

Development of Instant Khanom-Jeen Curry Paste Cube

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ABSTRACT



This research aimed to develop an instant Khanom-Jeen curry paste in a cube form using the foam-mat drying technique to meet the demand for convenience and extend the product's shelf life. The study investigated the optimal conditions for foaming agents and stabilizers, as well as the appropriate amount of glycerin for the cubing process. The results indicated that using 5% carboxymethyl cellulose (CMC) combined with 6% egg white powder was the optimal formulation for producing the curry paste powder, yielding the best physical properties, particularly water absorption and water solubility characteristics. For the cube formation, adding 12% glycerin provided the most suitable ratio. At this level, glycerin acted as

an effective binder, providing structural strength, resistance to breakage, and good rehydration properties in hot water. Furthermore, the product formulated with 12% glycerin received the highest sensory evaluation scores in all attributes, including color, appearance, texture, and overall acceptability. Regarding microbiological quality and safety, the product maintained a water activity (a_w) of less than 0.60 throughout a 3-month storage period at room temperature, which effectively inhibited microbial growth and complied with the Thai Community Product Standard (TCPS 734/2556). These findings demonstrate that this innovation has a high potential for adding value to traditional local foods and can be further developed for commercial production.

Keywords: Foam-mat drying, Instant food, Khanom-Jeen curry, Sensory evaluation, Shelf life

1. Introduction

Khanom-Jeen (rice noodles) is a traditional food product widely popular across all regions of Thailand. It is commonly served with "Nam-Ya" a rich curry soup consisting primarily of fish meat, herbal curry paste, and coconut milk, providing substantial proteins, lipids, and beneficial phytochemicals. However, the high moisture content and water activity ($a_w > 0.85$) of the curry create an environment highly conducive to the proliferation of pathogenic and spoilage microorganisms. Furthermore, the fatty acid profile of coconut milk is highly susceptible to lipid oxidation, leading to rapid rancidity upon exposure to oxygen and light. Consequently, fresh Khanom-Jeen curry paste exhibits a severely limited shelf life, posing a significant logistical barrier to product distribution (Damodaran & Parkin, 2017; Fellows, 2017).

Driven by the fast-paced nature of contemporary lifestyles, consumer behavior has shifted toward selecting food products that offer convenience and time-saving preparation. The transformation of traditional regional foods into instant formats is a crucial strategy for adding value, extending shelf life, and overcoming transportation limitations, thereby fulfilling the demands of the modern food industry market (Thanaratikul & Supaking, 2024).

In the industrial production of instant curries or soups, conventional spray drying often presents operational limitations when applied to feeds with high viscosity, high oil content, or suspended meat particulates, primarily due to nozzle clogging. Meanwhile, freeze-drying, although yielding superior product quality, incurs prohibitively high production costs. Consequently, foam-mat drying has emerged as a highly suitable and cost-effective alternative technology for dehydrating liquid or highly viscous foods, particularly materials containing heat-sensitive flavor compounds and pigments (Kalambe & Guhe, 2026).

The foam-mat drying process relies on whipping the feed mixture into a stable foam using foaming agents, such as egg white protein, which act as surface-active agents to reduce the interfacial tension between the liquid and air. These agents operate synergistically with stabilizers, such as carboxymethyl cellulose (CMC), which function as hydrocolloids to increase the viscosity of the continuous phase. Recent studies demonstrate that optimizing the ratio of CMC and egg albumin prevents air bubble coalescence and structural collapse during drying (Hao et al., 2024), while significantly enhancing the foaming power and physical yield of the resulting powder (Saragi et al., 2026). The resulting highly porous structure increases the specific surface area and reduces internal resistance, facilitating rapid heat and mass transfer. This drastically reduces drying time and temperature, allowing for superior retention of nutrients, color, flavor, and essential phytochemicals compared to conventional hot-air drying (Singkhum & Lapsongphon, 2025). Furthermore, this highly porous matrix provides the final product with excellent solubility and rapid rehydration properties upon contact with water (Franco et al., 2015; Rana et al., 2025; Muthukumaran et al., 2008; Rahu et al., 2021).

Although the curry powder obtained from foam-mat drying exhibits exceptional physicochemical properties, developing it into a compacted "cube" format offers distinct advantages, including packaging convenience, reduced dustiness, and precise portion control (Taiba et al., 2022). Typically, dehydrated food powders possess a low moisture content and exist in a glassy state, rendering them highly brittle and lacking in inter-particle cohesive forces. Therefore, the incorporation of binders and plasticizers, such as glycerin, is imperative. According to the free volume theory, plasticizers permeate the polymer chains of carbohydrates and proteins, disrupting intermolecular hydrogen bonds and lowering the glass transition temperature (T_g) (Roos, 1995). Recent investigations reveal that glycerin effectively reduces these intermolecular forces, imparting essential flexibility to the food matrix and significantly diminishing fracturability (Janowicz et al., 2024). This structural modification mitigates brittleness and improves textural characteristics, enabling the powder particles to bind cohesively, maintain structural integrity, and withstand mechanical impact during transportation (Barbosa-Cánovas et al., 2005; Taiba et al., 2022; Kitsawad & Tuntisripreecha, 2016).

Despite the established advantages of foam-mat drying, previous studies have predominantly limited its application to simple food matrices, such as fruit juices and single-ingredient vegetable purees. The application of this technology to complex, high-fat, and multi-ingredient traditional dishes, particularly coconut milk-based emulsions like Khanom-Jeen curry, remains largely unexplored. Furthermore, the majority of existing foam-mat drying research concludes at the powder production stage. While functional, fine powders often present handling challenges, including dustiness, poor portion control, and high hygroscopicity during storage. Transforming these powders into a compacted cube format offers a practical solution; however, it introduces significant technological hurdles, particularly in balancing the mechanical strength required for transportation with the rapid rehydration properties expected by consumers. Currently, there is a distinct lack of systematic research investigating the synergistic application of foam-mat drying and the subsequent use of plasticizers, such as glycerin,

to modulate the structural integrity and rehydration kinetics of compacted curry cubes. Addressing this research gap is essential for advancing the commercial viability of dehydrated traditional foods.

Therefore, this research aimed to develop an innovative instant Khanom-Jeen curry paste cube. The study systematically investigated the optimal conditions and ratios of foaming agents and stabilizers in the foam-mat drying process and examined the structural effects of plasticizer application during the cube compaction phase. Product quality was comprehensively evaluated through physical, chemical, and microbiological analyses, alongside sensory acceptability and shelf-life assessments. The ultimate goal was to formulate a high-quality, microbiologically safe instant Khanom-Jeen curry product that preserves the authentic sensory profile of the traditional dish, demonstrating robust potential for commercial-scale industrial production.

2. Research method

2.1. Preparation of Standard Khanom-Jeen Curry Paste

In the preparation of the traditional Khanom-Jeen curry paste, Asian seabass (*Lates calcarifer*) was explicitly utilized as the primary protein source. 1,000 mL of water was boiled with a mixture of herbs (lemongrass, shallots, kaffir lime leaves, and garlic). Subsequently, 500 g of fish meat was added and boiled for 20 minutes. The cooked fish meat was separated and processed into fish powder, while the fish broth was filtered and reserved. To prepare the Khanom-Jeen curry, 1,000 g of coconut cream and 100 g of curry paste were heated in a pan. The mixture was then seasoned with fish sauce, coconut sugar, lemongrass, and kaffir lime leaves. After cooking, the mixture was filtered to separate the solid residues from the liquid. The solid residues were dried in an oven at 70°C for 2 hours and subsequently ground into a fine powder. The filtered liquid curry was collected and utilized as the primary material for producing Khanom-Jeen curry powder via the foam-mat drying method in the subsequent step.

2.2. Study on the Concentration of Foaming Agents for Khanom-Jeen Curry Powder Production

The filtered Khanom-Jeen curry liquid was mixed with carboxymethyl cellulose (CMC) at concentrations of 5%, 10%, and 15%, along with egg white powder at 2%, 4%, and 6%, as detailed in Table 1. Maltodextrin was also added to the mixture at a constant concentration of 25%. The mixture was whipped using an electric mixer (E3HM1-100W, Electrolux) at maximum speed for 15 minutes to generate foam.

The foam-mat drying process was conducted in a hot-air oven at 70°C. To ensure structural reproducibility and consistent product quality across different batches, these baseline experiments confirmed that the setup consistently achieved the required dehydration endpoint, ensuring the final product moisture was reliably maintained below 5.0%. This targeted moisture approach provides a more scientifically robust and reproducible criterion for the dehydration process. The dried foam was then ground and sieved to obtain a fine powder. The quality of the powder was evaluated based on the following parameters:

- Physical properties: Color parameters (L^* , a^* , b^*) were measured using a colorimeter (LabScan, HunterLab, Reston, VA, USA), and foam stability was assessed.
- Chemical properties: Moisture content was analyzed according to standard methods (AOAC, 2019).
- Rehydration properties: The Water Absorption Index (WAI) and Water Solubility Index (WSI) (Anderson et al., 1970) were determined.

Table 1. Experimental formulations for the production of Khanom-Jeen curry powder

Formulation	Carboxymethyl Cellulose (CMC) (%)	Egg White Powder (%)
1		2
2	5	4
3		6
4		2
5	10	4
6		6
7		2
8	15	4
9		6

2.3. Formation of Khanom-Jeen Curry Paste Cubes

The optimal Khanom-Jeen curry powder obtained from the previous step was mixed with fish powder and dried herbal curry residue powder. Glycerin was incorporated into the mixture as a plasticizer at concentrations of 9%, 12%, and 15%. To ensure uniformity across all samples, the amount of powder per cube was carefully controlled. The resulting curry cubes were formed into a uniform square shape with dimensions of 5.0×5.0×2.0 cm³ and an average weight of 25.00 g per cube and compressed into cubes using a manual hydraulic pressing device. The resulting cubes were evaluated for color parameters, moisture content, Water Absorption Index (WAI), Water Solubility Index (WSI), and textural properties using Texture analyzer (TA.XT Plus, Stable Micro Systems, UK), with a specific focus on hardness and fracturability.

2.4. Nutritional Evaluation (Proximate Analysis)

The selected optimal Khanom-Jeen curry cube formulation was subjected to proximate analysis to determine its chemical composition, including moisture, crude protein, crude fat, ash, and carbohydrate contents, following standard analytical methods (AOAC, 2019).

2.5. Sensory Evaluation

A consumer acceptance test was conducted with 50 untrained panelists using a 9-point hedonic scale. The panelists evaluated the un-rehydrated Khanom-Jeen curry cubes (visual and physical assessment without tasting). The evaluation was based on four attributes: color, appearance, texture (physical feel/handling), and overall acceptability.

2.6. Shelf-life and Microbiological Quality Studies

The developed Khanom-Jeen curry cubes were packed into prototype packaging and stored at room temperature for 3 months. Samples were randomly taken at 1-month intervals to evaluate physical quality (color), chemical quality (moisture content, water activity (a_w), and microbiological quality (Total Plate Count, and Yeast and Mold), in accordance with the Thai Community Product Standards (TCPS. 734/2556).

2.7. Experimental Design and Statistical Analysis

All experimental treatments were conducted in triplicate ($n = 3$), and the data were expressed as mean $\pm$ standard deviation. A Completely Randomized Design (CRD) was employed for the physical and chemical experiments, while a Randomized Complete Block Design (RCBD) was used for sensory evaluation. The data were subjected to Analysis of Variance (ANOVA), and mean differences were compared using Duncan's Multiple Range Test (DMRT) at a 95% confidence level ($p \leq 0.05$).

3. Results and discussion

3.1. Optimal Concentration of Foaming Agents for Curry Powder Production via Foam-Mat Drying

The experiment, which varied the concentrations of CMC and egg white powder revealed that increasing the amounts of both agents resulted in higher foam stability and viscosity (transitioning from a liquid to a highly viscous state). This characteristic prevented the structural collapse of the foam during heating, which consequently led to an increase in lightness (L^*) and yellowness (b^*) values, while the redness (a^*) value decreased. This is primarily because the highly porous structure enhances light reflectance. Figure 1 illustrates the visual appearance of the Khanom-Jeen curry powder across all 9 formulations. It is evident that higher concentrations of CMC and egg white powder significantly affected the physical attributes of the product. Samples with greater amounts of CMC and egg white powder exhibited a lighter powder color, reflecting the increased L^* value. Concurrently, the red hue of the powder decreased, indicating a lower a^* value, whereas the yellow hue became more prominent, corresponding to the increased b^* value.

These experimental results are consistent with the findings reported by Rahu et al. (2021) and Maciel et al. (2020), who stated that the use of a stabilizer such as CMC in combination with egg white powder increases the viscosity of the mixture. This strengthening of the interfacial film surrounding the air bubbles prevents foam collapse during the drying process, resulting in a product with a highly porous structure. This porous structure directly influences the light reflection properties, causing the lightness (L^*) value to increase. Furthermore, the formation of stable foam increases the specific surface area and reduces the water evaporation time. This rapid drying process effectively preserves the heat-sensitive natural pigments in the Khanom-Jeen curry, allowing the yellowness (b^*) to be better retained compared to other drying methods.

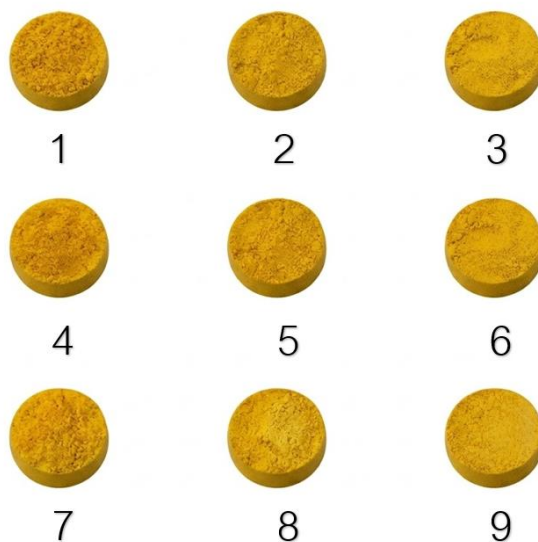


Figure 1. Visual appearance of Khanom-Jeen curry powder formulations.

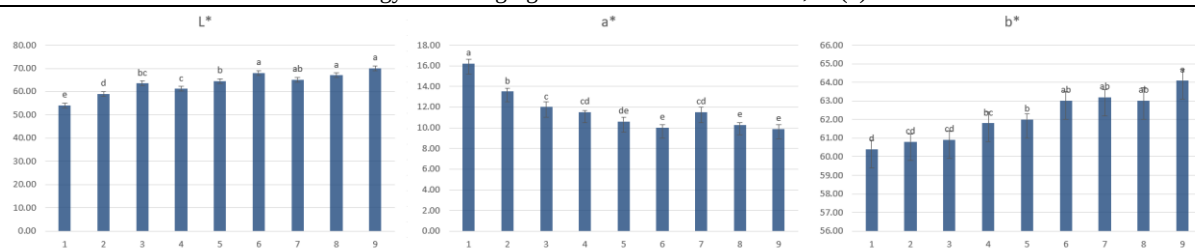


Figure 2. Color parameters (L*, a*, b*) of Khanom-Jeen curry powder across different formulations.

The moisture content of the Khanom-Jeen curry powder exhibited a significant downward trend as the concentrations of carboxymethyl cellulose (CMC) and egg white powder were increased. This phenomenon can be elucidated by the mass transfer mechanisms inherent in the foam-mat drying process. The incorporation of egg white powder as a foaming agent, synergistic with CMC as a stabilizer, modifies the rheological properties of the mixture, leading to the formation of a highly stable foam characterized by uniformly distributed micro-bubbles. This structural modification results in the creation of thin liquid films surrounding the air bubbles, which significantly reduces the internal resistance to moisture movement and increases the specific surface area per unit volume. Consequently, the rate of water evaporation from the interior to the product surface during the constant rate drying period occurs more rapidly and efficiently compared to conventional thin-layer drying (Kalambe & Guhe, 2026).

Furthermore, the generation of a porous and stable foam structure prevents case hardening, a common defect in high-protein or high-sugar food products during hot-air drying. These interconnected pores act as effective channels for vapor diffusion throughout the drying process, allowing the final moisture content to reach target levels within a shorter duration (Rahu et al., 2021). These results reflect that the optimal use of CMC and egg white powder serves not only to preserve the physical appearance and color of the Khanom-Jeen curry but is also a critical factor in enhancing dehydration efficiency. This efficiency is paramount for reducing water activity (a_w), thereby improving the chemical and microbiological stability of the powder product during long-term storage (Shaari et al., 2018).

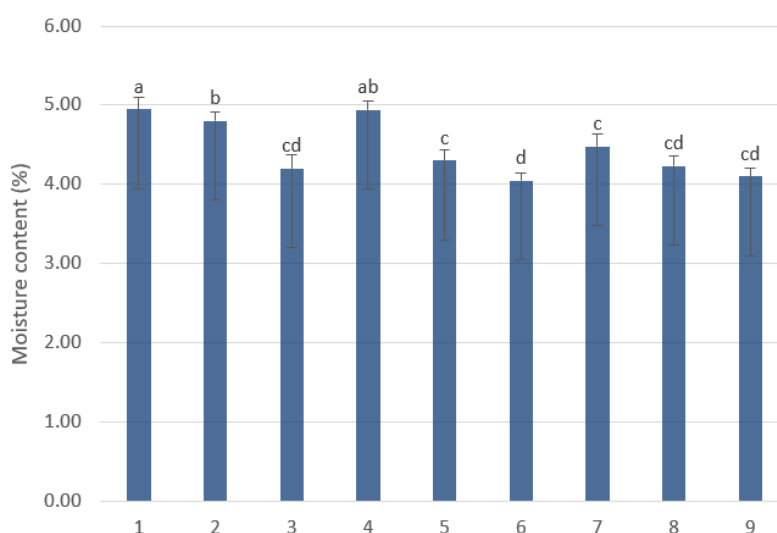


Figure 3. Moisture content of Khanom-Jeen curry powder across different formulations.

The yield percentage of the Khanom-Jeen curry powder exhibited a significant upward trend corresponding to the increased concentrations of carboxymethyl cellulose (CMC) and egg white powder in the formulations. Although the initial quantity of the liquid curry base remained constant across all formulations, the addition of foaming agents and stabilizers, both categorized as total soluble solids, contributed to an increase in the overall solid mass within the system, consequently leading to a higher post-drying yield. Furthermore, the observed reduction in final moisture content is consistent with the findings of Azizpour et al. (2016) and Kalambe & Guhe (2026), who noted that the synergistic effect of foaming agents and stabilizers facilitates the formation of a highly porous structure and significantly expands the specific surface area. This mechanism enhances the drying kinetics, allowing moisture to migrate from the interior to the product surface more rapidly than in conventional drying methods. As a result, the final product achieves low moisture content and a water activity (a_w) level that ensures microbiological stability during storage.

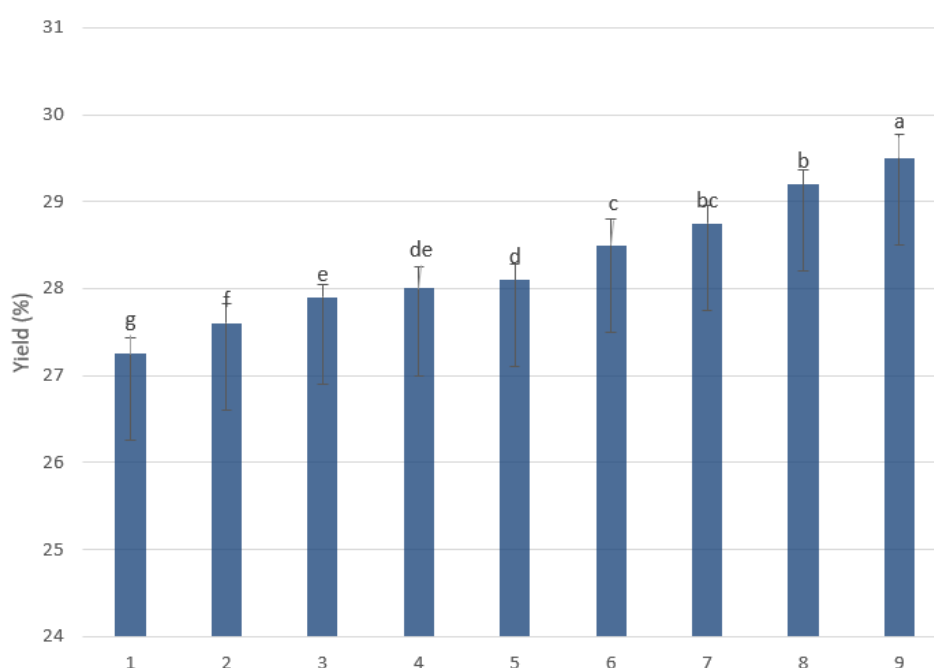


Figure 4. Yield of Khanom-Jeen curry powder across different formulations.

The analysis of the Water Absorption Index (WAI) for Khanom-Jeen curry powder (Figure 5) revealed significant variations across experimental formulations. Notably, higher concentrations of egg white powder led to a declining trend in WAI. This phenomenon can be attributed to thermal protein denaturation during the drying process, where the structural unfolding and subsequent aggregation of protein molecules mask hydrophilic functional groups, thereby reducing the available surface area for water binding. Formulation 3 (5% CMC and 6% egg white powder) yielded the highest WAI, suggesting an optimal balance between protein structure and the stabilizing reinforcement of the CMC network, which preserves structural porosity. This is consistent with Yu et al. (2004), who stated that excessive protein unfolding and aggregation diminish water-binding capacity. The superiority of Formulation 3 may be explained by the synergistic effect of CMC, which provides steric stabilization within the protein network, preventing dense aggregation and maintaining an open porous structure for efficient water uptake.

Conversely, the Water Solubility Index (WSI) exhibited a downward trend with increasing concentrations of CMC and egg white powder. While a porous foam structure typically facilitates rapid disintegration, the quantitative WSI values likely reflect the influence of increased internal viscosity within the food matrix. The combination of CMC and egg white powder forms a robust interfacial film around air bubbles; however, an overly dense film can impede water diffusion into the powder particles. These findings align with the research by Yousefi et al. (2011), who observed that excessive concentrations of thickening agents can hinder water penetration, leading to a significant decrease in solubility indices.

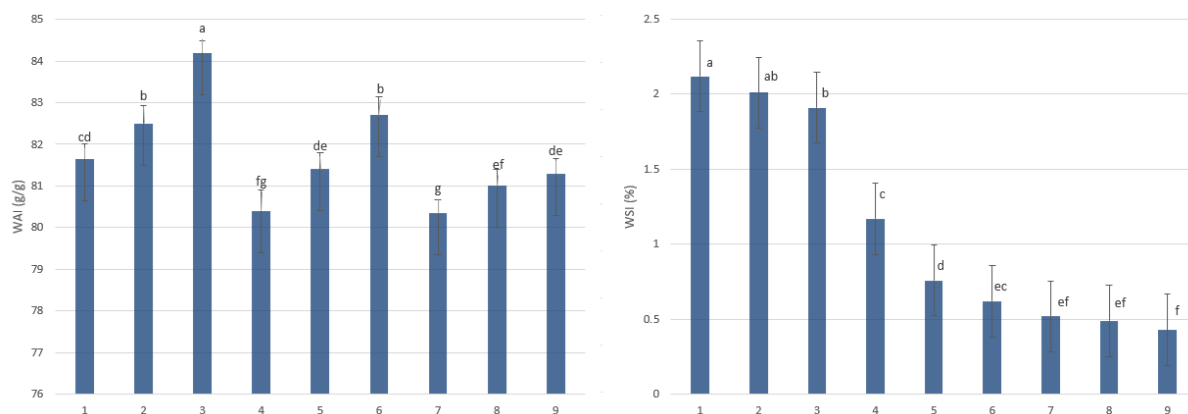


Figure 5. Water absorption index (WAI) and water solubility index (WSI) of Khanom-Jeen curry powder across different formulations.

The evaluation of the physical characteristics of Khanom-Jeen curry foam (Table 2) indicated that increasing the concentrations of carboxymethyl cellulose (CMC) and egg white powder directly and significantly influenced foam viscosity and stability. The foam characteristics evolved according to the concentration levels of the stabilizers, transitioning from a "liquid foam with low viscosity" in Formulation 1 to a "highly viscous and significantly cohesive foam" in Formulation 9. This increase in viscosity is attributed to the hydrocolloidal properties of CMC in creating a structured network within the continuous phase, alongside the role of egg white powder in reinforcing the interfacial film surrounding the air bubbles.

Table 2. Physical characteristics and stability of Khanom-Jeen curry foam across formulations.

Formulation	Physical Characteristics of Foam
1	Liquid foam with low viscosity
2	Liquid foam with increased viscosity compared to Formulation 1
3	Noticeably higher viscosity compared to Formulation 2
4	Viscous foam with increased cohesiveness compared to Formulation 3
5	Increased viscosity and cohesiveness compared to Formulation 4
6	Highly viscous and cohesive compared to Formulation 5
7	Stable, highly viscous, and cohesive foam similar to Formulation 6
8	Increased high viscosity and cohesiveness compared to Formulation 7
9	Maximum level of viscosity and cohesiveness

Based on the experimental results, the Khanom-Jeen curry powder produced with 5% CMC and 6% egg white powder (Formulation 3) demonstrated superior quality in terms of water absorption indices. Consequently, this formulation was selected as the optimal base for further investigation into the cube compaction process, utilizing various concentrations of glycerin as a plasticizer in the subsequent phase of the study.

3.2. Influence of Glycerin Concentration on the Characteristics of Khanom-Jeen Curry Cubes

The incorporation of glycerin at concentrations of 9%, 12%, and 15% significantly influenced the appearance and textural properties of the product. As the glycerin concentration increased, a decrease in lightness (L^*) and yellowness (b^*) values was observed, while the redness (a^*) value increased, resulting in a darker color tone. According to Figure 6, the formulation with 9% glycerin exhibited poor particle cohesiveness, leading to a brittle texture that failed to maintain complete structural integrity. This was likely due to insufficient glycerin to facilitate adequate intermolecular bonding. Conversely, utilizing 15% glycerin resulted in a cube that was excessively soft and suffered from a loss of structural integrity, making it unsuitable for packaging and storage. However, the 12% glycerin formulation yielded the most favorable physical results, producing cubes with optimal density and effective shape retention.

These findings align with Tarique et al. (2021), who noted that glycerin functions as a plasticizer that enhances flexibility and reduces brittleness in low-moisture food structures. A 12% glycerin concentration provided the optimal balance between intermolecular attractive forces and elasticity, allowing powder particles to adhere into a sufficiently strong matrix. Furthermore, the increase in glycerin content occupied internal air voids within the structure, thereby reducing light scattering and decreasing the lightness (L^*) value, a typical physical property of polyols when utilized in intermediate-moisture food products.



Figure 6. Visual appearance of Khanom-Jeen curry cubes with varying concentrations of glycerin.

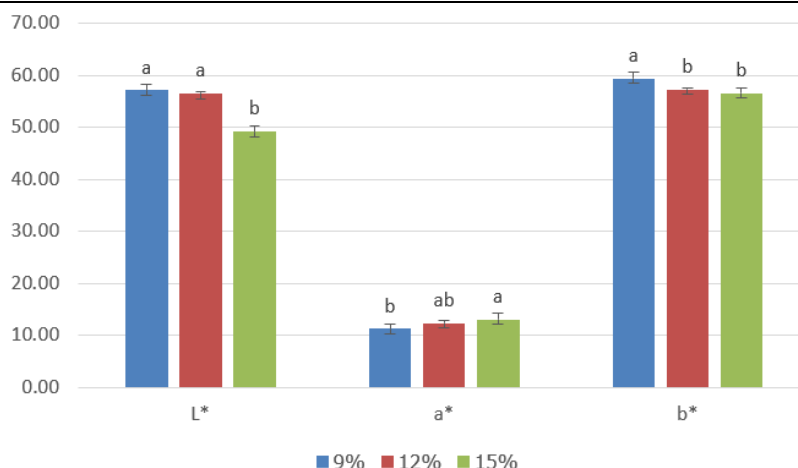


Figure 7. Color parameters (L*, a*, b*) of Khanom-Jeen curry cubes with varying glycerin concentrations.

Analysis of the moisture content in the Khanom-Jeen curry cubes (Figure 8) revealed a positive correlation with the concentration of incorporated glycerin. Specifically, the moisture content increased significantly as the proportion of glycerin rose, particularly at the 12% and 15% levels. This phenomenon is attributable to the chemical properties of glycerin, which functions as a polyol-based humectant. The molecular structure of glycerin contains multiple hydroxyl (-OH) groups that impart high hygroscopicity, allowing it to attract and form robust hydrogen bonds with water molecules, thereby enhancing overall moisture retention within the food matrix (Damodaran & Parkin, 2017).

While an increased moisture content can beneficially improve the perceived freshness and mitigate the excessive hardness of the cubes, the elevated moisture levels in the 15% glycerin formulation led to a marked reduction in deformation resistance. This resulted in an undesirable softening effect and a subsequent loss of shape retention properties (Roos, 1995). Consequently, maintaining a glycerin concentration of 12% was identified as the optimal condition for balancing moisture levels with the preferred textural attributes of the Khanom-Jeen curry cubes, ensuring both structural integrity and suitability for storage and packaging.

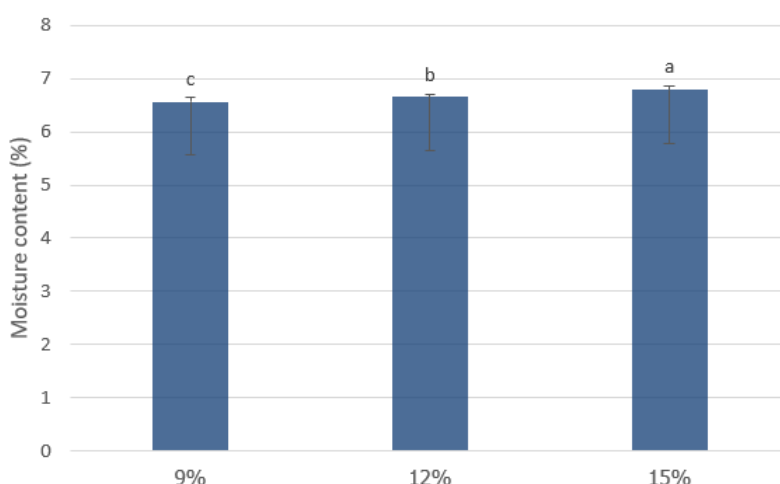


Figure 8. Moisture content of Khanom-Jeen curry cubes with varying glycerin concentrations.

The Water Absorption Index (WAI) of the Khanom-Jeen curry cubes (Figure 9) exhibited a significant positive correlation with increasing glycerin concentrations. This phenomenon can be elucidated by the molecular characteristics of glycerin, which functions dually as a plasticizer and a humectant owing to its highly hydrophilic hydroxyl (-OH) groups (Damodaran & Parkin, 2017). The incorporation of glycerin into the curry powder matrix diminishes the intermolecular forces between the protein and carbohydrate polymer chains, thereby expanding the free volume and enhancing flexibility within the internal food structure (Roos, 1995).

These structural modifications significantly improve the diffusion efficiency of water molecules into the curry cube matrix. Furthermore, glycerin mitigates excessive particle densification during the compaction process. Consequently, during the rehydration phase, the curry cubes are capable of absorbing water more rapidly and effectively, resulting in an absorption capacity that increases proportionally with the glycerin concentration utilized in the formulation (Biliaderis, 1991).

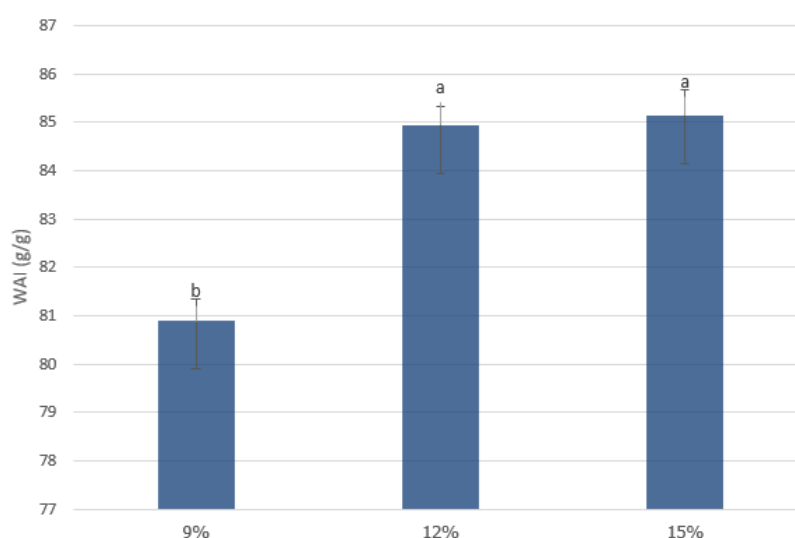


Figure 9. Water Absorption Index (WAI) of Khanom-Jeen curry cubes with varying concentrations of glycerin.

The Water Solubility Index (WSI) of the Khanom-Jeen curry cubes (Figure 10) demonstrated a progressive decline as the glycerin concentration increased from 9% to 15%. This phenomenon can be elucidated by the impact of glycerin on the rheological properties and the structural matrix of the product. As a highly viscous polyol, increased concentrations of glycerin occupy the interstitial spaces between particles and form robust hydrogen bonds with food polymers, thereby creating a denser and more cohesive internal structure (Damodaran & Parkin, 2017).

The elevated viscosity within this matrix functions as a kinetic barrier, impeding the diffusion of water molecules into the core of the cube. Consequently, the aqueous penetration required to disrupt inter-particle bonds becomes significantly more difficult and time-consuming (Roos, 1995). Furthermore, high glycerin concentrations facilitate the formation of a viscous interfacial film surrounding the curry powder particles. This film acts as a physical barrier that restricts the mass transfer rate between the solid phase and the solvent, culminating in a significant decrease in the quantitative solubility of the product compared with formulations containing lower glycerin concentrations (Biliaderis, 1991).

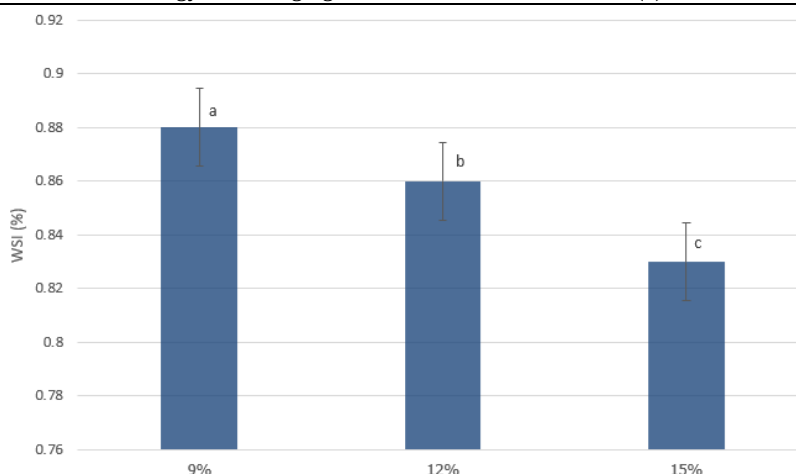


Figure 10. Water Solubility Index (WSI) of Khanom-Jeen curry cubes with varying concentrations of glycerin.m

The moisture content, Water Absorption Index (WAI), and Water Solubility Index (WSI) of the Khanom-Jeen curry cubes were directly correlated with the concentration of glycerin incorporated into the formulations. Experimental data revealed that increasing glycerin from 9% to 15% led to a significant rise in moisture content and WAI, whereas WSI exhibited a downward trend. This phenomenon is attributed to the chemical nature of glycerin, a polyol characterized by multiple hydrophilic hydroxyl (-OH) groups. Functioning as a humectant, glycerin increases the number of available binding sites for hydrogen bonding with water molecules, thereby enhancing the moisture retention capacity and the internal structural volume for water uptake during rehydration (Damodaran & Parkin, 2017).

However, despite the improved WAI, the decrease in solubility (WSI) at higher glycerin levels can be explained by its role as a plasticizer. Glycerin intercalates between the polymer chains of the ingredients, creating a denser food matrix with higher internal viscosity (Roos, 1995). This increased viscosity acts as a physical barrier that impedes the diffusion of water into the cube's core and reduces the release of soluble solids into the external liquid, thereby decelerating the dissolution process (Biliaderis, 1991). Consequently, optimizing the glycerin proportion, specifically at 12%, which received the highest sensory scores, is crucial for balancing textural rehydration and dissolution efficiency.

Regarding the textural properties (Figure 11), the 12% glycerin formulation exhibited the highest values for hardness and fracturability, aligning with its superior sensory scores for texture. This suggests that at 12% concentration, glycerin functions as an efficient binder, facilitating particle adhesion into a robust matrix resistant to breakage. Conversely, increasing glycerin to 15% caused a marked decline in both hardness and fracturability. This softening effect occurs because an excess of plasticizer increases the free volume within the food matrix and diminishes the intermolecular forces between the primary components (Roos, 1995). Consistent with food engineering principles, exceeding the structural carrying capacity for polyols leads to a loss of structural integrity and excessive softening (Damodaran & Parkin, 2017). These physical data reinforce the conclusion that 12% glycerin is the optimal concentration for both product formation and consumer acceptance.

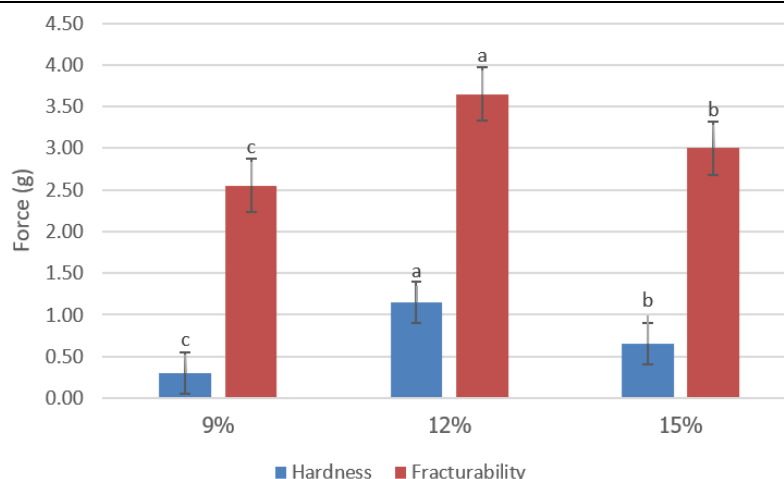


Figure 11. Textural properties of Khanom-Jeen curry cubes with varying concentrations of glycerin.

3.3. Sensory Evaluation

The sensory evaluation of Khanom-Jeen curry cubes, conducted using a 9-point Hedonic scale, indicated that the formulation containing 12% glycerin received the highest acceptance scores across nearly all attributes. Significant differences ($p \leq 0.05$) were observed when compared to the 9% and 15% glycerin treatments, specifically in terms of appearance (7.75), texture (7.85), and overall acceptability (8.05). Conversely, color attributes across all treatments were rated similarly, ranging from 7.10 to 7.35, with no significant differences detected ($p > 0.05$).

The superior consumer preference for the 12% glycerin level can be elucidated by its optimal dual function as a binder and a plasticizer. At this concentration, glycerin effectively facilitates particle adhesion while imparting sufficient structural flexibility, thereby reducing brittleness and preventing premature fracturing during the compaction process. These results align with Damodaran & Parkin (2017), who highlighted the role of polyols in enhancing the textural qualities of intermediate-moisture foods. Consequently, the 12% glycerin formulation is identified as the most suitable for maintaining the desired physical characteristics and consumer appeal for commercial product development.

Table 3. Sensory evaluation scores of Khanom-Jeen curry cubes.

Sensory Attributes	Glycerin content		
	9%	12%	15%
Color	7.10 ± 0.85 ^a	7.35 ± 0.90 ^a	7.20 ± 0.78 ^a
Appearance	6.45 ± 1.10 ^c	7.75 ± 0.95 ^a	7.15 ± 1.02 ^b
Texture	5.85 ± 1.20 ^c	7.85 ± 0.85 ^a	7.10 ± 1.05 ^b
Overall Acceptability	6.15 ± 0.95 ^c	8.05 ± 0.80 ^a	7.20 ± 1.12 ^b

Note: Values are presented as Mean ± SD. Different superscript letters within the same row indicate significant differences ($p \leq 0.05$).

3.4. Nutritional Composition (Proximate Analysis)

The nutritional composition of the optimal Khanom-Jeen curry cube formulation (12% glycerin), selected based on sensory acceptance, textural properties, and rehydration efficiency, is presented in Table 4. The analysis revealed that carbohydrates were the predominant component at 41.20%, followed by fats (27.80%), protein (15.10%), and ash (8.65%), respectively.

The moisture content of the product was recorded at a low level of 7.25%, which is considered optimal for compacted intermediate-moisture food products. This low moisture level is instrumental in

reducing water activity (a_w), thereby inhibiting the growth of spoilage and pathogenic microorganisms. Furthermore, such moisture levels effectively retard chemical degradation reactions, directly contributing to the preservation of product quality and enhancing the shelf-life stability of the curry cubes during storage.

Table 4. Chemical composition of Khanom-Jeen curry cubes.

Chemical Composition	Amount (%)
Moisture	7.25 ± 0.08
Protein	15.10 ± 0.42
Fat	27.80 ± 0.95
Ash	8.65 ± 0.18
Carbohydrate*	41.20 ± 0.08

Note: Values are Mean ± SD from triplicate analysis.

*Carbohydrates calculated by difference.

3.5. Microbiological Quality and Shelf-life Study

The evaluation of microbiological quality and the changes in water activity (a_w) of Khanom-Jeen curry cubes during storage at room temperature for 3 months (Table 5) indicated that the initial a_w was 0.45 and significantly increased ($p \leq 0.05$) to 0.55 by the third month. This increase in a_w is a common phenomenon in low-moisture food products, resulting from moisture sorption from the environment through the packaging material (Mathlouthi, 2001). Nevertheless, the a_w remained below 0.60 throughout the storage period, which is considered the critical limit in the food industry. At a_w levels below 0.60, the available free water is insufficient for the metabolic processes of most microorganisms, thereby effectively inhibiting the growth of pathogenic and spoilage bacteria, as well as most xerophilic molds and osmophilic yeasts (Beuchat, 1981; Damodaran & Parkin, 2017).

Effective control of a_w resulted in high microbiological stability over the storage period. This is consistent with the Total Plate Count (TPC) results, which, despite a slight increasing trend, remained as low as 4.8×10^2 CFU/g by month 3, well below the maximum limit ($< 1.0 \times 10^4$ CFU/g). Furthermore, yeast and mold counts were consistently detected at levels less than 10 CFU/g throughout the study, complying with the Thai Community Product Standard (TCPS No. 734/2556). These findings indicate that the Khanom-Jeen curry cube innovation, integrated with water activity management, is an effective technique for maintaining food safety. The product maintains a shelf-life of at least 3 months at room temperature while upholding acceptable microbiological standards.

Table 5. Water activity (a_w) and microbiological quality of Khanom-Jeen curry cubes during 3 months of storage.

Storage Period (Months)	Water Activity (a_w)	Total Plate Count (TPC) (CFU/g)	Yeast and Mold (CFU/g)
0 (Initial)	0.45 ± 0.02 ^c	$< 1.0 \times 10^2$	Not Detected
1	0.48 ± 0.01 ^b	1.2×10^2	Not Detected
2	0.52 ± 0.03 ^{ab}	2.5×10^2	<10
3	0.55 ± 0.02 ^a	4.8×10^2	<10
Standard Limit*	< 0.60	$< 1.0 \times 10^4$	< 100

Note: Values are Mean ± SD. Different superscript letters within the same column indicate significant differences ($p \leq 0.05$).

* Standard criteria based on Thai Community Product Standard (TCPS No. 734/2556).

4. Conclusion

This study successfully demonstrated the application of foam-mat drying technology to develop an innovative Khanom-Jeen curry cube that preserves traditional culinary characteristics while enhancing consumer convenience. The optimal processing condition was identified as the incorporation of 5% carboxymethyl cellulose (CMC) combined with 6% egg white powder, which yielded a highly stable foam structure and excellent rehydration properties. Regarding cube compaction, a 12% glycerin concentration was found to be the most effective level for its role as a plasticizer and binder, providing structural integrity and resistance to breakage while maintaining flexibility and rapid rehydration. These physical attributes directly correlated with the highest consumer preference scores in sensory evaluation.

Furthermore, the developed curry cubes exhibited superior physical and microbiological stability, maintaining a water activity (*aw*) level below 0.60 throughout a 3-month storage period at room temperature. The product quality consistently complied with the Thai Community Product Standard (TCPS No. 734/2556). The innovations derived from this research not only add significant value to local ethnic foods through modern processing technologies but also establish a viable prototype with high potential for commercialization and implementation within the functional food industry.

Despite these promising results regarding water activity and microbiological safety, a limitation of the current study is the absence of oxidative and sensory stability evaluations during storage. Given the high lipid content derived from coconut milk in the traditional curry matrix, which is highly susceptible to rancidity, future research should comprehensively investigate the chemical stability (e.g., peroxide value or TBARS) alongside sensory profiling of the curry cubes over an extended storage duration. Such additional studies are required for a comprehensive shelf-life determination and to fully validate the product's viability for commercial distribution.

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