6 J.g-1) was observed in optimized chapati than that of the control (580.4 J.g-1) from the DSC thermograms. The TGA studies illustrated the mass loss at (T > 375℃), was 18.2% and 16.52% in optimized and control chapaties, respectively. Hence, the study suggests the optimized combination of emulsifiers is useful in improving the palatability and shelf stability of ready-to-eat preserved chapaties.

Keywords

ready-to-eat, flatbread, starch retrogradation, optimization, additives, response surface methodology

Abbreviations

DATEM – diacetyl tartaric acid esters of monoglycerides; SSL – sodium stearoyl-2 lactylate; GMS – glycerol monostearate; aw – water activity; WSS – water-soluble starch; Hd – hardness; L* – lightness value; OAA – overall acceptability; ANOVA – analysis of variance

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Introduction

Chapaties are typically made fresh and eaten right away, as upon storage, their acceptability is reduced due to deteriorative changes such as loss of extensibility, pliability, increased texture hardness, and other staling effects. With rapidly evolving lifestyles, shifting socio-economic patterns, and growing urbanization, the demand for prepared foods, particularly those that are ready-to-eat (RTE), is increasing. The most recent addition to the category of "convenience foods" is RTE chapaties (Ghodke 2009; Gujral and Gaur 2005). However, two major limiting factors with large-scale production are staling and microbial spoilage of chapati. Application of innovative packaging, cold storage conditions, thermal processing, and the use of preservatives such as calcium propionate, fumaric acid, sorbic acid, and sodium caseinate has been shown to improve the shelf life of chapaties in many studies (Khan et al. 2017).

Staling or starch retrogradation in baked goods affects the overall quality of the product, making it undesirable for consumption. Numerous methods have been used to limit the staling mechanism, namely physical techniques (pressure, humidity, temperature, and storage settings), modification of starches, and use of food additives (emulsifiers, enzymes, hydrocolloids, and acids) (Zhygunov et al. 2018; Khan et al. 2023).

Food emulsifiers play a significant role as antistaling agents in many baked goods. They are surface-active agents that stabilize an emulsion by increasing its kinetic stability. These surfactants also interact with the helical inclusion complexes formed by amylose through physical entrapment, complex formation, or starch modification, potentially leading to retrogradation (Hasenhuettl 2008). Glycerol monostearate (GMS) is a non-ionic and amphoteric surfactant used for the improvement of texture in baked products. The monoglycerides in GMS form a complex with amylose, which is insoluble in water and does not involve gel formation. Hence, the complex amylose does not recrystallize upon cooling and will not contribute to the staling of baked products (Kumar and Sharma 2018). Anionic surfactants such as diacetyl tartaric acid esters of monoglycerides (DATEM) and sodium stearoyl-2 lactylate (SSL), primarily used in the baking industry as dough straighteners, tend to form complexes with both amylose and amylopectin within starch, resulting in a soft texture (Akdogan et al. 2006).

The addition of food additives along with certain ingredients has been shown to improve the physicochemical, textural, rheological, and sensory characteristics of flour and flatbreads. Studies on the interactive effect of additives on the long-term mechanism of staling are sparse (Hemalatha & Rao 2022). The present study aims to optimize the emulsifiers and analyze their interactive effect on the overall quality attributes of chapati upon heat treatment using response surface methodology.

Materials and Methods

Materials. Sharbati wheat variety was procured, cleaned, and milled (stone mill) and stored in cold temperatures. Food-grade preservatives such as sorbic acid and citric acid were procured from the market (Puramio Ltd., India). Three emulsifiers were studied as quality improvers: diacetyl tartaric acid esters of monoglycerides (DATEM), sodium stearoyl-2 lactylate (SSL) and glycerol monostearate (GMS). DATEM and SSL were provided by M/s. Savannah Surfactants Ltd. (Goa, India) and GMS (Bakers, India) were procured from the supermarket. The chemicals were procured from S.D Fine Chemicals Ltd. (Mumbai, India).

Methods. Wheat flour analysis. Wheat was analyzed for thousand kernel weight, kernel length, and width using a vernier caliper (ESAL Scientific Industries, India) (Ramya et al. 2010). The bulk density and tap density were estimated using a Lab India meter (TD1025, Lab India, Mumbai, India). Further, the moisture, water activity, ash, fat, protein, crude fiber, and gluten content were analyzed as per standard protocol (AOAC 2015).

Experimental design and analysis. A small central composite rotatable design (CCRD) was used to set up the experiment. Three independent variables and their range varied at five levels namely DATEM, SSL, and GMS were studied for their effect on the quality parameters of chapati. Preliminary experimental trials performed at the laboratory along with a literature survey enabled us to obtain the maximum and minimum levels of emulsifiers for the experiment. The number of experimental runs (design points) obtained was 20 comprised of

8 factorial points, 6 axial points, and 6 replicates of centre point (Table 1). The α values in the design outside the ranges were selected for the rotatability of the design. The responses for the study were quality attributes of chapati such as water activity (a_w), water-soluble starch (WSS), hardness (Hd), lightness value (L*), and overall acceptability (OAA). The regression analysis of the experimental design was conducted using a second-order polynomial equation by fitting suitable models represented by:

$$Y= \beta_{k0} + \sum^{k}_{i=1}\beta_{ki}Xi + \sum^{k}_{i=1,j=i+j}\beta_{kij}XiXj + \sum^{k}_{i=1}\beta_{kii}Xi^2 \quad \text{(Eq. 1)},$$

where β_{k0} was the value of the fitted response at the center point of the design, i.e., point (0, 0, 0); β_{ki}, $\beta_{kii,}$ and β_{kij} were the linear, quadratic and cross-product (interaction effect) regression terms; k, denoted as number of variables and Y, responses, respectively. Design expert software was used to set up the experimental design and to analyze the data. Similar designs have been used in many studies for product and process optimization (Bepary and Wadikar 2018).

Chapati preparation and processing. The dough was prepared from emulsifiers from the experimental design (Table 1) and kept constant as whole wheat flour, a DFRL-standardized preservative mixture (sorbic acid and citric acid), and 65% water based on flour weight using a tabletop dough kneader for 10 min.

Table 1. Actual and coded levels of independent variables and values of responses for RTE chapati prepared with different composition

Run order	Independent variables[1]			Quality parameters of chapati[2]				
	A: DATEM, %	B: SSL, %	C: GMS, %	Water activity, a_w	Water soluble starch, %	Hardness, N	Lightness value, L*	Sensory, OAA
1	0.5(0)	0.5(0)	0.75(0)	0.934	2.75	7.34	54.86	8
2	0.75(+1)	0.25(-1)	0.5(-1)	0.938	2.24	8.48	51.85	8
3	0.25(-1)	0.25(-1)	1(+1)	0.932	2.96	8.55	56.26	8.2
4	0.5(0)	0.07(-α)	0.75(0)	0.944	2.54	7.95	56.21	8.2
5	0.5(0)	0.5(0)	0.75(0)	0.933	2.72	7.58	53.13	7.8
6	0.5(0)	0.5(0)	0.32(-α)	0.941	2.02	9.53	56.19	8
7	0.25(-1)	0.75(+1)	1(+1)	0.924	3.02	6.8	58.42	8
8	0.5(0)	0.5(0)	0.75(0)	0.935	2.66	7.03	54.2	7.8
9	0.5(0)	0.5(0)	0.75(0)	0.934	2.74	7.09	54.39	8
10	0.25(-1)	0.25(-1)	0.5(-1)	0.944	2.39	8.97	59.73	8
11	0.5(0)	0.5(0)	1.17(+α)	0.928	3.09	7.52	55.31	7.8
12	0.07(-α)	0.5(0)	0.75(0)	0.934	2.25	5.13	58.37	8.2
13	0.75(+1)	0.75(+1)	1(+1)	0.939	2.98	4	52.48	7.8
14	0.5(0)	0.5(0)	0.75(0)	0.933	2.88	7.38	53.94	7.8
15	0.75(+1)	0.75(+1)	0.5(-1)	0.94	2.64	4.37	51.6	7.5
16	0.92(+α)	0.5(0)	0.75(0)	0.942	2.77	3.61	50.16	7.5
17	0.75(+1)	0.25(-1)	1(+1)	0.945	2.95	3.62	52.75	8
18	0.5(0)	0.5(0)	0.75(0)	0.931	2.6	7.01	53.73	8
19	0.25(-1)	0.75(+1)	0.5(-1)	0.939	2.81	3.85	57.14	8
20	0.5(0)	0.92(+α)	0.75(0)	0.94	2.66	3.94	56.88	7.8

[1] Corner (±1), central (0) and axial (±α) levels of each variable are designated as +1,-1,0,+ α,- α.

[2] The values are mean, n = 3.

The dough was kept aside for 20 min and cut into small pieces (40 g) using an automatic dough cutter. Dough balls were pressed into round-shaped flattened sheets with a diameter of 150 mm and thickness of 2 mm using a pneumatic chapati pressing machine (M/s. Sunray Industries, Mysore, India). Chapaties were baked for about 2 min at 210-220°C on a hot plate with the oil application. These were packed and thermally treated at 90°C for 120 min and kept at room temperature. The analysis was conducted within three days from the production day for all the test runs.

Physico-chemical analysis. The water activity a_w values were determined using a water activity meter (AquaLab 3TEB, Decagon, USA), with calibration done at ambient temperature (25°C) with distilled water (a_W = 0.999) using a standard protocol (Gabriel 2008). The water-soluble starch content was measured at 680 nm using a UV/visible spectrophotometer (Motras Scientific Instruments, Delhi, India) according to Shaik et al. (2008) procedure. The color measurements of chapaties were conducted with a ColorFlex EZ Spectrophotometer (Hunter Labs, Virginia, US). All these experiments were done in three replicates to obtain constant results.

Texture and sensory analysis. The texture of chapati was analyzed using the Texture Analyzer Plus (Model No. 01/TALS/LXE/UK; LLOYD Instruments, Hampshire, UK) with a needle probe according to procedure (Shaik et al. 2008). The chapaties were stacked, and the probe was penetrated at a speed of 2 $mm.s^{-1}$ and allowed to penetrate a distance of 20 mm in thickness. A total of five measurements were taken, expressed as the load (N) required for penetrating the chapati, and represented as the hardness value. Sensory analysis for all experimental runs was evaluated based on appearance, taste, aroma, texture, and overall acceptability on the 9-point Hedonic Scale by a sensory panel of 10 members (Khan et al. 2023).

Thermal analysis. The change in enthalpy was estimated using a Differential Scanning Calorimeter with a thermal analyst 2100 system (DSC 2910, TA Instruments, Newcastle, US) in the temperature range of 20 to 200°C within the nitrogen atmosphere and thermograms were recorded with a heating rate of 10°C.min^{-1} for each sample. The enthalpy value was estimated as the area between a baseline that connects points of onset and conclusion temperature and the thermogram, which was expressed as $J.g^{-1}$ (George et al. 2011; Shaik et al. 2008). Thermogravimetric analyzer (TGA Q50, TA Instruments, USA) was used as a thermal weight change analysis instrument by upholding the sample in a platinum crucible and heating the furnace from 30°C to 700°C at a rate of 10°C.min^{-1} with nitrogen gas flushing at 40 $ml.min^{-1}$. The percent weight loss was plotted against the temperature for each sample (George et al. 2011).

Results and Discussion

Wheat flour composition. The thousand kernel weight, average length and width of the kernel, bulk density, and tap density of the wheat procured were 36.28 ± 0.48 g, 6.38 ± 0.3 mm, 3.47 ± 0.11 mm, 0.84 ± 0.006 $g.ml^{-1}$, and 0.87 ± 0.005 $g.ml^{-1}$, respectively. The milled wheat flour had a moisture content of 7.59 ± 0.09%, water activity (0.614 ± 0.04), protein (13.98 ± 0.15%), ash content (1.48 ± 0.07%), crude fat (2.09 ± 0.05%), crude fiber (2.63 ± 0.2%), and gluten content (11.9 ± 0.15%), respectively.

Effect of emulsifiers on water activity (a_w). Water activity describes the energy state of water in a food matrix that influences chemical and biological reactions and microbial growth, which predicts the stability and safety of food (Chirife et al. 1996). The a_w of chapaties with emulsifier incorporation ranged between 0.924 and 0.945 (Table 1). The suitable model for the water activity was selected based on a significant value of F, a non-significant "lack of fit," an idealistic value of R^2, adjusted R^2, predicted R^2, CV, and PRESS (Table 2). The regression equation for water activity as a function of DATEM (A), SSL (B), and GMS (C) is mentioned below:

$$a_w = 0.933 + 0.0025A - 0.001B - 0.0027C + 0.0011AB + 0.0041AC - 0.0014BC + 0.0014A^2 + 0.0023B^2 - 0.001C^2 \quad \text{(Eq. 2)}$$

From Eq. 2, it is clear that two variables (B and C) had a negative impact on the response, and an increase in these two variables resulted in a decrease in a_W, whereas an increase in the level of DATEM (A) increased the a_w in chapatti. From Fig. 1(a), it appears that at a lower C value, maximum a_w occurred between 0.45 and 0.5% of B, with A at 0.5%, whereas at increased C and B concentrations, a_w had a substantial reduction. On the other hand, the utmost lower a_w was noticed with an increase in C concentration and a lowering A value with B at 0.5%, respectively Fig. 1(b).

Regardless of limited studies on the effect of emulsifiers on water activity, one way of postulating theory based on the results would be the ability of emulsifiers to form complexes with starches, proteins (gluten), and fat molecules (emulsion formation) that hold on to water molecules within their structural configuration, hence increasing the water retention capacity (Ribotta et al. 2004; Selomulyo and Zhou 2007). As water activity also defines the measurement of available water for biological reactions, it can be stated that the addition of emulsifiers lessened the free water or loss of water within the food matrix (Stampfli and Nersten 1995; Willhoft 1971).

Table 2. Coefficients of variables for response variables in the predictive model

Variables	**Water activity, a_w**	**Water soluble starch, %**	**Hardness, N**	**Lightness value, L***	**Sensory, OAA**
Model	Quadratic	Linear	Quadratic	Quadratic	Quadratic
Model (F-value)	24.06	16.13	100.02	17.04	9.55
Model (p-value)	<0.0001	<0.0001	<0.0001	<0.0001	0.0008
Lack of fit (F- value)	1.70	3.4	2.03	0.6669	0.4172
Lack of fit (p-value)	0.288	0.0938	0.2274	0.6663	0.8203
Intercept	0.9335	2.7	7.28	58.10	8.13
R^2	0.9559	0.7515	0.9890	0.9388	0.8958
Adjusted R^2	0.9161	0.7049	0.9791	0.8837	0.8021
Predicted R^2	0.7426	0.5583	0.9325	0.7010	0.6353
Adequate Precision	19.5831	15.5177	31.4161	14.0951	11.6112
Coefficient of variance (CV), %	0.1694	5.74	4.37	0.6899	1.08

Effect of emulsifiers on hardness value (Hd). The hardness value of chapati with different concentrations of emulsifiers ranged from 3.61 N to 9.53 N (Table 1). The model for Hd was quadratic, which exhibited strong fitness with a significant value of F, a non-significant “lack of fit,” a realistic value of CV, R^2, adjusted R^2, predicted R2, and adequate precision (Table 2**).** The regression equation for Hd as functions DATEM (A), SSL (B), and GMS (C) is mentioned below:

$$\text{Hd (N)} = 7.28 - 0.8448A - 1.28B - 0.2681C + 0.3925AB - 0.97AC + 0.9825BC - 0.9076A^2 - 0.4579B^2 + 0.1676C^2 \quad \text{(Eq. 3)}$$

The coefficients of A, B, and C were negative, implying that the Hd of chapati decreased with the addition of emulsifiers. A significant ($p < 0.05$) value of F was seen in the quadratic model and for all the variables used in the study, showing the criticality of this response. It is noted in Fig. 1**(**c) that an increase in A and B with 0.75% of C reduced the hardness value. Similar studies reported (Patil and Arya 2016) wherein the incorporation of SSL and DATEM has been shown to reduce the tear force significantly upon storage. This was attributed to the SSL's ability to form complexes with amylase, resulting in an improvement in texture. Both DATEM and SSL, known as dough strengtheners, tend to affect the gluten due to their structural configuration, which helps increase the water retention capacity of the bread. Studies have also shown that DATEM and SSL incorporation produced dough with higher resistance to extension and reduced bread firmness (Eduardo et al. 2014; Gómez et al. 2013). These emulsifiers, also called monoacylglycerols, are the most efficient crumb softeners due to the presence of stearic acid within their structure, which has a higher complex-forming power than amylose. Additionally, these emulsifiers produce strong dough by binding to hydrophobic

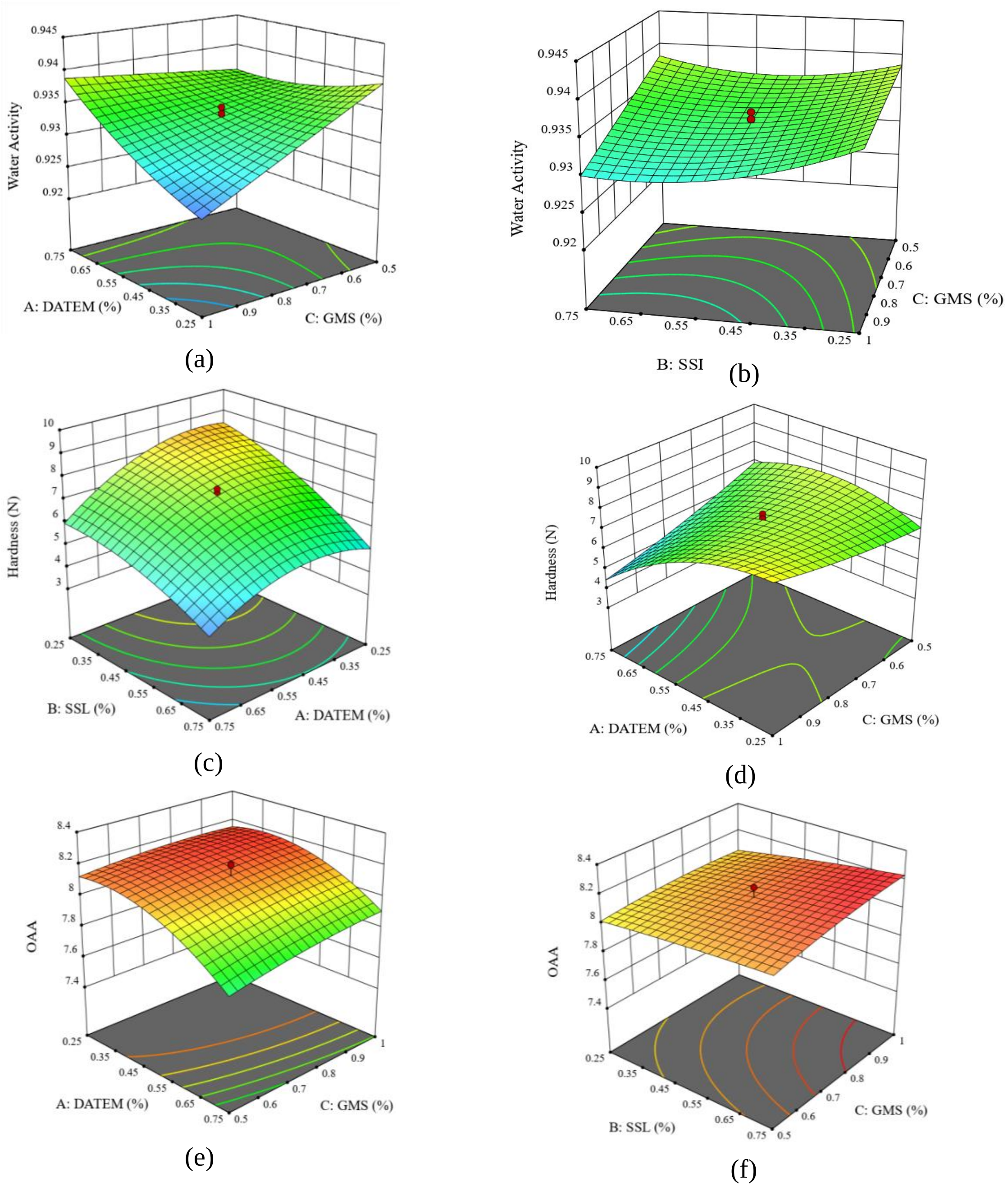


Figure 1. Effect of emulsifiers on water activity (a) and (b), hardness (c) and (d), and overall acceptability (e) and (f) of processed chapati

regions of gluten proteins with their lipophilic tails within their structure (Ribotta et al. 2004; Selomulyo and Zhou 2007). Fig. 1(d) also shows that beyond 0.55% of A, the Hd value is reduced with increasing concentrations of C at 0.5% of B. Similar results were reported by Gujral et al. (2002), the addition of GMS decreased the rupture force of chapati upon 24-h storage, which may be attributed to the ability of GMS to cause denaturation of gluten protein that holds more water leading to a soft texture (Willhoft 1971).

Effect of emulsifiers on overall acceptability (OAA) of chapati. Acceptability of the food is a subjective measure based on hedonics (pleasure), which is influenced by sensory properties of the food such as appearance, flavor, taste, and texture. The overall acceptability (OAA) of the chapati with the emulsifiers' addition ranged between 7.5-8.2 values (Table 1). The quadratic model was found suitable to represent the results of OAA based on values of R^2 (0.89), adjusted R^2 (0.8), predicted R^2 (0.63), adequate precision (11.61), and a non-significant "lack of fit" value (Table 2). The regression equation for OAA as a function of DATEM (A), SSL (B), and GMS (C) is mentioned below:

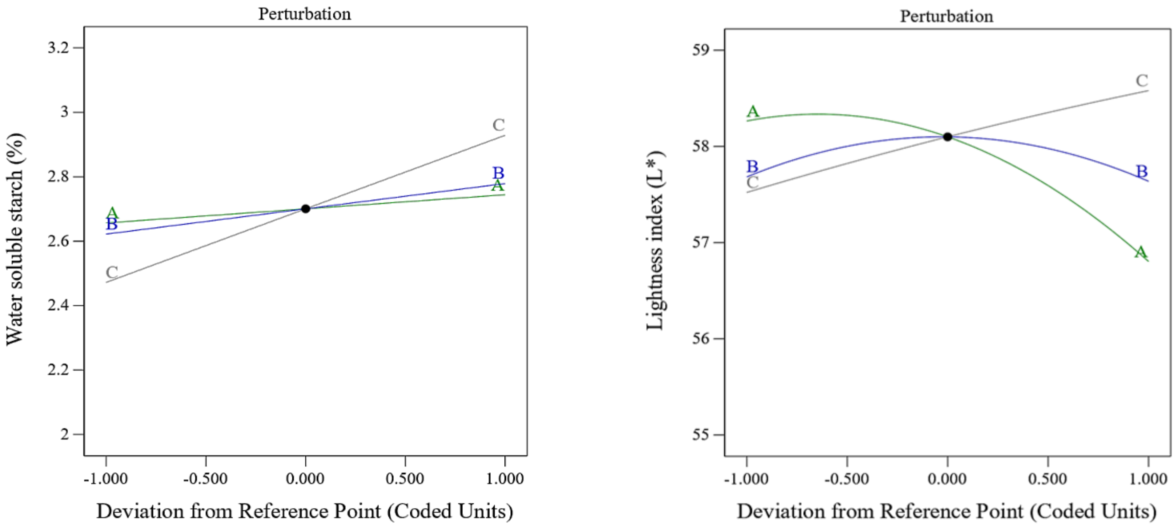
$$OAA = 8.13 - 0.1475A + 0.0642B + 0.0416C - 0.025AB + 0.025AC + 0.025BC - 0.1194A^2 - 0.0082B^2 - 0.0218C^2 \quad \text{(Eq. 4)}$$

A positive coefficient of B and C shows a positive effect on OAA, whereas a negative coefficient of A reflects a decrease in the OAA of the product. From Fig. 1(e)**,** the increase in A from 0.25-0.75% reduced the OAA irrespective of the C concentration, whereas, at a lower A concentration, the C percentage did not modify the OAA, which ranged within 8.0-8.2. This could be due to the strong tart flavor of tartaric acid present within DATEM, which had an impact on the OAA of chapati more than that of GMS, which exhibited a bland taste. A maximum OAA was observed at 0.25-0.35% A and 0.9-1% C at a constant concentration of B (0.5%). On the contrary, the interaction within B and C did not influence the OAA of chapaties, which ranged between 8.0 and 8.2, as shown in Fig. 1(f).

Effect of emulsifiers on water soluble starch (WSS). Starch, precisely amylose in a linear chain, dissolves in water during thermal processing and is characterized by high crystallinity, high thermosatbility, and high susceptibility to retrogradation. On aging, the amylose forms a double helical association with 40-70 glucose units, which organize into crystallites and cannot accommodate the iodine unit, reducing the blue iodine complex formation (Egharevba and Henry 2020). The soluble starch content of chapaties with the addition of emulsifiers ranged between 2.02 and 3.09% (Table 1). A linear model was found suitable for the WSS based on the observations recorded against the changes in design variables (Table 2). The regression equation for WSS as a function of DATEM (A), SSL (B), and GMS (C) is mentioned below:

$$WSS\ (\%) = 2.7 + 0.0437A + 0.0785B + 0.2283C \quad \text{(Eq.5)}$$

The increase in levels of A, B, and C has been shown to increase the WSS values based on Eq. 5.



(a) (b)

Figure 2. Effect of emulsifiers on water soluble starch (a) and lightness value (b) of processed chapati

Fig. 2(a) depicts an increase in WSS with increasing concentrations of emulsifiers, where variable C had a greater impact. Similarly, the incorporation of additives such as xylanase, GMS, and SSL has also been shown to reduce the extent of starch solubilization in bread when compared with the control (Shaik et al. 2008; Hemalatha and Rao 2022). This might be attributed to the hydrophobic and hydrophilic moieties of surfactants within their molecular structure that have been reported to form complexes with amylose and amylopectin fractions, thereby reducing the percent loss of soluble starch in the food matrix.

Effect of emulsifiers on lightness value (L*). The visual appearance of chapati is an important parameter in its perceptible acceptance. Concerning chapati, the preferred color is creamish to brown, and the parameter also determines the baking time and quality of the product. During thermal treatment, the baked goods undergo a Maillard reaction, which is undesirable in chapati concerning its acceptability (Al-Abbasy et al. 2024). Thus, analyzing the lightness value indirectly evaluates the rate of browning in the product. A quadratic model was suited for data analysis of lightness values due to adequate values of R^2, adjusted R^2, predicted R^2, CV, and PRESS (Table 2). The regression equation for lightness value as a function of DATEM (A), SSL (B), and GMS(C) is mentioned below:

$$L^* = 58.10 - 0.7302A - 0.0227B + 0.5292C + 0.5292AB - 0.5125AC + 0.105BC - 0.5653A^2 - 0.4392B^2 - 0.0486C^2 \quad \text{(Eq. 6)}$$

L* values for sterilized chapati ranged from 55.23 to 58.97 (Table 1). The negative coefficients of A and B variables indicate a decrease in lightness value from Eq. 6. Fig. 2(b) also depicts similar results of reduced lightness value concerning the increase in concentration of variable A and the minimum effect of variable B. While there is no supporting literature, this could be due to the specific yellow color of the additives, which indirectly affected the color of the chapati.

Optimization and validation of experimental design. The independent variable (emulsifiers) levels were optimized using a numerical optimization method to obtain maximum desirability with equal importance to all the independent variables and responses**.** Chapaties were prepared by incorporating the emulsifiers at their optimized levels of DATEM (0.26%), SSL (0.5%), and GMS (1%) in the chapati formulation and were in-pack treated at 90°C for 2 h. The expected outcomes of the responses were confirmed against the predicted values which were reasonably similar (Table 3); hence, the models obtained are validated and are acceptable in the prediction of responses.

Comparison of quality characteristics. The comparative analysis of thermally treated optimized chapati and the control chapati (without emulsifiers) revealed that the moisture content and water-soluble starch Fig. 3(a) increased from (26.7 ± 0.21%) to (30.5 ± 0.08%) and (1.9 ± 0.08%) to (3.04 ± 0.12%) in the optimized chapati compared to the control. Hemalatha and Rao (2022) reported that the addition of surfactant increased the soluble starch and amylose percentages in chapati and reduced the moisture percentage of the product during storage. The optimized chapati had reduced

Table 3. Predicted values v/s experimental values for optimization of variables

Response	DATEM	SSL	GMS	Water activity, a_w	Water soluble starch,%	Hardness, N	Lightness value, L*	OAA
Predicted values	0.262	0.50	1.0	0.926	2.887	8.086	59.251	8.161
Experimental values	0.262	0.50	1.0	0.925 ± 0.001	2.806 ± 0.035	7.893 ± 0.18	58.783 ± 0.54	8.23 ± 0.28

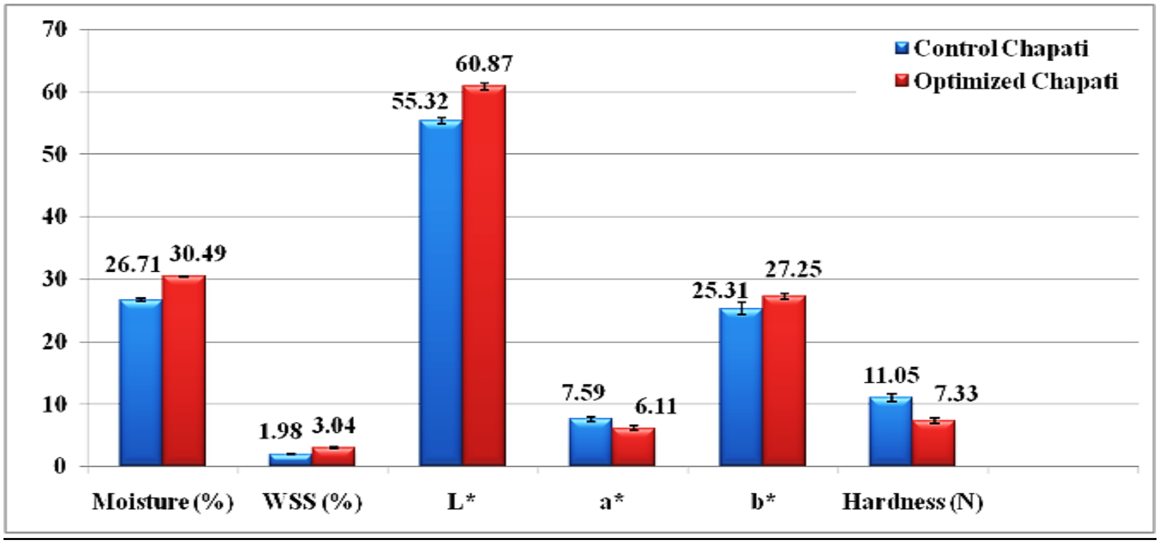


Figure 3(a). Comparison of control chapati and optimized chapati with respect to physico-chemical characteristics

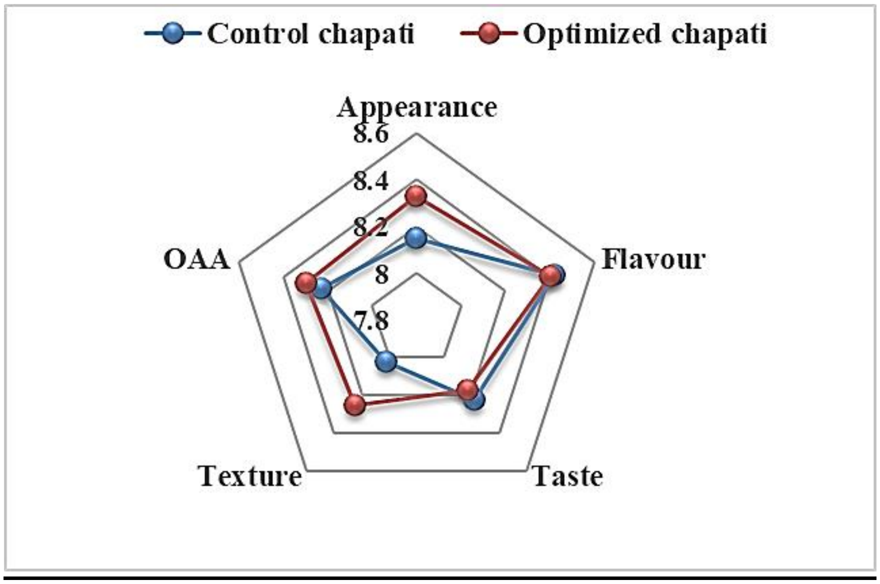


Figure 3(b). Comparison of control chapati and optimized chapati with respect to sensory attributes

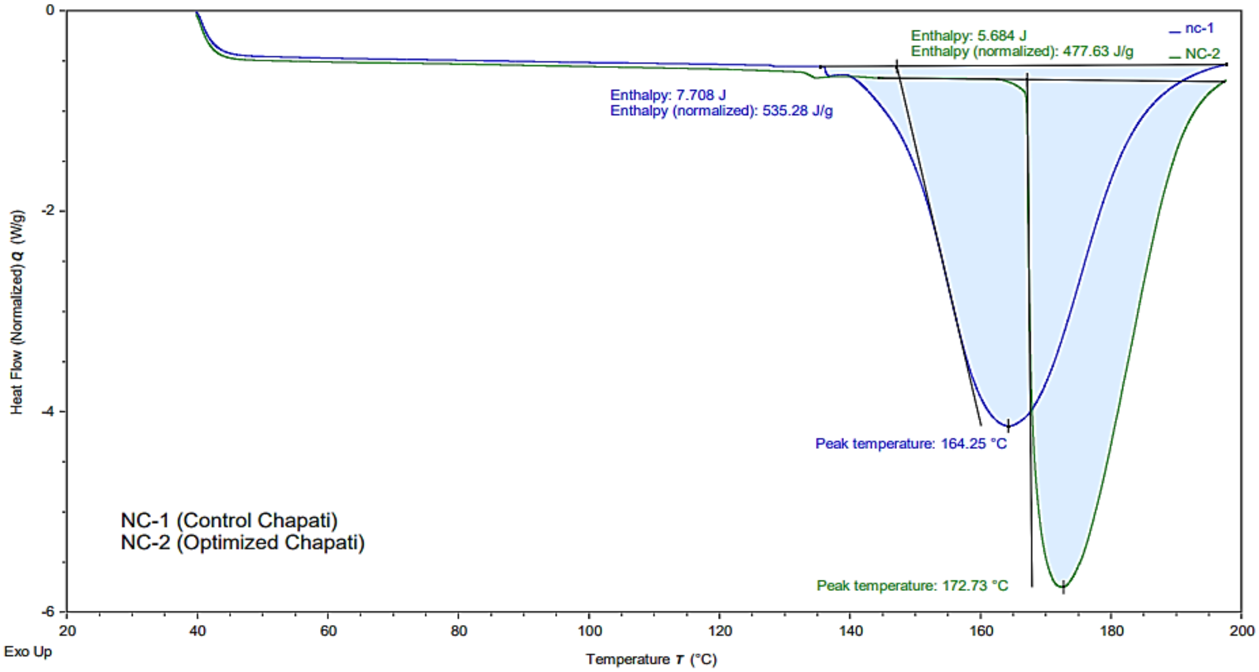


Figure 3(c). Comparison of control chapati and optimized chapati with respect to DSC studies

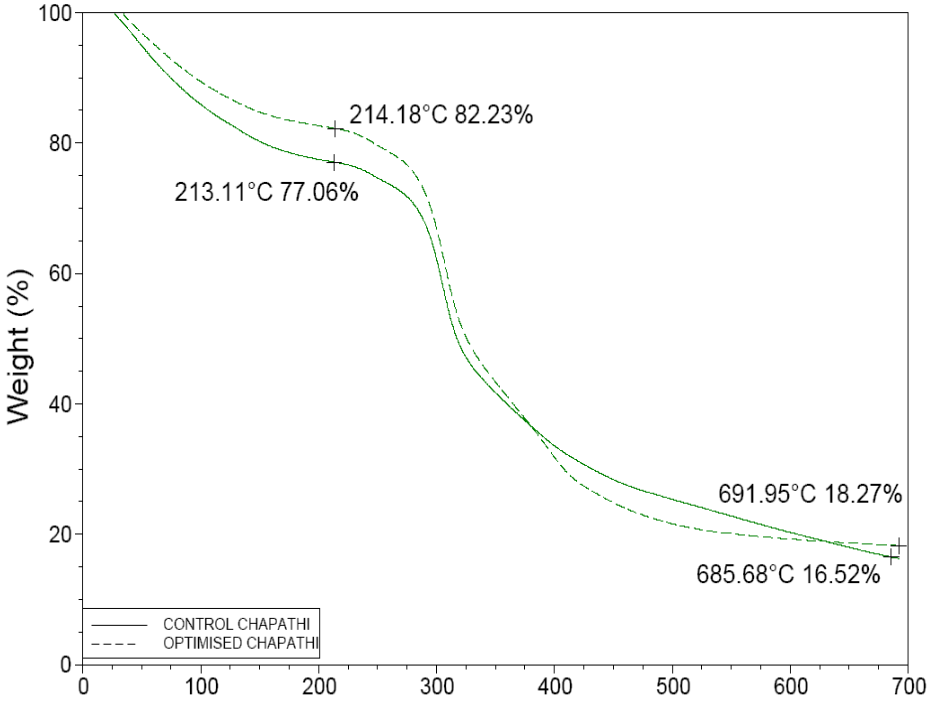


Figure 3(d). Comparison of control chapati and optimized chapati with respect to TGA studies redness (a*) and increased lightness (L*) compared to the control chapati. The hardness value was reduced with the addition of emulsifiers, which was similar to the finding of Shaik et al. (2008) where the addition of SSL and GMS showed a reduced texture force of 168.2 G and 162.9 G compared to that of the control chapati with 225.1 G through her study. Furthermore, emulsifiers tend to interact with starch, cause a delay in starch swelling, and form complexes with amylose, causing no gel formation and hence unable to recrystallize, thus reducing the firmness of the product (Pareyt et al 2011; Tebben et al. 2022). Sensory analysis of optimized chapati showed better appearance/color, with no difference in flavor and difference in taste due to emulsifiers than the color chapati. The texture was found to be soft with good extensibility and an overall acceptability of 8.33 when compared with control chapati (8.25) - Fig. 3(b).

DSC thermograms (Fig. 3c), reveal that the enthalpy value was higher in the control sample (535.28 $J.g^{-1}$) than in the optimized chapati (477.63 $J.g^{-1}$), indicating considerable amylopectin retrogradation. The enthalpy value provides a quantitative measure of the energy transformation that occurs due amylopectin during this endothermic event. The addition of emulsifiers reduced the amylopectin retrogradation within the chapati, thereby obtaining a lower enthalpy value. These results support earlier findings where the addition of SSL in bread inhibited the retrogradation of amylopectin during storage (Rao et al. 1992). The lower peak temperature of the control sample than the optimized chapati indicates melting of crystallites occurred more readily in retrograded starch. to the melting of recrystallized Wang et al. (2016) reported lower onset and peak temperatures in retrograded starch gels than in native starch. TGA measures the mass loss of the sample as a function of temperature, where the retrogradation degree can be characterized by measuring the mass loss of bound water (Shujun et al. 2006; Tian et al. 2009). Fig.3d shows the mass loss of control and optimized chapaties at the first stage (T < 225℃) was 77.06% and 82.23%, which is the evaporation of volatile substances, especially water, whereas, at the third stage (T > 375℃), it was 16.52% and 18.27%, which is due to the occurrence of carbonization, indicating the complete decomposition of starch (Zhang and Zhang 2019).

Conclusions

Optimization studies using emulsifiers as variables and examining their interactive effect on the quality characteristics of chapati using responses revealed that the optimum concentrations of emulsifiers were DATEM (0.26%), SSL (0.5%), and GMS (1%), which had the maximum desirability function (0.916). Based on observations from 20 experimental designs, each of the emulsifiers appears to affect the quality of chapati distinctly due to their functional and structural composition. In comparison with the control chapati, the chapati incorporated with optimized emulsifiers was found to be superior in terms of reduced hardness, increased moisture, and soluble starch content. Thermal analysis also indicated retrogradation was less prominent in chapati with emulsifiers. Hence, this combination of emulsifiers could facilitate maintaining the shelf stability of ready-to-eat chapaties.

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