Development of halal plant-based cheese using local ingredients for sustainable food innovation

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Abstract. Increasing demand for sustainable, ethical, and halal-compliant food products has encouraged the development of plant-based alternatives that offer lower environmental impact and greater inclusivity. Conventional dairy cheese production is associated with high resource use and significant greenhouse gas emissions, underscoring the need for locally derived, environmentally conscious alternatives. This study aims to develop a halal plant-based cheese using local ingredients, specifically Bogor nut (*Vigna subterranea*), for sustainable food innovation. The methodological framework includes formulation development, processing, halal assurance, and sensory evaluation. Local ingredients were processed using simple techniques to align with green processing principles. Halal assurance was implemented by applying the five criteria of the *Sistem Jaminan Produk Halal* (SJPH), which included commitment and responsibility, material verification, control of the halal product process, conformity of the final product, and continuous monitoring and evaluation. Sensory evaluation focusing on aroma, flavor, appearance, and texture served as the primary performance indicator. The findings indicate that the product achieved satisfactory sensory acceptance while fully complying with halal standards and utilizing environmentally responsible processing methods. This study provides a practical and replicable model for integrating local agro-resources, halal certification, and low-impact processing in the development of sustainable food innovations.

1 Introduction

The global demand for food products that are sustainable, ethical, and inclusive has increased substantially over the past decade. This trend is driven by growing environmental awareness, shifts toward plant-forward diets, and a rising preference for foods that comply with religious and cultural standards, including halal requirements [1].

Within this context, the development of plant-based alternatives has emerged as a promising strategy to reduce the environmental burden of conventional animal-based food

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production. Cheese is a processed animal product obtained from the clumping and fermentation process of milk using lactic acid bacteria [2]. The dairy sector, particularly cheese manufacturing, is known to contribute significantly to greenhouse gas emissions, freshwater consumption, and land use due to its reliance on ruminant livestock [3]. Cheese derived from cow's milk requires substantial inputs of feed, energy, and water and generates a considerable carbon footprint, underscoring the need for low-impact, plant-based alternatives.

Plant-based cheeses have gained increasing attention because they offer inclusivity to consumers with lactose intolerance, dairy allergies, vegan preferences, and religious dietary requirements. However, the majority of plant-based cheese products rely on imported nuts such as almonds or cashews, which raises concerns regarding cost, sustainability, and dependence on global supply chains. Utilizing underexplored local ingredients presents an opportunity to strengthen food resilience while reducing environmental impacts. One such ingredient is the Bogor nut (*Vigna subterranea*), also known as Bambara groundnut, a local drought-tolerant legume widely recognized for its sustainability attributes and nutritional value. Bambara groundnut seed contained 16.53% proteins, 3.04% ash, 7.83% fats and 55.22% carbohydrates in dry basis (db) with 52.71% starch and 7.47% (db) dietary fiber [4], making it a potential raw material for plant-based dairy analogs. Its minimal input requirements and resilience to harsh climates position it as a smart candidate for climate-adaptive sustainable food innovation.

Alongside sustainability considerations, halal assurance plays an essential role in food product development in Muslim-majority countries like Indonesia. Although plant-based products are generally assumed to be halal, critical control points may still arise during formulation, processing, additive selection, sanitation, and equipment usage [1]. Indonesia's halal certification system, particularly the self-declare mechanism for micro and small enterprises under the Halal Product Assurance Law (UU No. 33/2014) and *Badan Penyelenggara Jaminan Produk Halal* (BPJPH No. 22/2023 and No. 944/2024).

Despite the rapid growth of the plant-based food sector, research on halal plant-based cheese produced from local Indonesian ingredients remains limited. Most existing studies focus on imported legumes or commercial raw materials, while exploration of Indonesian agro-resources for plant-based dairy analogs is still underdeveloped. Furthermore, there is a lack of integrated studies that combine formulation development, sustainable processing, sensory evaluation, and halal certification. Therefore, this study aims to develop a halal plant-based analog spread cheese using Bogor nut as a locally sourced ingredient. The research integrates environmentally conscious processing techniques, halal assurance, and sensory performance assessment to create a replicable model for sustainable food innovation. By leveraging an underutilized local crop and incorporating halal certification procedures, this work contributes to Indonesia's strategic goals in food sovereignty, green processing, and halal industry development.

2 Materials and methods

2.1 Materials

Bogor nut (*Vigna subterranea*) was selected as the primary raw material due to its high protein content, functional properties, and suitability for sustainable food processing. The nuts were sourced from a local agricultural cooperative in West Java, Indonesia. Additional ingredients included coconut milk, tapioca starch, nutritional yeast, refined salt, lemon extract, xanthan gum, cheese flavor, vanili, tapioca starch, and salt. All supporting ingredients were selected based on their availability, safety, and compatibility with plant-based cheese

formulation. Only ingredients bearing an official halal logo were used in this study. Ingredients whose origins were ambiguous or of potential animal-derived concern were excluded.

2.2 Formulation development

Plant-based cheese formulations were developed through iterative trials focusing on achieving desirable texture, meltability, and flavor. The formulation accounted for ratios of Bogor nut milk, oil phase, hydrocolloids, and starch, referencing approaches used in plant-based cheese research [5]. Hydrocolloids (tapioca starch and plant-based gelling agents) were incorporated to improve firmness and cohesiveness. The mixture was homogenized manually or using a bench-top mixer to ensure even dispersion of components. The formulation was heated to activate starch gelatinization and to facilitate emulsification of water and oil phases.

2.3 Processing development

The processing development was designed to emphasize minimal equipment use, energy efficiency, and low-waste practices in line with green food processing principles. After homogenization, the mixture was heated to 70–85 °C under continuous stirring. Continuous agitation was applied to ensure proper dispersion of all components and to support the formation of a stable matrix. During the heating process, coconut milk was gradually added. After the heating and emulsification stages, the hot mixture was poured into stainless-steel molds. The molded samples were then allowed to cool at room temperature until they became firm, enabling structural setting through starch gelatinization and hydrocolloid network formation. Subsequently, the samples were subjected to a chilling process by refrigeration at 4 °C for at least 12 hours. This step was applied to allow further stabilization of the product structure prior to evaluation and analysis.

2.4 Animal DNA test

An animal DNA test was conducted at an accredited external laboratory to further ensure the absence of animal-derived components in the formulation. The analysis was performed using the WI.T.04.01-005 method based on qualitative Polymerase Chain Reaction (qPCR). This method is widely recognized for its high sensitivity and specificity in detecting trace amounts of animal DNA.

2.5 Halal assurance procedures

The halal assurance procedure in this study was conducted in accordance with the five core criteria of the *Sistem Jaminan Produk Halal* (SJPH). These criteria were applied to ensure that halal principles were integrated throughout the development process, including commitment and responsibility, material verification, control of the halal product process, compliance of the final product, and continuous monitoring and evaluation. This approach provided a systematic framework to maintain halal integrity during formulation and processing.

2.6 Sensory evaluation

Sensory analysis was conducted to evaluate consumer acceptance of the Bogor nut plant-based cheese. A total of 30 panelists participated in the evaluation with sensory attributes

such as appearance (color, uniformity), aroma (nutty notes, cheese-like aroma), flavor (overall liking, aftertaste), texture (firmness, meltability, mouthfeel), and overall. A 9-point hedonic scale was used (9: Like extremely, 8: Like very much, 7: Like moderately, 6: Like slightly, 5: Neither like nor dislike, 4: Dislike slightly, 3: Dislike moderately, 2: Dislike very much, and 1: Dislike extremely). Samples were served at refrigerated temperature (4–8°C), coded with random three-digit numbers, and presented in randomized order to minimize bias.

3 Result and discussion

3.1 Formulation

The developed plant-based spreadable cheese utilized a formulation comprising water, Bogor nut, coconut milk, tapioca starch, salt, nutritional yeast, lemon juice, xanthan gum, cheese flavoring, and vanilli. Each ingredient played a functional role in achieving the desired sensory and structural properties. Bogor nut served as the primary protein source, contributing to the body and taste of the product. Protein contribute to structure formation by creating a protein network that provides firmness and meltability, primarily through water and fat retention [5]. Coconut milk provided additional fat content, enhancing spreadability and contributing to a richer mouthfeel. This use of coconut milk is consistent with previous findings showing that plant-derived fats can effectively replace dairy fat in cheese analogs, improving lubrication and flavor delivery.

Nutritional yeast acted as a natural flavor enhancer due to its umami-rich compounds, which are widely recognized for imparting cheese-like notes in vegan cheese formulations. Lemon juice contributed mild acidity, balancing flavor and aiding in protein–starch interaction during heating. Tapioca starch functioned as the main thickener, providing elasticity and cohesiveness upon gelatinization at elevated temperatures. The inclusion of xanthan gum improved viscosity stability, preventing phase separation during processing and storage, an effect well documented in hydrocolloid-based cheese analog systems [5].

Prior to formulation, an animal DNA analysis was carried out to verify that all materials and processing conditions were completely free from animal-derived components, ensuring that the developed product was genuinely plant-based. The test was performed using a sensitive and specific molecular detection method, which is capable of identifying trace amounts of animal DNA that may originate from raw materials, additives, processing aids, or cross-contamination during handling. The results showed that no animal DNA was detected in the samples, indicating the absence of any animal-origin substances in the formulation. This finding confirms that all ingredients used were of plant or permissible non-animal origin and that the processing environment was properly controlled to prevent contamination.

Table 1. Composition of bogor nut-based analog spread cheese.

Ingredients	Formulation (%)
Water	60-70
Bogor (Bambara Ground) Nut	20-30
Coconut milk	3-5
Tapioca starch	2-3
Nutritional yeast	1-2
Refined Salt	1-2
Lemon Extract	0.5-1
Xanthan gum	0.05-0.1
Cheese Flavor	0.05-0.1
Vanili	0.01-0.05

The formulation ranges presented in Table 1 were designed to provide flexibility in adjusting the physicochemical and sensory characteristics of the spreadable cheese analog. The high proportion of water (60–70%) functioned as the main dispersion medium, ensuring a soft and spreadable consistency, while the Bogor nut content (20–30%) determined the protein matrix and overall body of the product. Variations in coconut milk (3–5%) allowed modulation of fat content, which influenced creaminess and mouthfeel. Tapioca starch (2–3%) acted as the primary structuring agent through gelatinization, contributing to firmness and cohesiveness, whereas xanthan gum (0.05–0.1%) enhanced viscosity and stability of the emulsion system. Nutritional yeast (1–2%) and cheese flavor (0.05–0.1%) were optimized to deliver a cheese-like sensory profile, while refined salt (1–2%) provided basic seasoning and flavor balance. Lemon extract (0.5–1%) was included to adjust acidity and improve flavor freshness, as well as to support protein–starch interactions during heating. Finally, vanilla (0.01–0.05%) was added in a minimal amount to soften the overall aroma profile and mask undesirable beany notes from the Bogor nut. Together, these formulation ranges allowed systematic control of texture, flavor, and stability while maintaining the functional characteristics required for a spreadable plant-based cheese.

3.2 Processing

The processing of Bogor nut spreadable cheese analog followed a sequence of stages beginning with the preliminary treatment of the Bogor nuts. Two treatments were evaluated (Figure 1): processing the nuts with their skins intact and processing them after skin removal. This comparison was conducted because the seed coat of legumes is known to influence texture, color, and processability due to its high content of fiber, tannins, and phenolic compounds [6, 7].

Fig. 1. Spreadable analog cheese made from nuts with (left) and without skin (right)

When the nuts were processed with their skins, the mixture required longer homogenization. The seed coat contributed additional insoluble fiber, causing slight graininess even after extended blending. The resulting slurry also showed a darker cream color, reflecting the presence of natural pigments such as anthocyanins and tannins typically

found in Bambara groundnut seed coats [7]. In contrast, processing Bogor nuts without the skin produced a smoother texture with substantially reduced blending time. Removal of the seed coat decreased the fiber load and eliminated most coarse particles, resulting in a lighter-colored, more homogeneous slurry. This outcome is consistent with literature on plant-based milk and cheese analogs, which shows that dehulling improves smoothness and increases consumer acceptance by reducing beany or astringent notes [8, 9]. The milder base flavor also allowed nutritional yeast and cheese flavoring to integrate more effectively, producing a cleaner cheese-like profile.

Both versions underwent hydration and blanching at 70–90 °C for 3–5 minutes. Blanching reduced the raw legume flavor, enhanced protein solubility, and softened the cotyledons for efficient homogenization. After hydration, all ingredients included coconut milk, tapioca starch, salt, nutritional yeast, lemon juice, xanthan gum, cheese flavoring, and vanilla were blended until fully homogenized. The homogenization step was more efficient with skinless nuts due to lower fiber interference. Achieving a uniform dispersion is critical for plant-based cheeses because stable emulsification of fats and proteins determines textural quality [5]. Coconut milk lipids, when properly emulsified, form a smooth fat network similar to dairy cheese, while tapioca starch gelatinization contributes to elasticity and body [5]

The mixture then underwent thermal gelation at 80–90 °C, during which several key transformations occurred. Tapioca starch granules gelatinized and swelled, creating a cohesive gel matrix, while xanthan gum increased viscosity and prevented syneresis. These thermo-functional properties are well documented in starch–hydrocolloid systems used in cheese analog formulations [5, 10]. The heating process also improved fat integration and contributed to the mild acidity–umami balance produced by lemon juice and nutritional yeast. Heating within this temperature range is commonly applied in vegan cheese processing to enhance structural stability while preventing over-thickening.

Finally, the mixture was packaged while hot and allowed to cool at room temperature before refrigeration. Cooling facilitated gel network stabilization, resulting in a smooth and spreadable cheese analog. The skinless formulation produced the most desirable texture and color, whereas the formulation processed with skin resulted in a slightly darker, thicker spread with subtle rustic notes. Both outcomes reflect how fiber content, pigment compounds, and emulsion dynamics directly influence the final sensory attributes—a relationship widely recognized in plant-based dairy research [11, 12].

Fig. 2. Spreadable analog cheese prepared from mature nuts (left) and immature nuts (right)

After selecting the formulation prepared without the outer skin as the preferred treatment, the effect of raw material maturity was further evaluated using Bogor nuts at two different stages, namely mature and immature nuts. As shown in Figure 2, the left sample represents the formulation made from mature nuts, while the right sample represents that made from immature nuts. The formulation made from mature Bogor nuts exhibited a smoother texture,

a lighter and more uniform color, and a more cohesive structure. This is likely due to the higher starch and protein contents in mature legumes, which support better gelatinization, emulsification, and network formation during heating. In contrast, the formulation using immature nuts tended to have higher moisture content and lower structural components, resulting in a softer but less stable and slightly grainier texture. Moreover, the immature nuts contributed a noticeable raw or "green" nut flavor, which reduced overall sensory acceptance. These results indicate that the maturity level of Bogor nuts significantly influences both the functional and sensory properties of the plant-based cheese analog, with mature nuts being more suitable for producing a stable, creamy, and organoleptically acceptable spread.

3.3 Halal product assurance system

The halal assurance procedure implemented in the development of the Bogor nut plant-based cheese followed the five core criteria of the *Sistem Jaminan Produk Halal* (SJPH), ensuring that the product aligned with halal. The first criterion, commitment and responsibility, was reflected in the research team's explicit intention to design a vegan and halal-friendly product. This commitment guided the selection of raw materials, evaluation of suppliers, equipment use, and the overall processing design. Responsibility for halal oversight was assigned within the research team, who acted as the internal body responsible for identifying potential halal risks, controlling critical points, and ensuring that every decision was aligned with halal integrity.

The second criterion, materials (Table 2), was addressed through a comprehensive verification of each ingredient used in the formulation. All inputs, including Bogor nuts, coconut milk, tapioca starch, nutritional yeast, xanthan gum, cheese flavor, vanilla essence, lemon extract, and water, were screened based on their botanical origin, manufacturer declaration, the presence or absence of animal-derived components, and the potential use of high-risk processing aids [13]. Ingredients with unclear or unverifiable halal status were excluded to ensure that only permissible and halal-safe materials were used. This approach aligns with documented best practices for halal ingredient selection, which emphasize source transparency and the avoidance of syubhat (doubtful) materials [14]. Cleaning agents and sanitation chemicals were also reviewed to confirm the absence of animal-derived surfactants, as certain detergents and lubricants may contain tallow or other non-halal components. This step is consistent with findings in halal logistics literature, which highlight sanitation inputs as a common but often overlooked source of contamination risk [14, 15].

The third criterion, halal product process, was operationalized by identifying and controlling potential halal-critical points during production. The evaluation included reviewing equipment to ensure it had no history of contact with non-halal substances, verifying that sanitation agents did not contain animal-derived surfactants, and ensuring that storage, preparation, and handling practices were free from cross-contamination risks [1]. The process was designed to maintain halal integrity from the initial preparation of Bogor nuts through heating, homogenization, gelation, and packaging. These precautions align with halal supply chain frameworks that emphasize contamination prevention at every stage of production.

The fourth criterion, product, was addressed by ensuring that the final plant-based cheese met halal requirements not only based on ingredients and processing but also in terms of sensory acceptability and physical characteristics. Because the formulation was entirely plant-based and free from non-halal critical inputs, the final product inherently met halal standards. In addition, documentation of materials and processes allows the product to be traceable and verifiable should halal certification be pursued in the future.

The fifth and final criterion, monitoring and evaluation, was reflected in the systematic recording and review of ingredient information, halal status verification, processing

activities, and identification of critical points. Throughout the research, the team continuously monitored compliance with halal requirements, ensuring that no deviations occurred during formulation or processing. Evaluation was also applied through documentation matrices similar to those used in halal self-declare procedures, enabling traceability and serving as evidence of compliance.

Incorporating these five SJPH criteria ensured that the plant-based cheese prototype was developed with robust halal assurance measures. This approach aligns with contemporary halal science literature, which emphasizes that proactive halal integration during product development strengthens product integrity, reduces risks, and enhances consumer trust. This integration ensures that the product is inherently halal-friendly and minimizes future barriers should certification be pursued.

Table 2. Ingredients used in Bogor nut-based spread analog cheese.

No	Ingredient Name & Brand	Ingredient Type	Manufacturer	Halal Certificate Issuing Body	Halal Certificate Number
1.	Water	Raw material	PDAM	-	Positive List
2.	Bogor Nut (Bambara Ground Nut)	Raw material	Local Farmers	-	Positive List
3.	Coconut milk *Sasa*	Raw material	Sasa Inti	BPJPH	ID00410000 202960321
4.	Tapioca starch *Gunung Agung*	Raw material	PT. Budi Starch & Sweetener, Tbk	BPJPH	ID00410000 088710720
5.	Nutritional Yeast *Club Sehat*	Food Additive	PT. Misi Sehat Alami	BPJPH	ID00310000 081811020
6.	Refined Salt *Dolpin*	Food Additive	PT. Susanti Megah	BPJPH	ID35310000 119890621
7.	Lemon Extract *Nutrifarm*	Food Additive	PT Nutrifarm Prima Indonesia	BPJPH	ID36110022 138220525
8.	Xanthan gum *Ziboxan F200*	Food Additive	Deosen Biochemical (Ordos) Ltd.	BPJPH	ID00410000 237970222
9.	Cheese Flavor *Toffieco*	Food Additive	Pilarose	BPJPH	ID36310000 131140321
10.	Vanilla Flavor *Koepoe Koepoe*	Food Additive	Gunacipta Multirasa	BPJPH	ID00410000 230801221
11.	Dishwashing liquid *Sunlight*	Cleaning Agent	PT. Unilever Indonesia Tbk	BPJPH	ID00410000 008400120
12.	Jar Bottle	Packaging	Traditional Market	-	Positive List

3.4 Sensory evaluation

The sensory evaluation of the Bogor nut (without skin) spreadable cheese analog was carried out using a 9-point hedonic scale with 30 panelists with. The results demonstrated a generally positive level of acceptance, with differences across the evaluated attributes such as color, aroma, flavor, texture, and overall liking reflecting the strengths and potential areas for refinement in the product formulation.

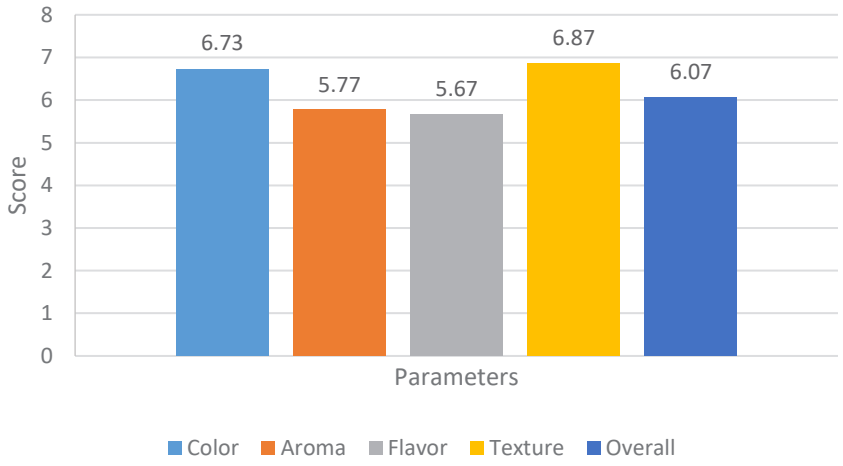

Fig. 3. The sensory evaluation of Bogor-nut based spread analog cheese

Color received a mean score of 6.73, placing it within the "moderately like" category. Panelists perceived the product's color as appealing and consistent with expectations for a plant-based cheese spread. The light cream appearance, resulting from the use of peeled Bogor nuts, coconut milk, and nutritional yeast, likely contributed to this positive perception. Similar findings have been reported in plant-based cheese studies, where lighter and more uniform coloration is generally associated with higher visual acceptability [11, 12]. The minimal browning effect also indicates that thermal processing at 80–90°C did not induce significant pigment degradation or Maillard reactions.

Aroma obtained an average score of 5.77, indicating that panelists "slightly liked" the aromatic profile. While acceptable, the score suggests that some legume-related volatiles commonly associated with beany notes may still have been detectable. This phenomenon is well-documented in pulse-based dairy analogs, where aldehydes, ketones, and lipoxygenase-related oxidation products contribute to characteristic legume aromas [9]. The addition of nutritional yeast and cheese flavoring likely improved aroma acceptability, but further flavor masking or fermentation-based enhancement may be required to elevate aromatic quality.

Flavor was rated similarly to aroma, with a mean score of 5.67, also falling within the "slightly like" category. Panelists described the flavor as mildly cheese-like, balanced by acidity from lemon juice and umami from nutritional yeast. However, the intensity of cheese flavor remained modest. Literature shows that achieving strong cheese notes in vegan cheese analogs is challenging due to limitations in non-dairy precursors that provide depth of flavor, especially without fermentation [11]. Enhancing natural umami components or incorporating controlled fermentation could help strengthen flavor complexity in future product iterations.

Texture was the highest-rated sensory attribute, with a score of 6.87, corresponding to "moderately like." This indicates that the product achieved the soft, creamy, and spreadable characteristics desired in cheese spreads. The textural performance was likely driven by the combination of tapioca starch, known for producing elastic and cohesive gels, and xanthan gum, which stabilizes viscosity and prevents syneresis. These findings align with previous research demonstrating that starch–hydrocolloid systems play a central role in textural optimization of plant-based cheese analogs [5]. Coconut milk fat further contributed to smooth mouthfeel and spreadability.

The overall liking score of 6.07 suggests that panelists generally liked the product. Texture and color were the strongest contributors to overall acceptance, consistent with consumer studies showing that visual appeal and mouthfeel heavily influence acceptance of

plant-based dairy substitutes [11, 12]. Conversely, aroma and flavor, though acceptable, were relatively lower and represent primary targets for improvement. Strategies such as flavor precursor fermentation, enzymatic modification, or the addition of natural cheese volatiles may enhance consumer liking in future formulations.

Overall, the sensory evaluation demonstrates that the Bogor nut–based cheese analog has strong potential as a vegan, lactose-free, and locally sourced dairy alternative. The product's textural and color attributes were well-received, while aroma and flavor provide pathways for further optimization. These findings are consistent with trends in plant-based cheese research, which emphasize the difficulty of flavor replication but highlight the feasibility of achieving desirable texture and appearance through starch-hydrocolloid technology.

4 Conclusion

This research demonstrates a replicable model for integrating local agro-resources, sustainable processing, and halal assurance into plant-based food innovation. The developed product provides an inclusive alternative for vegan, lactose-intolerant, and Muslim consumers, while also supporting Indonesia's efforts to diversify local food sources and reduce dependence on environmentally intensive dairy production. To further enhance its commercial potential, future studies should focus on flavor optimization, nutritional profiling, shelf-life evaluation, and pilot-scale production to strengthen product quality, stability, and market readiness.

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