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Optimization condition to produce sweet-noodles in milk using reverse spherification technique

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ABSTRACT

The principle of reverse spherification relies on the formation of calcium alginate, in which sodium alginate undergoes gelation in the presence of calcium ions. In this study, sweet-noodles in milk balls were produced by incorporating calcium lactate into the core solution and submerging it in a sodium alginate bath to form spherical gel structures. Optimization of the production conditions was conducted using Response Surface Methodology (RSM) with a Central Composite Design (CCD), focusing on two independent variables: sodium alginate concentration (X_1: 1.0–1.5%) and soaking time (X_2: 3–5 minutes). Each formulation was evaluated for its physical properties, including weight, size, color (L*, a*, b*), and membrane thickness. The results indicated that increasing both alginate concentration and soaking time enhanced gelation, resulting in increased bead size and film thickness. The optimal condition for producing sweet-noodles in milk balls was found to be 1.50% alginate concentration and 3 minutes of soaking time. Under this condition, the actual bead size was 15.93 mm. The predictive model was further validated, yielding a predicted bead size of 15.43 ± 0.49 mm, confirming the reliability of the optimization model.

Keywords: sweet-noodles in milk, reverse spherification, gelation

INTRODUCTION

Sweet-noodles in milk (Sarim) are a traditional Thai dessert made from mung bean flour served with aromatic sweetened coconut milk. It is especially popular during hot weather due to its refreshing nature (Tinnawong and Kamolbhibhat, 2015). As part of preserving and revitalizing traditional Thai desserts, there is a growing need to present them in novel forms to attract modern consumers. This aligns with global food trends emphasizing innovation and experiential consumption, as observed in the 2018 food innovation movement. Therefore, this study applied the spherification technique a modern culinary approach to develop a new form of Sarim, aiming to enhance its visual appeal and textural uniqueness while maintaining its original flavor identity.

In recent years, molecular gastronomy has introduced innovative techniques to transform the texture and appearance of traditional foods. Among these techniques, reverse spherification has gained considerable attention in modernist cuisine for its ability to create novel sensory experiences (Barrett, 2012). This technique involves incorporating calcium lactate into a liquid food matrix, which is then submerged in a sodium alginate bath, resulting in the formation of spherical structures (Vega & Castells, 2012). Depending on the formulation and processing conditions, the resulting beads can vary from having a thin, delicate membrane encapsulating a liquid core to being fully gelled throughout (Lee & Roger, 2012).

The fundamental mechanism of reverse spherification is based on the gelation of sodium alginate (SA) in the presence of calcium ions, leading to the formation of calcium alginate a stable hydrogel network (Navarro et al., 2012). Sodium alginate is a widely available, safe, and edible polysaccharide derived from brown seaweed. It is composed of β-D-mannuronic acid (M) and α-L-guluronic acid (G) units arranged in linear, non-branched chains (Saqib et al., 2022). Its ionic gelation property, especially in the presence of divalent or trivalent cations such as Ca^{2+}, promotes the cross-linking of polymer chains to form a gel membrane that effectively encapsulates a liquid core (Xu et al., 2024).

Calcium ions (Ca2+) is the most commonly used cross-linking ion in food or cosmetic systems. Typically, dropping a liquid containing Ca^{2+} into a polysaccharide solution (sodium alginate) to form hydrogel beads is known as “reverse spherification”. Studies have shown that the reverse spherification technique is suitable for preparing hydrogel beads with a large liquid core and a well-maintained spherical shape (Bubin et al., 2019) Therefore, the objective of this study is to investigate the optimal conditions specifically the concentrations of sodium alginate and the soaking time using Response Surface Methodology (RSM), to develop “sweet-noodles in milk” (Sarim) in spherical form via reverse spherification.

MATERIALS AND METHODS

Material for prepared sweet-noodles included pasteurized milk (Meji brand) and mung bean flour (PINE brand), with product from Sitthinan Co., Ltd. The chemical reagents used for the production of sweet-noodles in milk balls were food-grade. Sodium alginate was obtained from Kimica Corporation Ltd., Japan, and calcium lactate was purchased from Nutrition Co., Ltd., Thailand.

Production of green bean flour Sarim noodles in fresh milk

Mix 104.5 grams of green bean flour with 557 grams of water. Stir until fully dissolved. Heat the mixture over low heat, adding food coloring drops as needed: dark green and pink noodles. Cook over low heat, stirring constantly for 15 minutes. Once the mixture becomes translucent, transfer it into a piping tool and press into room-temperature water (using about ¾ of the pot's volume). After forming the noodles, scoop them out and allow the excess water to drain. Set the noodles aside for further experimental use.

Preparation of sweet-noodles in milk balls

Sweet-noodles in milk balls was prepared by adding sweet-noodle into sphere mold. After that, use the syringe to suck milk (adding calcium lactate) up and then pour it into sphere mold, with having sweet-noodle. Move the sphere mold into the freezer (-8 ^{o}C) until 24 hours. After a time, remove sweet-noodle in milk from sphere mold. As the sweet-noodle in milk drop-wise into the sodium alginate bath, a gelled membrane instantly formed around the sweet-noodle milky sphere. Then sweet-noodle milk ball was soaked in sterile distilled water and stored at 4 ^{o}C in the refrigerator.

Determination of physical properties of sweet-noodle milk ball

The weight of the sweet-noodle milk balls was measured using a two - digit precision digital balance. The diameter (size) was determined using a Vernier caliper. Color values, including lightness (L*), redness (a*), and yellowness (b*), were analyzed using a Hunter Lab MiniScan EZ (LAV series) colorimeter. The thickness of the gel layer was measured using a micrometer. To determine the optimal conditions for sodium alginate concentration and immersion time, the physical analysis results were used to examine the relationships between the variables of interest through Response Surface Methodology (RSM).

Study of optimized condition of sweet-noodle milk ball

A statistical experiment design based on the response surface methodology to central composite design (CCD) was planned. The two independent variables were concentrations of alginate (X_1) and soaking time (X_2). The sodium alginate concentrations were varied from 1 to 1.5% and soaking was varied from 3 to 5 minutes. The sweet-noodle milk balls were prepared as described above and their physical properties were examined.

Statistical analysis

A statistical experimental optimized condition to produce sweet-noodle milk balls was measured by using response surface methodology to central composite design to study the effect of sodium alginate and soaking time on the gelation of sweet-noodle milk balls.

Mix mung bean flour with water
↓
Stir until dissolved, add food coloring dissolved
↓
Heat and stir continuously for 8 - 10 minutes until translucent
↓
Add air to make strands using a piping tool
↓
Sarim noodles
↓
Put sarim noodles into the mold

Warm pasteurized milk
↓
Add sugar and stir until
↓
Smoke with candles 2 times
↓
Smoked milk
↓
Mixed with calcium lactate
↓
Stir until dissolved

↓
Inject milk into a mold
↓
Frozen at -8ºC for least 24 hours
↓
Remove from mold
↓
Dissolve in sodium alginate solution
↓
Sweet-noodles in milk balls

Figure 1 Process for producing Sweet-noodles in milk balls

RESULTS AND DISCUSSION

Study of the optimized condition of sweet-noodle milk ball

A statistical experiment design based on the response surface methodology to central composite design (CCD) was planned. The two independent variables were concentrations of alginate (X_1) and soaking time (X_2). The total runs of the experiment was described on Table 1. The physical properties of all the sweet-noodle milk balls were examined (Table 1). The result showed that the differential concentration of sodium alginate and soaking time effect to physical properties of sweet-noodle milk ball, in which the quality of the gel is dependent on the concentration of alginate, the concentration of calcium and time to soaking in solution (Le Roux et al., 1999). As the concentration of alginate constant, increasing in soaking time, the weight and thickness of the sweet-noodle milk balls increased while the size of sphere decreased. Also, as the soaking time constant, increasing in alginate content, the thickness of the film and weight increased but size decreased. In all the parameters that were studied, the size of the sweet-noodle milk ball was greatly affected.

The fitting of all the examined to various models (linear, two factorials, quadratic and cubic) and their subsequently analysis of variance (ANOVA) were shown on the table 2. The analysis of variance shown that model of the weight, size and thickness equations could be used to predict the result because a lack of fit were not significant and the coefficient R^2 of the response in the range 0.76 - 0.81 which shown the possibilities. As size of sphere was greatly affected by the concentration of alginate and soaking time and its coefficient R^2 was highest (0.81). In the present study, the model of size would be use to find the suitable condition to produce sweet-noodle milk ball. Fitting of the examined size data to various models, their subsequently ANOVA showed that the size was most suitably described with quadratic polynomial model.

$$\text{Size (mm)} = 10.07+19.64*X_1-5.32*X_2-4.77*X_1*X_2+0.48*X_1^2+1.41*X_2^2$$

Where X_1 is the concentration of alginate; X_2 the soaking time. Coefficient value of determination (R^2) was 0.81 ($p<0.05$).

Response surface and contour plot that described the effect of sodium alginate soaking time on the size of sweet-noodle milk balls were shown on Figure 3. The effects of sodium alginate concentration and soaking time on the size of sweet-noodle milk balls were found to be significant, with both variables directly influencing the diameter of the formed spheres. This phenomenon is chiefly attributable to the augmented cross-linking interactions between alginate and calcium ions, which culminates in a more robust gel membrane encasing the liquid core, thereby facilitating an increase in the size of the milk spheres (Paoletti and Donati, 2022). While prolonged soaking times enhance the cross-linking process, leading to larger bead sizes and improved structural integrity, The interaction time with calcium ions is crucial for achieving the desired gel strength and size (Li et al., 2015). Additionally, the rheological properties of the polysaccharide solution play a crucial role in the reverse spherification process (Hu et al., 2025). Furthermore, a low-viscosity environment facilitates the diffusion of Ca^{2+} ions into the alginate matrix, improving the efficiency of gel formation and enhancing the spherification process as a whole (Bennacef et al., 2021). Conversely, the excessive viscosity not only hinders the immersion of the ice ball but also limits the diffusion of Ca2+, reducing the rate and success rate of spherification (Nair et al., 2020). Gelation of alginate becomes more pronounced with higher concentrations and longer interaction times, resulting in a thicker gel membrane (Sen, 2017). In addition, the ratio of mannuronic acid (M) to guluronic acid (G) in sodium alginate significantly affects the gel network formation (Stewart et al., 2014). The G blocks can form crosslinking with the presence of divalent cations leading to the formation of alginate gel (El Hariri El et al., 2022; George & Abraham, 2006). The duration of interaction between alginate and calcium ions affects bead size, as extended contact promotes cross-linking and strengthens gel connectivity, leading to larger and more structured hydrogel beads (Tsai et al., 2017). In this study, the optimal conditions for producing sweet-noodle milk balls were found to be a sodium alginate concentration of 1.50% and a soaking time of 3 minutes. Under these conditions, the experimentally obtained bead size was 15.93 mm. The predictive equation derived from the response surface model was then validated, yielding a predicted size of 15.43 ± 0.49 mm. This result confirms the accuracy and reliability of the model for estimating the outcome under optimal processing conditions.

Table 1 The experiment design and the response of the central composite design factors.

RUN	Alginate (%)	Time (min)	Weight (g)	Size (mm)	Color L^*	Color a^*	Color b^*	Thickness (mm)
1	1.00	5.00	31.10	15.80	64.30	1.17	3.66	0.03
2	1.25	5.41	30.89	15.54	64.00	0.79	3.73	0.03
3	1.25	2.59	32.04	15.26	63.81	0.20	3.31	0.02
4	1.00	3.00	31.11	12.82	53.48	0.91	2.12	0.03
5	1.25	4.00	32.82	13.04	66.28	0.74	4.10	0.05
6	1.50	3.00	32.40	16.52	45.20	0.80	2.45	0.04
7	1.50	5.00	31.73	14.01	66.27	0.66	3.16	0.03
8	1.60	4.00	29.76	12.96	44.68	1.32	1.12	0.04
9	0.90	4.00	29.28	12.31	58.15	2.37	2.17	0.03
10	1.25	4.00	29.54	11.55	50.10	0.10	2.24	0.03
11	1.25	4.00	30.95	12.33	60.32	0.53	3.96	0.03
12	1.25	4.00	30.10	13.33	63.07	2.83	2.74	0.02
13	1.25	4.00	31.59	14.10	64.94	1.04	3.82	0.02

Table 2 Analysis of variance of alginate and time that effect the physical properties of sweet-noodle milk ball.

Source	p-value Prob>F						
	df	weight	size	L	a	b	thickness
Model	5	0.0186**	0.0173**	0.1130**	-	0.0917 ns	0.0008**
A-alginate	1	0.9874	0.1774	0.2084	-	0.4099	0.0004
B-time	1	0.9236	0.9525	0.6067	-	0.4754	0.0562
AB	1	0.9938	0.0247	0.0393	-	0.1359	-
A^2	1	0.0021	0.9273	-	-	0.0162	-
B^2	1	0.0144	0.0030	-	-	0.5968	-
Lack of Fit	3	0.2201 ns	0.7660 ns	0.4807 ns	0.9196 ns	0.9076 ns	0.4965 ns
R^2	-	0.80	0.81	0.46	0.00	0.68	0.76

** Significant at $p<0.05$

Figure 2 Sweet-noodles in milk balls product

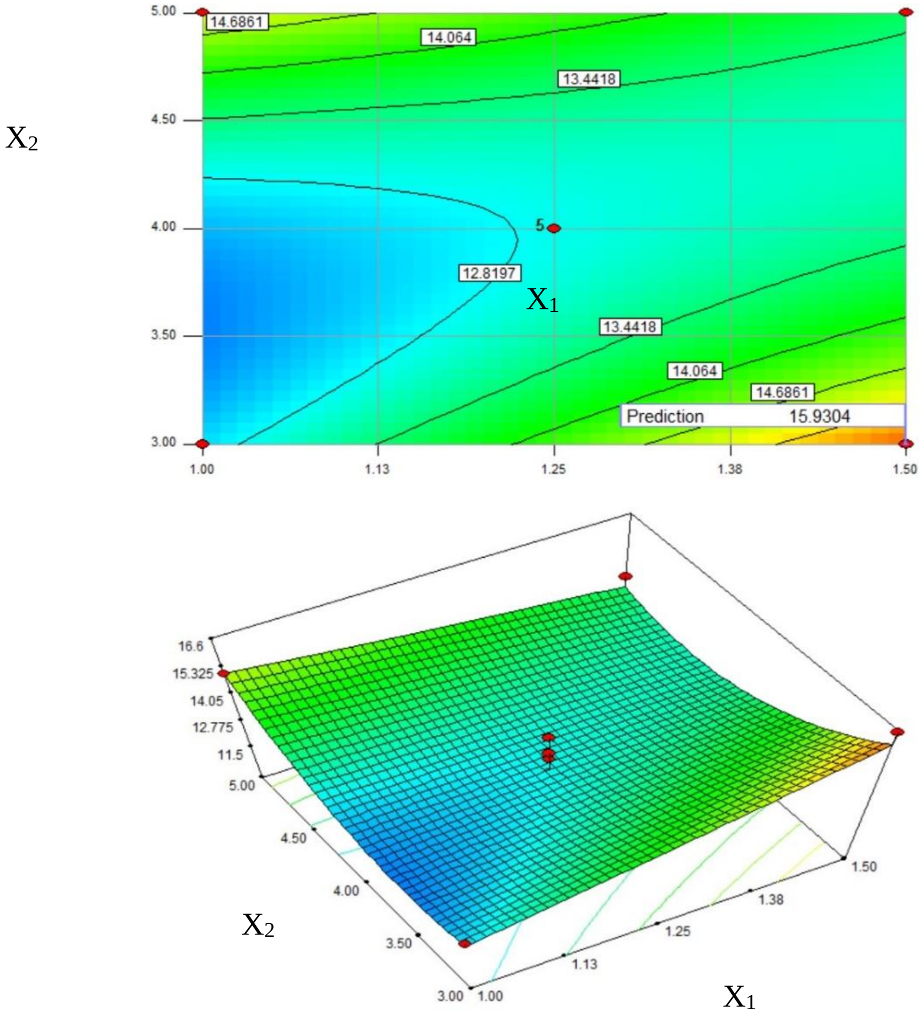

Figure 3 Response surface (a) and contour plot (b) showed the effect of alginate and soaking time on the size of sweet-noodle milk ball.

CONCLUSIONS

The production of sweet-noodle milk balls by using the reverse spherification technique was studied. The effect of sodium alginate and soaking time for the preparation of sweet-noodle milk ball were determined using response surface methodology (RSM). The model of size would be used to find the suitable condition to produce sweet-noodle milk balls. The optimal production condition was alginate concentration of 1.50% and a soaking time of 5 minutes. The predicted responses for this production condition was 15.43 ± 0.49 mm which was similar to that from the experiment.

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