Cassava Peel Starch–Hibiscus rosa-sinensis Leaf Extract: A Plant-Based Alternative Composite for Soft Capsule Shells

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Abstract

Capsule dosage forms are widely used in pharmaceuticals, with soft capsules offering advantages for liquid and semi-solid formulations. However, conventional gelatin-based shells raise sustainability and halal compliance concerns, prompting the search for plant-based alternatives. This study investigates the development of environmentally friendly soft capsule shells using cassava peel starch, hibiscus leaf gel extract, carrageenan, and glycerin. Hibiscus gel extract was obtained via maceration with 70% ethanol for five days, yielding 40.8%, which meets the Indonesian Herbal Pharmacopoeia standard. Four formulations with varying ratios of starch, gel extract, carrageenan, and glycerin were prepared and tested for disintegration in distilled water and 0.1 N HCl. Results showed that the 1:1:1 formulation with 25% glycerin exhibited the most favorable performance, with disintegration times of 15 minutes in water and 17 minutes, 25 seconds in acidic medium, aligning with pharmacopeial requirements. These findings highlight cassava peel starch and hibiscus gel extract as promising raw materials for sustainable, halal-compliant soft capsule shells, offering an effective alternative to gelatin.

Keywords: soft capsule shell, cassava peel starch, hibiscus leaf gel extract

INTRODUCTION

Capsule dosage forms are widely utilized in pharmaceutical preparations due to their ability to mask unpleasant drug tastes and preserve the stability of active pharmaceutical ingredients. Two major types of capsule shells dominate the industry are comprised of hard capsules and soft capsules (Mohitkar et al., 2023; Thejaswini et al., 2025). Hard capsules are typically composed of gelatin and water, sometimes with minor additives, and are primarily used for dry, powdered, or pelletized formulations (Garg et al., 2023). Their advantages include ease of manufacture, versatility in filling, and suitability for solid dosage forms; however, they are less effective for liquid or oily substances (Garg et al., 2023; Mohitkar et al., 2023; Thejaswini et al., 2025).

In contrast, soft capsules are designed to encapsulate liquids, suspensions, or semi-solid formulations (Praveenkumar et al., 2024). They are conventionally prepared from gelatin, sugar, and water, with the addition of plasticizers such as glycerin, sorbitol, or other polyhydric alcohols to impart flexibility and mechanical strength (Naharros-molinero, 2025; Praveenkumar et al., 2024). Soft capsules offer improved bioavailability for certain drugs and provide a hermetically sealed shell that enhances stability (Naharros-molinero, 2025; Naharros-molinero et al., 2024; Palomero-Hernández et al., 2025; Praveenkumar et al., 2024). Nevertheless, reliance on animal-derived gelatin raises concerns regarding sustainability, halal compliance, and consumer acceptance, thereby driving research into plant-based and renewable alternatives.

Data shows that the global gelatin market is projected to reach USD 5.0 billion by 2025, driven by rising consumption across food, pharmaceutical, and cosmetic sectors. Continued demand growth is expected to push the market further to USD 6.7 billion by 2027, reflecting a compound annual growth rate (CAGR) of approximately 9.29% (Rather et al., 2022). Commercial gelatin production is predominantly sourced from porcine materials, with pig skin and cartilage contributing approximately 46% of global supply (Muhammad Yazid Razali et al., 2022; Rather et al., 2022). Bovine skin and bones account for around 29.4%, while other sources which including marine and poultry by-products represent only about 1.5% of total production (Muhammad Yazid Razali et al., 2022). Porcine gelatin is favored for its lower cost and superior functional properties, but its use is restricted by religious acceptability, ethical considerations, and safety issues (Muhammad Yazid Razali et al., 2022; Rather et al., 2022). Gelatin from fish and poultry offers potential alternatives. However, their limited production capacity restricts widespread application. Consequently, the development of non-animal substitutes, especially those derived from plant-based materials such as starch, has become increasingly important.

Starch, one of the most abundant carbohydrates in plants, is composed primarily of amylose and amylopectin, has been used as the gelatin substitutes (Crescentiana Dewi Poeloengasih et al., 2023; Khan et al., 2021; Muhammad Yazid Razali et al., 2022; Perwatasari et al., 2025; Torrejon et al., 2023; Vinicius et al., 2022). To enhance the mechanical strength and stability of soft starch capsules, starch is often blended with supplementary gelling agents such as gelatin, carrageenan, agar, alginates, carboxymethyl cellulose (CMC), or polyvinyl alcohol (PVA) (Palomero-Hernández et al., 2025). Different starches have been used in the formulation of soft capsule. Modified starch including cassava, potato, and sago were utilized as fillers on the formulation of iota carrageenan-based soft capsule shells (Perwatasari et al., 2025). Sago starch in combination with carrageenan have been investigated its ability in the capsule shells production (Perwatasari et al., 2025). Meanwhile the application of maize, waxy maize, potato, and cassava on the preparation of soft-capsule was reported (Young et al., 2020). Among the various available starch sources, cassava peel which containing approximately contains 44-59% (dry basis) of starch along with protein, crude fiber, pectin, fat, and calcium (Maharsih et al., 2021), emerges as a promising candidate due to its high starch content and underutilized potential. This dual advantage not only highlights its potential as a functional raw material but also positions cassava peel as a sustainable option for value-added product development.

In addition to starch, the formulation of soft capsules requires the incorporation of gelling agents to enhance film strength, elasticity, and overall structural integrity. Commonly employed agents include gelatin, carrageenan, agar, alginates, carboxymethyl cellulose (CMC), and polyvinyl alcohol (PVA), each contributing specific functional properties that improve the mechanical performance and stability of starch-based capsule shells (Kizza et al., 2026). Mucilage, a natural polysaccharide-rich hydrocolloid found in various plant tissues, has attracted growing interest as a functional gelling agent in capsule formulation (Caballero et al., 2019; Jadhav et al., 2025; Salim et al., 2024; Yahaya & Anuar, 2023). Mucilage of hibiscus leaf (Hibiscus rosa-sinensis L.) can serve as a natural gelling agent as the comparative analysis has demonstrated that Hibiscus rosa-sinensis mucilage provides a unique combination of high swelling index, high gelling capacity, and stable matrix formation and differentiation from other natural polymers (Jadhav et al., 2025; Kizza et al., 2026; Salim et al., 2024; Yahaya & Anuar, 2023).

Previous studies have highlighted that hard capsule shells derived from cassava starch combined with hibiscus leaf gel exhibit favorable physical properties (Mardina et al., 2022). Notably, increasing the starch concentration enhances viscosity, thickness, and shell hardness. These findings underscore the importance of advancing plant-based capsule shell development as an environmentally sustainable and halal alternative to conventional gelatin-based materials. Building on this foundation, the present study seeks to formulate soft capsule shells using cassava peel starch and hibiscus leaf gel extract, with the dual objectives of determining the optimal formulation ratio and assessing their potential as a viable, eco-friendly capsule shell material.

MATERIAL AND METHODS

Material and Equipment

The equipment employed in this study comprised an electric grinder, furnace, porcelain crucible, funnel, desiccator, measuring cylinder, analytical balance, beaker, Erlenmeyer flask, electric stove, magnetic stirrer, filter paper, filter cloth, 1.5-L glass jar, rotary evaporator, water bath, disintegration tester, aluminum foil, and oven.

The materials utilized included cassava peel starch, hibiscus leaves, glycerol ($C_3H_8O_3$), filter paper, 70% ethanol, distilled water, and carrageenan.

Experimental Procedure

Cassava peel starch was prepared as the primary material, followed by the extraction of hibiscus leaf gel. To obtain the gel, hibiscus leaves were first dried under direct sunlight for several days until fully dehydrated, then ground into powder and sieved through a 100-mesh filter to produce simplisia powder. The extraction process employed maceration, in which 200 g of hibiscus leaf powder was soaked in 1000 mL of 70% ethanol for five days with periodic stirring to maximize solvent penetration and extraction efficiency. After maceration, the mixture was filtered through cloth and filter paper, and the resulting filtrate was concentrated using a rotary evaporator to yield a viscous extract. Finally, the concentrate was heated in a water bath to remove residual ethanol, thereby stabilizing the hibiscus gel extract as the final product. The gel extract yield (% w/w) was calculated using the formula of Equation 1.

$$\text{Yield (\%)} = (\text{weight of concentrated extract (g)} / \text{weight of simplisia (g)}) \times 100\% \quad (1)$$

The experiments were then followed by the preparation of 4 formula with variations in the composition ratio of cassava peel starch, hibiscus gel extract, carrageenan, and glycerin:

(i) Formula I (1:2:1, 15%)
(ii) Formula II (1:2:1, 20%)

(iii) Formula III (1:1:1, 25%)
(iv) Formula IV (1:1:1, 30%)

The formulation process involved mixing cassava peel starch, hibiscus gel extract, and carrageenan. This mixture was dissolved in 200 mL of distilled water, after which glycerin was added according to the specified ratio in a beaker. The solution was heated on a hot plate equipped with a magnetic stirrer at 70 °C and stirred at 250 rpm until a homogeneous, viscous consistency was achieved. The resulting thickened solution was then cast into petri dishes and dried in an oven at 60 °C for 3–4 hours to produce soft capsule shell films. Subsequent analyses included characterization of the disintegration time of the capsule shells in both water and acidic media.

RESULT AND DISCUSSION

Hibiscus Leaf Extract Yield

The extraction yield of hibiscus leaves varied considerably depending on the solvent type, extraction duration, and leaf condition. In this study, maceration using 70% ethanol for five days produced a yield of 40.8% (Table 1), which meets the minimum requirement of the Indonesian Herbal Pharmacopoeia (≥10%). This result demonstrates that extended maceration time can enhance extraction efficiency by allowing prolonged solvent–plant material interaction.

Interestingly, it was reported that a significantly higher yields when using ethanol for one day: 84.69% with wet leaves and 73.64% with dried leaves (Gerda Pintoko Tunjungsari, Muhamad Aditya Hidayah, Alfandi Ahmad, 2022). These values suggest that leaf moisture content plays a critical role in extraction outcomes, as wet leaves may facilitate faster solvent penetration and compound release. Conversely, methanol-based maceration yielded lower values (48.91% for wet leaves; 58.62% for dried leaves), indicating that ethanol may be a more effective solvent for hibiscus leaf extraction under similar conditions (Gerda Pintoko Tunjungsari, Muhamad Aditya Hidayah, Alfandi Ahmad, 2022).

Table 1. Yield of the extraction of Hibiscus leaves

No	Extraction methods	Yield	References
1	Maceration; 70% of ethanol; t= 5 days	40.8%	This work
2	Maceration; ethanol, t = 1 day; wet leaves	84.69%	(Gerda Pintoko Tunjungsari, Muhamad Aditya Hidayah, Alfandi Ahmad, 2022)
3	Maceration; ethanol, t = 1 day; dried leaves	73.64%	(Gerda Pintoko Tunjungsari, Muhamad Aditya Hidayah, Alfandi Ahmad, 2022)
4	Maceration; methanol, t = 1 day; wet	48.91%	(Gerda Pintoko

	leaves		Tunjungsari, Muhamad Aditya Hidayah, Alfandi Ahmad, 2022)
5	Maceration; methanol, t = 1 day; dried leaves	58.62%	(Gerda Pintoko Tunjungsari, Muhamad Aditya Hidayah, Alfandi Ahmad, 2022)
6	UAE; methanol; 60 minutes	17%	(Fazlina et al., 2021)
7	UAE; ethanol; 60 minutes	7.4%	(Fazlina et al., 2021)
8	UAE; ethyl acetate; 60 minutes	3%	(Fazlina et al., 2021)
9	UAE; acetone; 60 minutes	3.2%	(Fazlina et al., 2021)

In contrast, ultrasonic-assisted extraction (UAE) produced much lower yields, ranging from 3% to 17% depending on the solvent used (Fazlina et al., 2021). While UAE is generally considered efficient for rapid extraction, the short duration (60 minutes) and solvent choice appear to limit yield compared to maceration. Ethanol under UAE conditions resulted in only 7.4%, far below the maceration outcomes (Fazlina et al., 2021). Overall, the findings highlight that extraction yields are strongly influenced by solvent type, leaf condition, and extraction duration. Ethanol maceration, particularly with extended time, consistently provides higher yields than UAE or methanol-based methods. This suggests that traditional maceration remains a reliable approach for obtaining hibiscus gel extract, especially when yield optimization is a priority.

Disintegration Test of Soft Capsule Shells

The hibiscus leaf extract obtained was subsequently incorporated into the formulation of soft capsules, which were then analyzed for their dissolution characteristics. Dissolution, or solubility, is a fundamental parameter in capsule evaluation as it directly affects drug release, absorption, and therapeutic efficacy. A capsule must remain stable long enough to be swallowed but disintegrate promptly once it reaches the gastrointestinal tract (M Soraya et al., 2023; Soraya et al., 2024, 2025).

Table 2. Disintegration Time of Soft Capsule Shells in Water and Acidic Media

Soft capsule formula	Disintegration Time (Water)	Disintegration Time (Acidic Medium)	
Cassava peel starch, hibiscus gel extract, carrageenan, and glycerin (1:2:1, 15%)	45 minutes	30 minutes	This work
Cassava peel starch, hibiscus gel extract, carrageenan, and glycerin (1:2:1, 20%)	42 minutes	35 minutes,10 s	This work
Cassava peel starch, hibiscus	15 minutes	17 minutes, 25s	This work

gel extract, carrageenan, and glycerin (1:1:1, 25%)			
Cassava peel starch, hibiscus gel extract, carrageenan, and glycerin (1:1:1, 30%)	35 minutes	41 minutes, 10s	This work
NaCMC, K-carrageenan, Tween 80, Aquadest		47 minutes, 02s	(Soraya et al., 2025)
CCS, K-carrageenan, Tween 80, Aquadest		40 minutes, 45s	(Soraya et al., 2025)
Promogel, K-carrageenan, Tween 80, Aquadest		36 minutes, 21s	(Soraya et al., 2025) (Soraya et al., 2025)
PVP, K-carrageenan, Tween 80, Aquadest		48 minutes, 26s	

In this study, dissolution testing was conducted using two media: distilled water (aquades) and 0.1 N HCl. Testing in water serves to evaluate capsule stability during swallowing by confirming its resistance under aqueous conditions. In contrast, testing in acidic media simulates gastric conditions, ensuring that the capsule shell disintegrates efficiently to allow drug absorption and metabolism. Regulatory guidelines, including those outlined in the Farmakope, recommend a maximum disintegration time of 15 minutes to ensure optimal drug release and therapeutic effectiveness (M Soraya et al., 2023; Soraya et al., 2024). The disintegration time of soft capsule shells formulated from cassava peel starch, hibiscus leaf gel extract, carrageenan, and glycerin was evaluated in both water and acidic media using a disintegration tester. The results of these tests are presented in Table 2.

The disintegration time of soft capsule shells varied depending on the formulation ratio and glycerin concentration. Formulations with higher starch-to-gel ratios and moderate glycerin levels generally exhibited longer disintegration times. For example, the 1:2:1 formulation with 15% glycerin disintegrated in 45 minutes in water and 30 minutes in acidic medium, while increasing glycerin to 20% slightly reduced the disintegration time in water (42 minutes) but extended it in acidic medium (35 minutes, 10 seconds) (Table 2).

In contrast, the 1:1:1 formulation with 25% glycerin showed the most favorable performance, with disintegration times of 15 minutes in water and 17 minutes, 25 seconds in acidic medium, aligning closely with pharmacopeial standards that recommend a maximum of 15 minutes for optimal drug absorption. However, further increasing glycerin to 30% resulted in prolonged disintegration (35 minutes in water; 41 minutes, 10 seconds in acidic medium), suggesting that excessive plasticizer content may hinder capsule breakdown. Although it was mentioned that the concentration og gelatin can be up to 40% (Patel et al., 2025).

Comparisons with formulations reported on the literature that highlight that conventional capsule shell bases such as NaCMC, CCS, Promogel, and PVP combined with carrageenan and Tween 80 exhibited disintegration times ranging from 36 to 48 minutes in acidic medium, which are longer than the optimized cassava–hibiscus formulation (Soraya et al., 2025). This indicates that plant-based capsule shells incorporating cassava peel starch and hibiscus gel extract can achieve faster disintegration, thereby offering improved bioavailability while maintaining environmental and halal compliance.

Overall, the findings demonstrate that formulation ratio and glycerin concentration are critical factors influencing capsule disintegration, with the 1:1:1 ratio at 25% glycerin emerging as the most promising candidate for sustainable soft capsule development.

CONCLUSION

This study demonstrates the potential of cassava peel starch and hibiscus leaf gel extract as environmentally friendly and halal-compliant materials for soft capsule shell formulation. The extraction process yielded hibiscus gel extract at 40.8%, confirming the efficiency of extended maceration. Among the tested formulations, the 1:1:1 ratio with 25% glycerin achieved optimal disintegration times in both water and acidic media, meeting pharmacopeial standards for capsule performance. Comparisons with conventional capsule shell bases further emphasize the superior disintegration properties of the cassava–hibiscus formulation. Overall, the results establish cassava peel starch and hibiscus gel extract as viable plant-based alternatives to gelatin, supporting sustainable pharmaceutical innovation and expanding opportunities for eco-friendly capsule production.

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