Optimization of olive oil-based oleogel as a shortening replacer in cocoa cream spread

Zahra Nazari*

Department of Food quality and safety, Academic Center for Education Culture and Research (ACECR), Mashhad, Iran

*Corresponding author (Zahra Nazari)

Abstract

Shortening is commonly utilized in producing cocoa cream spreads because of its distinctive fatty acid and triacylglycerol composition, along with its crystallization properties, making it ideal for fat-based spreadable items. An intriguing alternative that allows for the substitution of shortening is provided by oleogels created with oils of high nutritional value. This research examined how substituting shortening with various polyglycerol polyricinoleate /olive oil-based oleogels, along with the varying quantities of PGPR used in oleogel formation, affected the oil binding ability, spreadability, and sensory characteristics of cocoa spreads. A design of experiment (DoE) method, utilizing the D-optimal design, was employed to formulate the cocoa cram spreads, aiming to discover the best formulation that meets the desired quality characteristics related to spreadability, and oil binding capacity. The optimized formulation that emerged was recognized in a spread defined by a complete substitution of shortening with an oleogel composed of ٩٦٪ olive oil and ٤٪ PGPR.

Keywords: Oleogel, PGPR, Olive oil, cocoa cream

١. Introduction

Cocoa cream is a complex colloidal system consisting of a dispersed phase, solid particles, and a continuous liquid phase (Borriello et al., ٢٠٢٢). The key attributes of cocoa cream, such as stability, spreadability, and melting behavior, are largely influenced by the type of fat utilized in its formulation. Shortenings are the most widely employed fats in cocoa cream production due to their functional properties. However, despite their technological benefits, the use of shortenings raises health concerns, particularly for children, the primary consumers of cocoa cream products (Arris et al., ٢٠٢٠). A promising alternative to shortenings is the incorporation of oleogels, which are derived from nutritionally superior oils (Malvano et al., ٢٠٢٢). Oleogelation is a process that transforms liquid vegetable oils into semi-solid gels (oleogels) with textural and thermal properties akin to those of solid fats. Oleogels are semi-solid systems characterized by a continuous hydrophobic liquid phase, stabilized by a three-dimensional network formed by an oleogelator, which physically entraps the liquid (Arshad et al., ٢٠٢٤). Among the various lipid-based gelators, natural waxes and saturated monoglycerides have been extensively researched as substitutes for saturated and trans fats in a range of food products, including ice cream(Liu et al., ٢٠٢٤) and cream cheese (Park et al., ٢٠١٨). David et al. (David et al., ٢٠٢١) explored the role of biopolymers, such as hydroxypropyl methylcellulose (HPMC) and cellulose derivatives, in the preparation of oleogels as fat replacements in chocolate cream. Fayaz et al. (Fayaz et al., ٢٠١٧) investigated the structural and rheological properties of chocolate creams formulated with a blend of monoglyceride-based and wax-based oleogels with palm oil. The present study aims to evaluate the effects of replacing shortening (ranging from ٠ to ١٠٠٪) with polyglycerol polyricinoleate (PGPR) and olive oil-based oleogels on the oil-binding capacity, spreadability, and sensory attributes of cocoa creams.

٢. Materials and Methods

٢,١. Materials

The raw materials used in the formulation of cocoa cream, including sucrose, cocoa paste, cocoa powder, milk powder, and lecithin, were procured from local markets in Mashhad, Iran. Shortening was sourced from Mahan Company (Tehran, Iran), olive oil from Rudbar (Gilan, Iran), and polyglycerol polyricinoleate (PGPR) from Chemicenter (Tehran, Iran).

٢,٢. Preparation of Oleogels

Oleogels were prepared by dissolving varying concentrations of PGPR (٢–٥٪ w/w) in olive oil (OO) at temperatures above the melting point of PGPR. The mixture was stirred magnetically at ١٠٠ rpm until homogeneous. The prepared oleogels were stored at room temperature for at least ٢٤ hours before analysis.

٢,٣. Preparation and Characterization of Cocoa Creams

The cocoa cream formulation consisted of sugar, fat (shortening or oleogel), cocoa paste, cocoa powder, skim milk powder, and soy lecithin. The fat phase (cocoa paste and shortening/oleogel) was heated to ٥٠°C to achieve a uniform mixture. Dry ingredients were then dispersed into the molten fat phase and mixed for ٢ hours. The resulting creams were stored under cool, dry conditions for ٢٤ hours before analysis.

٢,٣,١. Oil-Binding Capacity (OBC)

Approximately ٨ g of each sample was centrifuged at ٥٠٠٠ rpm for ١٥ minutes. The separated oil was removed using a pipette, and the weight of the remaining cream was recorded. OBC was calculated using the following formula:

OBC (%) =(١−m٠−mm٠) ×١٠٠OBC (%) =(١−*m*٠*m*٠−*m*) ×١٠٠

Where m٠*m*٠ is the initial mass of the cream and m*m* is the mass after centrifugation. Measurements were performed in triplicate.

۲,۳,۲. Texture Analysis

A texture analyzer (Stable Micro Systems, TA-XT-plus, UK) was employed to assess the textural properties (hardness and spreadability) of the cocoa cream samples. A conical probe penetrated the sample to a depth of ۲۰ mm at a speed of ۲٥ mm/min. Hardness was determined as the maximum force (in Newtons) required for penetration, while spreadability was measured as the area under the force-time curve (in Newton-seconds). Lower area values indicated greater spreadability. All measurements were conducted in triplicate.

۲,۳,۳. Sensory Evaluation

Sensory analysis was conducted by a panel of ten trained evaluators with expertise in cocoa cream assessment. Panelists were selected based on their ability to detect odors and the five basic tastes (Kuesten & Bi, ۲۰۲۱). Samples were served at room temperature in white porcelain cups labeled with three-digit codes, accompanied by toast slices and plastic spoons. The evaluation order was randomized using an incomplete block design. Judges rated the samples on a ۹-point scale, assessing textural attributes (smoothness and spreadability) and taste attributes (meltability, mouth adhesion, and flavor). Spreadability was evaluated by spreading the sample on a toast slice. The panel evaluated the control cream and ۱٥ experimental formulations in separate sessions.

۲,٤. Experimental Design and Data Analysis

A D-Optimal design was employed to investigate the effects of fat replacement in cocoa cream formulations using olive oil-based oleogels. Independent variables included the percentage of olive oil in the oleogel formulation (x۱, ۹٥–۹۸٪), the percentage of PGPR in the oleogel formulation (x۲, ۲–٥٪), and the proportion of shortening replaced (z, ۰٪, ۲٥٪, ٥۰٪, and ۷٥٪). Dependent variables (responses) included spreadability (y۱) and oil-binding capacity (y۲). Data were analyzed to determine the optimal formulation for achieving desired quality parameters.

۳. Results

۳,۱. Oil-Binding Capacity (OBC)

Oil-binding capacity (OBC) is a critical parameter that reflects the extent of oil migration, a common issue in spreadable creams that can negatively impact consumer perception of product quality. The OBC values measured in this study (Table ۱) revealed that oil release after centrifugation was less than ۹٪ across all samples. The lowest OBC values were observed in creams formulated with complete replacement of shortening by oleogel and low oleogelator content (۲٪, ۲,٤٪, and ٤,۳٪ PGPR). In contrast, creams with partial shortening replacement (٥۰٪ and ۷٥٪) exhibited OBC values comparable to the control sample. These findings highlight the superior oil-retention ability and physical stability of oleogel-based cocoa creams. When shortening was entirely replaced, the OBC reached approximately ۹۱٪, compared to ۹۸٪ for the control sample. This confirms the effective oil-binding properties of the oleogel, demonstrating its potential as a viable alternative to traditional shortenings.

۳,۲. Texture Properties

Hardness and spreadability are key textural attributes that significantly influence consumer perception of anhydrous cocoa-based creams. The hardness and spreadability values for the various cocoa cream formulations are presented in Table ۱. A strong negative correlation was observed between hardness and spreadability, indicating that higher hardness values corresponded to greater resistance to spreading. For formulations with the same PGPR content, hardness and spreadability decreased significantly (p < ۰,۰٥) as the proportion of shortening in the formulation was reduced. The lowest hardness and spreadability values were recorded in creams prepared with complete replacement of shortening by oleogel. Furthermore, no significant differences in hardness or spreadability were observed among cocoa creams containing the same oleogel content but varying PGPR percentages, except for the sample with ٥٪ PGPR and ۷٥٪ shortening replacement. This sample exhibited higher hardness and spreadability values compared to the control, suggesting a potential interaction between PGPR and shortening at higher concentrations.

٣،٣. Sensory Evaluation

Principal Component Analysis (PCA) was employed to analyze the relationships between sensory attributes and the different cocoa cream formulations. The first and second principal components accounted for ٧٣،٤٪ and ١٢،٣٪ of the total variance, respectively. PC١ effectively distinguished creams with higher shortening content (٥٠٪ and ٧٥٪) and those with elevated PGPR levels (٥٪) from other samples, particularly those formulated with ١٠٠٪ oleogel. Sensory analysis revealed that creams with high shortening content (٧٥٪ of the fat phase), the control sample (١٠٠٪ shortening), and those with both high PGPR and shortening content were characterized by mouth adhesion. This attribute negatively correlated with spreadability, meltability, and smoothness. This behavior can be attributed to the high melting points of pure shortening (٣٥°C) and the olive oil-PGPR oleogel (٥٠°C), as well as the role of PGPR in enhancing the crystallization of shortening and vegetable oil mixtures, thereby strengthening the fat crystal network and increasing the melting point (Fayaz et al., ٢٠١٧). In contrast, cream samples formulated with PGPR-based oleogels and lower shortening content exhibited strong correlations with desirable technological attributes, such as spreadability, smoothness, and meltability, indicating favorable melting properties in the mouth. No significant correlation was found between flavor and the other sensory attributes evaluated.

Table ١. OBC, Hardness and spreadability of cocoa cream samples.

Run	OBC%	Hardness (N)	Spreadability (N mm)	Run	OBC%	Hardness (N)	Spreadability (N mm)
control	٩٨,٧٣ ± ٠,١٢ ^{d}	١٥,٩٨ ± ٠,٤٥ ^{d}	٦٠,٢٢ ± ٢,٣٢ ^{f}	٨	٩٦,٥٥ ± ٠,٥٥ ^{c}	١٠,٥٥ ± ١,٢٩ ^{c}	٣٦,٠٨ ± ١,١٢ ^{d}
١	٩١,٨١ ± ٠,٥١ ^{a}	١,٩٠ ± ٠,٠٢ ^{a}	٦,٧٥ ± ٠,١٢ ^{a}	٩	٩٥,٧٣ ± ٠,٧١ ^{c}	١,٧٦ ± ٠,١٨ ^{a}	٩,١٦ ± ٠,١٤ ^{a}
٢	٩٧,٩٠ ± ٠,١١ ^{d}	٥,٧١ ± ٠,٢١ ^{b}	٢٠,٤٣ ± ١,٠٧ ^{b}	١٠	٩٦,٦٦ ± ٠,١٦ ^{c}	٧,٩٢ ± ٠,٥٥ ^{b}	٣٠,٣٠ ± ٠,١٠ ^{c}
٣	٩٧,٩٧ ± ٠,٣٢ ^{d}	٦,١٩ ± ٠,١٨ ^{b}	٢٣,٠٨ ± ٠,١٣ ^{b}	١١	٩٨,٧٣ ± ٠,٥١ ^{d}	٧,٤١ ± ٠,٨١ ^{b}	٢٦,٨١ ± ٣,٠١ ^{b}
٤	٩٨,٣٧ ± ٠,٦١ ^{d}	١١,٨٤ ± ٠,٢٢ ^{c}	٤١,٩١ ± ١,١١ ^{e}	١٢	٩٧,٧١ ± ٠,٢١ ^{c}	٢,٥٦ ± ٠,٢٤ ^{a}	٨,٥١ ± ١,٤٧ ^{a}
٥	٩٣,٦٨ ± ٠,١٣ b	٢,٠٩ ± ١,١٥ ^{a}	٧,٥٩ ± ١,٣٣ ^{a}	١٣	٩٥,٨٢ ± ٠,٠٤ ^{c}	٧,٥٤ ± ٠,٠٧ ^{b}	٢٧,٠٩ ± ١,٢١ ^{b}
٦	٩٧,٣٤ ± ٠,٤٢ ^{c}	٥,٤٠ ± ٠,٦٦ ^{b}	٢٣,٣٤ ± ٠,٥٥ ^{b}	١٤	٩٧,٥٦ ± ٠,١٥ ^{c}	٧,١٩ ± ١,٥٥ ^{b}	٣٠,٩٩ ± ١,٤٥ ^{c}
٧	٩٧,٠٥ ± ٠,٣٧ ^{c}	٦,٣٤ ± ١,٢٢ ^{b}	٢١,٢٩ ± ٢,٥١ ^{b}	١٥	٩٨,٦٢ ± ٠,٠٢ ^{d}	٣١,١٨ ± ٠,٨٩ ^{e}	٥٦,٤٢ ± ٠,١١ ^{f}

Different letters (a–d), in the same column reveal significant differences (p < ٠،٠٥) between the samples.

٣،٤. Multivariate Optimization

The mathematical models developed in this study were utilized to predict the optimal cocoa cream formulation. Multiple optimization analyses were conducted to determine the ideal proportions of olive oil, PGPR, and shortening replacement to achieve a cream with optimal spreadability and oil-binding capacity. The final optimized formulation consisted of a cocoa cream in which shortening was entirely replaced with an oleogel composed of ٩٦٪ olive oil and ٤٪ PGPR. This formulation achieved an overall desirability score of ٠،٩٨٨٩, indicating excellent product quality and acceptability.

٤. Conclusion

This study investigated the application of D-optimal design to replace shortening with olive oil-based oleogels in cocoa cream formulations, aiming to identify the optimal formulation with desirable quality attributes. Using experimental design methodologies, ١٥ distinct cocoa cream formulations were prepared and evaluated for oil-binding capacity (OBC) and spreadability, which represent key quality parameters. This approach facilitated the development of mathematical models for each attribute, enabling the calculation of the optimal ingredient composition to maximize overall desirability. Statistical analysis of the results revealed that spreadability and hardness decreased significantly as the proportion of shortening in the formulations was reduced, for a given amount of PGPR in the oleogel. The lowest values for these textural properties were observed in creams formulated with complete replacement of shortening by oleogel. OBC measurements demonstrated excellent oil retention across all samples, with oil release after centrifugation remaining below ۹٪. Optimization results identified the best-performing formulation as one in which shortening was entirely replaced with an oleogel composed of ۹۶٪ olive oil and ٤٪ PGPR, based on the desirability function method. In conclusion, this study underscores the potential of experimental design techniques, particularly D-optimal design, in formulating food products such as cocoa creams. The findings highlight the feasibility of using oleogels as a replacement for saturated fats in food formulations that require solid fats to achieve specific technological and sensory properties. This approach not only addresses health concerns associated with traditional shortenings but also ensures the retention of desirable product characteristics, offering a promising pathway for the development of healthier food alternatives.

References:

Arris, F. A., Thai, V. T. S., Manan, W. N., & Sajab, M. S. (2020). A Revisit to the Formation and Mitigation of 3-Chloropropane-1,2-Diol in Palm Oil Production. Foods, 9(12). https://doi.org/10.3390/foods9121769

Arshad, R., Mazhar, F. B., Arshad, K., & Xu, B. (2024). Unlocking the potential of oleogels in edible applications and health impacts. Applied Food Research, 4(2), 100620. https://doi.org/https://doi.org/10.1016/j.afres.2024.100620

Borriello, A., Miele, N. A., Masi, P., & Cavella, S. (2022). Rheological Properties, Particle Size Distribution and Physical Stability of Novel Refined Pumpkin Seed Oil Creams with Oleogel and Lucuma Powder. Foods, 11(13).

David, A., David, M., Lesniarek, P., Corfias, E., Pululu, Y., Delample, M., & Snabre, P. (2021). Oleogelation of rapeseed oil with cellulose fibers as an innovative strategy for palm oil substitution in chocolate spreads. Journal of Food Engineering, 292, 110315. https://doi.org/https://doi.org/10.1016/j.jfoodeng.2020.110315

Fayaz, G., Goli, S. A. H., Kadivar, M., Valoppi, F., Barba, L., Calligaris, S., & Nicoli, M. C. (2017). Potential application of pomegranate seed oil oleogels based on monoglycerides, beeswax and propolis wax as partial substitutes of palm oil in functional chocolate spread. LWT, 86, 523-529. https://doi.org/https://doi.org/10.1016/j.lwt.2017.08.036

Kuesten, C., & Bi, J. (2021). Application of a panel performance reliability versus product effect size (PR-ES) framework: A protein powder case study. Food Quality and Preference, 89, 104152. https://doi.org/https://doi.org/10.1016/j.foodqual.2020.104152

Liu, N., Nan, J., Zhang, K., Li, D., Zhang, Z., Yang, D., Zhang, P., Nishinari, K., & Yao, X. (2024). Fat coalescence and texture improvement of ice cream based on medium-chain triglyceride oleogel: Effect of gelator type. Food Hydrocolloids, 152, 109921. https://doi.org/https://doi.org/10.1016/j.foodhyd.2024.109921

Malvano, F., Laudisio, M., Albanese, D., d'Amore, M., & Marra, F. (2022). Olive Oil-Based Oleogel as Fat Replacer in a Sponge Cake: A Comparative Study and Optimization. Foods, 11(17).

Park, C., Bemer, H., & Maleky, F. (2018). Oxidative Stability of Rice Bran Wax Oleogels and an Oleogel Cream Cheese Product. Journal of the American Oil Chemists' Society, 95. https://doi.org/10.1002/aocs.12095