

Reverse-Creamed Soybean Aquafaba Marble Cake: Development and Sensory Appraisal

ABSTRACT

Removing whole egg from cake disrupts aeration, emulsification, moisture balance, and heat-set structure, so complete replacement requires reformulation rather than a direct ingredient exchange. This study developed an egg-free marble cake with soybean aquafaba through preliminary aquafaba work and four sequential single-batch cake trials. The selected formula removed 85 g whole egg from the reference recipe and used 80 g soybean aquafaba, divided between the liquid phase (45 g) and a separately whipped meringue (35 g), within a reverse-creaming process. Trial 4 retained its shape after cooling and was taken forward for product appraisal. Fifteen Culinary Arts students evaluated the cake on one testing day; five lecturers or pastry professionals evaluated it on another. Student-session means for volume suitability, color, aroma, taste, texture, and overall acceptance were 3.73, 4.47, 4.40, 4.53, 4.07, and 4.40; lecturer/professional-session means were 3.60, 3.80, 3.80, 4.20, 3.40, and 4.00. Because the study record does not establish that both sessions received cake from the same production batch, the session results are reported separately. The study documents a defined formulation and process for subsequent replication and controlled testing, but does not establish equivalence with egg-based marble cake.

Keywords: *soybean aquafaba; marble cake; egg replacement; product development; panelist evaluation*

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INTRODUCTION

Whole egg is difficult to remove from cake because it contributes at several stages of batter formation and baking. Dispersed or whipped egg assists air incorporation, yolk constituents support emulsification, egg water affects batter consistency, and proteins contribute to the structure that sets during heating. Removing the whole-egg fraction therefore changes the balance

among air, water, fat, dissolved solids, starch, and gluten-forming proteins. In cake systems, these changes are commonly expressed as lower volume, denser crumb, altered cell structure, or greater firmness (Wilderjans et al., 2008; Yazıcı & Özer, 2021).

Aquafaba offers a plant-derived route to egg-free formulation because legume cooking liquids contain soluble components with foaming and emulsifying capacity. Their performance, however, varies with legume species, seed-to-water ratio, cooking conditions,

concentration, pH, and storage (Buhl et al., 2019; He et al., 2021; Hanoğlu & Karaoğlu, 2025). This variability matters when evidence derived mainly from chickpea aquafaba is transferred to soybean systems. Soybean aquafaba has demonstrated useful foaming functionality, but its composition and processing conditions differ sufficiently that its behavior in cake must be established within the formulation in which it is used (Shim et al., 2021).

Structural changes have been reported at high aquafaba replacement levels across several cake systems. Aslan and Ertas (2020) reported lower volume index and greater firmness as chickpea-aquafaba replacement increased. Oh and Yoon (2021) found decreasing specific volume and the greatest hardness at 100% replacement in sponge cake. Arum et al. (2025) reported a similar reduction in specific volume as soybean-aquafaba substitution increased in cupcakes. More recent work has also shown that aquafaba source and formulation can alter foam behavior, cake volume, and texture, reinforcing the need to report preparation and processing conditions rather than treating aquafaba as a uniform ingredient (Crawford et al., 2024; Konal et al., 2025).

Marble cake adds a practical processing requirement. The batter must retain sufficient aeration and cohesion to bake into a sliceable cake while allowing vanilla and cocoa portions to be combined without excessive mixing or loss of structure. Preliminary work in the present study also recorded phase separation when aquafaba was incorporated through a conventional creaming route. The development question focused on how soybean aquafaba preparation and batter-building sequence could be organized into a workable egg-free marble-cake process. Sequential culinary product development was used to develop the process and describe the selected product through production observations and panelist appraisal. It was not designed as a controlled comparison with an egg-based cake or as a population-level consumer study.

METHOD

This applied product-development study was conducted in the pastry kitchen laboratory of Politeknik Pariwisata Makassar from April to June 2026. The study record notes three preliminary soybean-aquafaba preparation trials before four sequential marble-cake trials. Trial-level conditions and responses for the three preliminary aquafaba trials were not preserved in sufficient detail for comparative reporting; the manuscript therefore reports the selected aquafaba protocol rather than reconstructing those trials. Each cake trial comprised one production batch, and formulation or process changes were made after observing the preceding batch. The sequence documents product development, not replicated experimental treatments. Trial 4 was selected for panelist appraisal.

Reference Formulation And Basis Of Egg Replacement

The starting point was the marble cake formula reported by Suas (2008), which contained 85 g whole egg (Table 1). The developed formula omitted that ingredient entirely and used 80 g soybean aquafaba, divided between the batter (45 g) and a separately whipped meringue (35 g). Complete egg replacement in this study therefore means removal of the

whole-egg ingredient from the reference formula; it does not imply a gram-for-gram substitution. Development also involved changes to flour and starch, sugar distribution, fat, leavening, dairy ingredients, and processing. The final product should consequently be read as a reformulated egg-free marble cake rather than as an isolated aquafaba substitution treatment.

Table 1

Reference Formulation Used as the Development Basis

Ingredient	Unit	Quantity
Unsalted butter	g	70.9
Caster sugar	g	99
Glucose	g	21
Whole egg	g	85
Vanilla extract	g	3.5
Pastry flour	g	85
Potato starch	g	35
Baking powder	g	3.5
Baking soda	g	0.6
Salt	g	0.7
Full-cream milk	mL	35
Sour cream	mL	35
Dark cocoa powder	g	11
Sour cream for chocolate component	mL	11

Note. Reference formulation adapted from Suas (2008).

Soybean Aquafaba Preparation

For the selected aquafaba procedure, 200 g of whole, clean yellow soybeans were washed three times and soaked under chilled conditions for 16 h at a soybean-to-water ratio of 1:4 (200 g soybeans to 800 mL water). The beans were drained, rinsed once under running water, and weighed. Fresh water was added at a 1:1 ratio to the post-soaking bean mass. The beans were pressure-cooked over low heat for 90 min, followed by 30 min of natural pressure release with the cooker closed. The cooking liquid was separated through a fine strainer. The study record identifies the raw material as whole, clean yellow soybeans but does not preserve supplier or lot information.

The filtered cooking liquid was held for 30 min at room temperature and then for 30 min under chilled conditions before reduction. It was reduced over low heat, without a rolling boil, to approximately half of its initial volume, cooled for 1 h at room temperature, and chilled for at least 4 h or overnight. Final aquafaba yield after reduction was not recorded. For cake production, the practical endpoint was a homogeneous, semi-thick liquid that, after whipping, formed a stiff peak remaining visibly intact for 15 min. Viscosity, solids concentration, foaming capacity, and foam stability were not measured instrumentally.

Final Marble Cake Formulation and Production

Table 2*Final Marble Cake Formulation*

Ingredient	Amount
All-purpose flour	120 g
Cornstarch	20 g
Full-cream milk powder	10 g
Caster sugar	80 g (64 g dry mixture; 16 g meringue)
Baking powder	4 g
Baking soda	0.3 g
Salt	1.2 g
Unsalted butter	60 g
Neutral oil	10 mL
Soybean aquafaba	80 g (45 g batter; 35 g meringue)
Full-cream milk	35 mL
Plain yogurt	35 g
Vanilla extract	3 g
Cream of tartar	0.2 g
Cocoa powder	7 g
Hot water	8 mL
Glucose	15 g

The final process used reverse creaming as the base-batter method. All-purpose flour, cornstarch, full-cream milk powder, 64 g caster sugar, baking powder, baking soda, and salt were mixed at low speed for 45-60 s. Softened butter was then worked through the dry mixture until it had a moist, sand-like appearance, followed by neutral oil. A liquid mixture containing 45 g soybean aquafaba, full-cream milk, plain yogurt, vanilla extract, and glucose was incorporated in three stages and mixed at low to medium speed for approximately 45-60 s until the batter was thick and homogeneous.

Separately, 35 g chilled soybean aquafaba was whipped with cream of tartar while 16 g caster sugar was added gradually until a glossy stiff peak formed. The meringue was folded into the base batter in three additions. Cocoa powder and hot water were mixed to a paste, cooled to 35-38°C, and combined with 50 g base batter. Vanilla batter and small dollops of chocolate batter were layered in a parchment-lined 20 × 10 cm loaf pan, then swirled two to three times with a figure-eight movement. The cake was baked at 165°C for 20 min, then at 160°C upper heat and 155°C lower heat for approximately 60 min or until the practical doneness criteria were met. The temperature was reduced to 120°C for a further 20 min. Doneness was assessed by three criteria: a skewer showed no wet batter, the center no longer jiggled when the pan was moved gently, and the surface sprang back when touched lightly. The oven was then switched off and the door left slightly open for 10 min. The cake remained in the pan for 15 min and was cooled on a rack for at least 3 h before slicing and evaluation.

Panelist Appraisal

Twenty panelists evaluated the selected formulation over two testing days. Fifteen were Culinary Arts students who had completed pastry coursework and practical classes; five were Culinary Arts lecturers or pastry professionals. The students had not completed a formal sensory-training or calibration program. The exercise is therefore reported as product appraisal rather than trained descriptive sensory analysis.

On the first testing day, the 15 student panelists were divided into three sessions of five. The five lecturer/professional panelists completed the evaluation on the second day. Sessions lasted approximately 10-15 min in the pastry kitchen laboratory. Panelists completed the assessment individually and were instructed not to discuss their responses during testing. The study record does not establish whether the two testing days used portions from the same production batch or document storage history between sessions. Each panelist received one portion of the selected marble cake at room temperature after at least 3 h of cooling. Portions were cut to a visually similar size, although mass and dimensions were not recorded. Because one formulation was presented within each session, serving-order randomization was not applicable. Samples were not blind-coded, and panelists knew that the cake contained soybean aquafaba.

Panelists rated volume, color, aroma, taste, texture, and overall acceptance using five-point scales. Volume, color, aroma, taste, and texture used the anchors 1 = strongly unsuitable, 2 = unsuitable, 3 = moderately suitable, 4 = suitable, and 5 = strongly suitable. Overall acceptance used 1 = very poor, 2 = poor, 3 = fair, 4 = good, and 5 = very good. The first five items were suitability judgments, not descriptive sensory-intensity measures.

Data Analysis

Completed forms were checked before tabulation. All 20 panelists provided ratings for the six attributes. Totals and arithmetic means were calculated separately for the student session (n = 15) and lecturer/professional session (n = 5). The two sessions were not compared inferentially because panel type was confounded with testing day and the production-batch identity across days could not be established. The four product-development trials were also not subjected to inferential testing because each represented a single production batch.

The original five-point response anchors are reported directly. Mean scores were retained as descriptive summaries and were not converted into additional interval-based verbal categories. Individual-level response distributions were unavailable in the retained study record and were therefore not analyzed.

Participant Information and Protection

Panelists were briefed on the product and evaluation procedure before testing. The study record does not document formal ethics-committee approval, written informed consent, or food-allergy screening.

RESULTS

Development Sequence

Four cake trials followed the preliminary aquafaba work. Table 3 records the formulation or process change introduced at each stage, the production response observed in that batch, and the decision taken before the next trial. The preliminary aquafaba work is not tabulated because trial-level conditions and responses were not preserved with sufficient detail for defensible reconstruction.

Table 3
Sequential Development of the Soybean-Aquafaba Marble Cake

Trial	Development change	Observed response	Next step
1	Initial formula with 95 g aquafaba and the preliminary aquafaba procedure.	Aquafaba remained thin and did not form a stiff peak that remained intact. Batter was fluid. The cake rose during baking but lost volume during cooling; the center was gummy and dense, the surface cracked, and soybean aroma remained pronounced.	Revise aquafaba preparation and formulation.
2	Aquafaba preparation revised; total aquafaba reduced to 80 g, with 45 g for the batter and 35 g for whipping.	Aquafaba became semi-thick and formed a foam that retained the target stiff peak; batter became thick and homogeneous. The cake rose well but lost some volume after baking. Dense, gummy crumb, minor cracking, and residual soybean aroma remained.	Refine formulation and process.
3	Sugar allocation and baking conditions revised.	Aquafaba retained the target stiff peak, the batter remained thick and homogeneous, and the cake retained its volume after cooling. The crumb remained relatively dense, minor surface cracking persisted, and soybean aroma was less dominant.	Proceed to final refinement.
4	Sugar allocation finalized at 64 g in the dry mixture and 16 g in the meringue; marble assembly and baking/cooling were refined.	No visible post-cooling collapse was observed. Gumminess was reduced, minor cracking remained, the marble pattern was defined, and soybean aroma was no longer dominant after cooling.	Select for panelist evaluation.

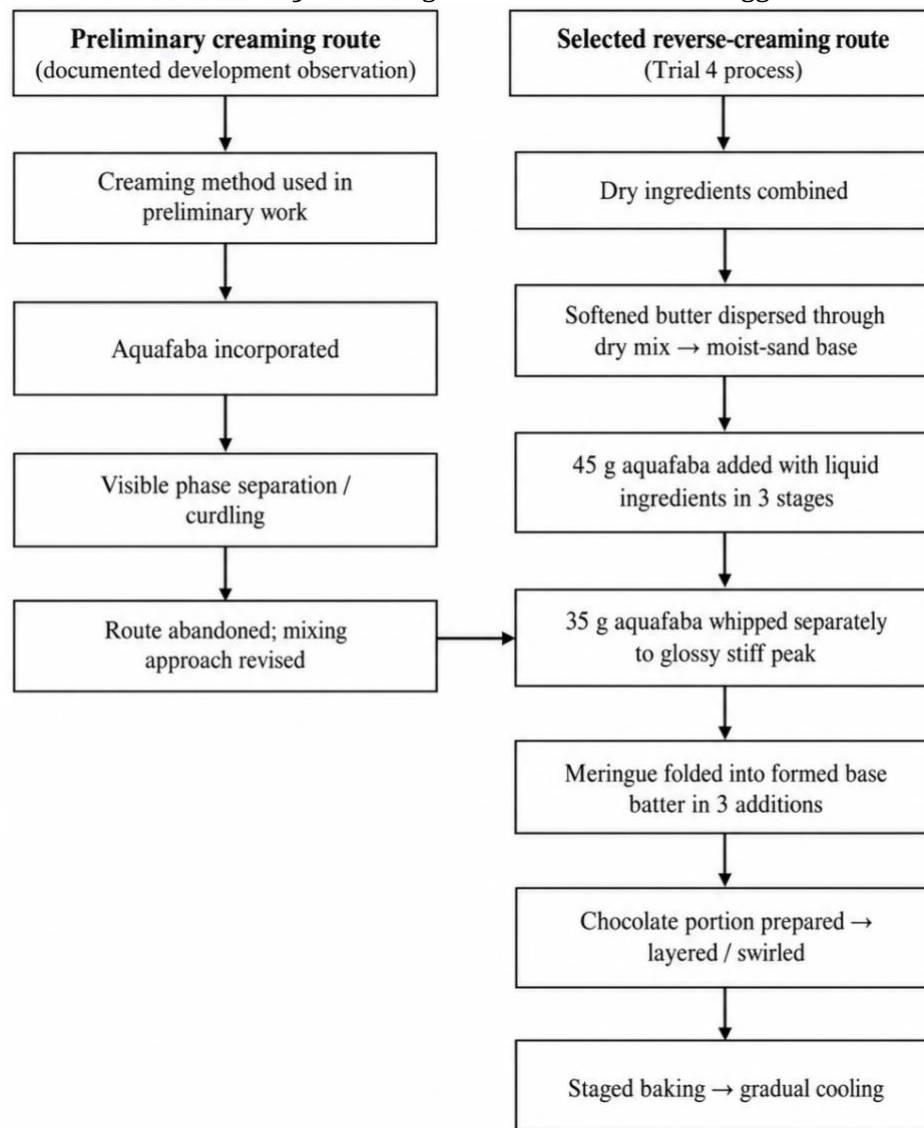
Note. Each trial consisted of one production batch. The observations describe the development sequence and were not analyzed as replicated treatment effects.

Selected Aquafaba and Product Documentation

The aquafaba used for Trial 4 was cream-colored, homogeneous, and semi-thick. When whipped, it formed a stiff peak that remained visibly intact for 15 min, meeting the practical production endpoint used in the study. Figure 1 summarizes the process contrast documented during development. The preliminary route is shown only to the level recorded in the study notes; it is not presented as a controlled comparison with the selected method.

Figure 1

Process Framework From Preliminary Creaming Failure to the Selected Egg-Free Marble Cake Process



Note. The left panel represents the preliminary observation documented in the study record: conventional creaming followed by aquafaba incorporation produced phase separation (curdling). The study did not conduct a controlled head-to-head comparison of mixing methods. The right panel reproduces the selected Trial 4 process sequence. Arrows indicate process order, not experimentally isolated causal effects.

Figure 2

Selected Soybean Aquafaba after Reduction and Chilling



Note. The photographs document the aquafaba used for the selected formulation; no quantitative image analysis was performed.

Figures 3 and 4 provide documentary photographs of the development batches and the selected Trial 4 product after cooling and slicing.

Figure 3

Documentary Photographs of Marble Cake Trials 1-3



Note. Trials 1-3 are shown from left to right. The photographs illustrate the development sequence and were not used for quantitative comparison.

Figure 4

Final Marble Cake from Trial 4 after Cooling and Slicing



Note. The photograph shows the selected product after cooling and slicing; no quantitative image analysis was performed.

Panelist Ratings

All 20 panelists completed the six ratings. Table 4 reports the arithmetic means separately for the student and lecturer/professional testing sessions.

Table 4

Panelist Ratings of the Selected Marble Cake

Attribute	Student session (n=15)	Lecturer/professional session (n=5)
Volume suitability	3.73	3.60
Color	4.47	3.80
Aroma	4.40	3.80
Taste	4.53	4.20
Texture	4.07	3.40
Overall acceptance	4.40	4.00

Note. Student means are based on 15 panelists and lecturer/professional means on five panelists. The first five attributes used suitability anchors; overall acceptance used a very poor-to-very good scale. No inferential group comparison was performed.

Taste received the highest rating in both sessions, whereas volume suitability and texture were among the lower-rated attributes. Because panel type, testing day, possible batch identity, and storage history were not separable in the study record, differences between sessions were not interpreted as panel-type effects.

DISCUSSION

The selected cake emerged from a sequence of process and formulation changes rather than from aquafaba addition alone. Preliminary conventional creaming was abandoned after aquafaba incorporation produced visible phase separation. Reverse creaming was then used to build the base batter by dispersing softened butter through the dry mixture before liquid addition. Trial 1 nevertheless remained unsuccessful: the aquafaba was thin and did not retain the target stiff peak, the batter was fluid, and the cake lost volume during cooling and developed a gummy center. Reverse creaming was therefore part of the workable process, but the development record does not support treating it as an isolated causal treatment.

The process became workable after tighter control of aquafaba preparation and staged incorporation. In the selected formula, 45 g aquafaba entered with milk, yogurt, vanilla, and glucose after the fat-coated dry base had formed. A separate 35 g fraction was whipped with cream of tartar and 16 g caster sugar to a glossy stiff peak, then folded into the batter in three additions. This arrangement separated the liquid and aerated uses of aquafaba and reduced the subsequent mixing applied to the whipped fraction.

The batter-building sequence provides a plausible explanation for the observed workability. Reverse creaming distributes fat through the dry ingredients before substantial liquid is introduced (Suas, 2008). Cake-system research further shows that flour-protein composition and batter viscosity influence air retention, oven expansion, and final cake structure (Wilderjans et al., 2008). In the present development sequence, a relatively thick base batter was formed before the whipped aquafaba was folded in. This interpretation is consistent with the observed change from curdled preliminary batter to a stable final process, but flour hydration, gluten development, emulsion stability, batter rheology, and air-cell retention were not measured.

Aquafaba preparation was also part of the workable process. In Trial 1, reverse creaming was used with aquafaba that remained thin and did not hold the target stiff peak. After the cooking liquid was reduced and chilled, the selected aquafaba was semi-thick and held a visible stiff peak for 15 min; Trial 2 then produced a thick, homogeneous batter, although the cake still required refinement. Published studies likewise show that aquafaba functionality varies with legume source, concentration, cooking conditions, and formulation, with consequences for foaming behavior and cake properties (Buhl et al., 2019; He et al., 2021; Shim et al., 2021; Crawford et al., 2024; Konal et al., 2025). These studies provide mechanistic context for the observed process sequence; the present study did not measure the underlying physicochemical mechanisms.

The appraisal data identify structure-related attributes as the lower-rated features of the selected product. In both testing sessions, taste and overall acceptance were rated at or

above 4.00, while volume suitability and texture were among the lower-rated attributes. This pattern is consistent with aquafaba cake studies in which high egg replacement has been associated with lower cake volume or altered firmness (Aslan & Ertaş, 2020; Oh & Yoon, 2021; Arum et al., 2025). The present appraisal did not measure specific volume or instrumental texture, so this comparison is limited to the direction of the published evidence rather than physical equivalence with egg-based cake.

LIMITATIONS

The study has four main constraints. First, each development trial comprised one production batch and no concurrently prepared egg control was included, so batch variability and treatment effects cannot be estimated. Second, instrumental measurements of aquafaba functionality, batter rheology, specific volume, moisture, texture, and color were not collected. Third, the two appraisal groups were tested on different days, and the record does not establish production-batch identity or storage history across sessions. Fourth, participant-protection documentation did not include formal ethics approval, written consent, or food-allergy screening.

The appraisal panel was small and purposively selected; student panelists were not formally trained for descriptive sensory analysis, samples were not blind-coded, and portion mass was not recorded. Future work should use independently replicated batches, a concurrently prepared egg control, standardized blind-coded servings, documented participant-protection procedures, and instrumental measurements targeted to the structural questions raised here.

CONCLUSION

This study developed and documented a kitchen-scale process for an egg-free soybean-aquafaba marble cake using reverse creaming and staged aquafaba incorporation. The selected formula removed 85 g whole egg from the reference formulation and used 80 g soybean aquafaba, with 45 g incorporated in the liquid phase and 35 g whipped separately and folded into the formed batter. The development sequence showed that reverse creaming alone was insufficient; workable batter and cake characteristics emerged as aquafaba preparation, staged incorporation, formulation, baking, and cooling were refined together. Trial 4 retained its shape after cooling and was selected for appraisal. The resulting formulation and process record provides a defined basis for subsequent replication and controlled testing. Demonstrating batch reproducibility, mixing-method superiority, causal mechanisms, or physical equivalence with egg-based marble cake requires a controlled, independently replicated design.

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