SALACCA-TAN: Bioactive Gel Formulation Based on Snake Fruit Seed Waste (Salacca zalacca) as an Environmentally Friendly Dual-Function Antioxidant and Protease Inhibitor Agent

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The increase in tropical fruit waste in Indonesia poses a challenge to sustainable resource management. One potential waste product is salak seeds (Salacca zalacca), which are rich in antioxidant compounds. This study aims to utilise salak seed extract as an active ingredient in environmentally friendly antioxidant gels based on sodium carboxymethyl cellulose (Na-CMC). The extract was obtained through maceration in 70% ethanol and formulated into three variants: a control gel without extract, and gels with 5 mL and 8 mL of extract. The formulation tests included pH, homogeneity, spreadability, organoleptic properties, and apple browning test. The results showed a pH of 5.5-5.8 (in accordance with skin pH), homogeneous texture, and light brown colour with a distinctive salak seed aroma that was liked by the panelists. Spreadability increased from 2.5 cm (control) to 2.8 cm (5 mL) and 3.0 cm (8 mL). The gel with 8 mL extract was also most effective in inhibiting enzymatic browning in apples, indicating high antioxidant activity. With good physical stability and antioxidant efficacy, salak seed extract gel has the potential to be developed as a natural cosmetic product and green biotherapeutic innovation based on local waste.
Keywords: Salacca zalacca, bioactivity, gel antioxidant, agricultural waste, green biotechnology

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1. Introduction

The utilization of salak seed waste as a bioactive wound-healing gel, SALACCA-TAN, has a strong scientific basis as it aligns with two main focuses of modern research: the utilization of natural antioxidant compounds from *Salacca zalacca* and the control of oxidative stress and matrix metalloproteinase (MMP) activity in chronic wounds. Various studies show that salak seeds contain important bioactive compounds such as phenols, flavonoids, and tannins that act as natural antioxidants. A study by Werdyani et al. reported that the ethanol extract of salak seeds has antioxidant activity through the DPPH method with the best IC_{50} value of around 110.16 µg/mL, indicating the ability to scavenge free radicals in the moderate to strong category (Werdyani et al., 2017). Furthermore, a comprehensive review of snake fruit also explains that salak has nutraceutical and therapeutic potential due to its antioxidant, antidiabetic, anticancer, and anti-inflammatory activities (Yadav et al., 2025).

Not only the seeds, but other parts of the salak fruit also show high bioactive potential. Research by Șuică-Bunghez et al. found that salak flesh and peel contain flavonoids, tannins, polyphenols, and monoterpenoids with significant antioxidant activity (Șuică-Bunghez et al., 2016). Recent research on Bali salak peel even shows high antioxidant capacity in protecting the brain tissue of mice from oxidative stress due to alloxan induction, thus strengthening the potential of salak as a source of protective compounds against cell

damage (Padmiswari et al., 2025). Another finding from Rifani et al. also shows that salak seed extract has a high enough flavonoid and tannin content to be utilized as a green corrosion inhibitor, demonstrating the stability and biological activity of the active compounds within it (Rifani et al., 2025).

This antioxidant potential is highly relevant to the wound healing mechanism. In the healing process, reactive oxygen species (ROS) are actually needed to kill microbes and support angiogenesis. However, excessive levels of ROS can cause oxidative stress, damage collagen, prolong the inflammatory phase, and inhibit the transition to the proliferative phase, causing the wound to become chronic (Dunnill et al., 2017; Wang et al., 2022). Hunt et al. (2024) explained that ROS have a dual role in wound healing: as cellular signaling mediators and as factors causing tissue damage if uncontrolled. Therefore, modern wound treatment strategies are heavily focused on controlling ROS using natural antioxidants. Ukaegbu et al. (2025) mentioned that antioxidant compounds such as vitamin E, curcumin, resveratrol, and plant polyphenols are able to accelerate wound healing by reducing oxidative damage and increasing cellular recovery. Ramzan et al. (2025) also emphasized that ROS balance is an important factor in determining the success of the tissue regeneration process in chronic wounds.

In addition to ROS, another factor that greatly influences chronic wounds is the hyperactivity of matrix metalloproteinases (MMPs). These enzymes function to regulate the degradation and formation of the extracellular matrix during the wound healing process. However, when MMP activity is excessive, collagen and new tissue actually experience damage, making the wound difficult to close (Caley et al., 2015). Kandhwal et al. (2022) explained that MMPs play an important role in angiogenesis, tissue remodeling, and re-epithelialization, but an imbalance in their activity can worsen chronic wound conditions. In diabetic ulcers, increased MMPs are known to correlate with slow wound healing and have become a target of modern therapy (Chen et al., 2023). Trojanek (2023) also asserted that inhibiting MMP activity in chronic wounds can help restore tissue healing capabilities. Interestingly, various natural products based on flavonoids, tannins, and polyphenols are reported to be able to modulate MMP pathways, thus potentially accelerating wound tissue regeneration (Chen et al., 2023).

In recent years, hydrogels and biomaterials based on plant extracts have developed into innovative strategies in wound therapy because they are able to deliver bioactive compounds directly and maintain wound moisture. Sherbeni and Nair (2023) reported that various plant extracts and natural compounds show high effectiveness in accelerating wound closure, increasing collagen synthesis, and decreasing inflammation when formulated in the form of polymer-based dressings. Yazarlu et al. (2021) also explained that herbal medicines have multifunctional healing mechanisms, including antioxidant, antibacterial, anti-inflammatory activities, and stimulation of fibroblast proliferation. Research by Mercy et al. (2024) showed that nanohydrogels containing plant extracts and nanosilver are able to accelerate tissue regeneration and increase the release of active compounds in wounds. In addition, Wang et al. (2024) successfully developed 3D-printed hydrogels loaded with *Centella asiatica* extract that effectively accelerate wound healing by regulating the immune response and adapting to the shape of chronic wounds. A recent study by Yang et al. (2025) also confirmed that bioactive herbal extract-based dressings can improve tissue regeneration through modulation of molecular pathways and increased local antioxidant activity in the wound area.

Based on the synthesis of these various studies, the concept of SALACCA-TAN as a bioactive gel made from salak seed waste has a very strong scientific rationale. The polyphenol, flavonoid, and tannin content in salak seeds has the potential to function as natural antioxidants to control ROS while modulating excessive MMP activity in chronic wounds. Formulation in the form of a gel or hydrogel allows for the delivery of active compounds in a more stable and effective manner directly to the wound area. Thus, the utilization of salak seed waste not only supports environmentally friendly and zero-waste biomaterial

innovation but also has the potential to produce local natural-based chronic wound therapies that are safer, more economical, and sustainable.

2. Literature Review

Agricultural waste is one of the environmental problems that continues to increase alongside the growth of agricultural production and agro-industrial activities. This waste generally consists of crop residues, fruit peels, seeds, and other unused organic materials. If not properly managed, agricultural waste is often openly dumped or burned, leading to soil and water pollution, eutrophication, greenhouse gas emissions, and the growth of pathogenic microorganisms. Therefore, a waste management approach based on reuse and value-added products is highly important to support sustainable development and the circular economy. Indonesia, as one of the largest producers of snake fruit in Southeast Asia, generates a significant amount of snake fruit seed waste from processing industries such as candied fruit, syrup, and chips production (Harahap & Sitorus, 2023). Despite being considered waste with little economic value, snake fruit seeds possess strong potential as a source of natural bioactive compounds for health and biotechnology applications.

Studies have shown that the ethanol extract of snake fruit seeds contains various secondary metabolites, including tannins, quinones, monoterpenes, sesquiterpenes, alkaloids, and polyphenols, which exhibit antioxidant properties (Werdyani et al., 2017). In addition, snake fruit also contains flavonoids, flavonols, anthocyanins, polyphenols, and β-carotene that function as natural antioxidants (Rejeki et al., 2024). Antioxidants play a critical role in neutralizing free radicals and reducing Reactive Oxygen Species (ROS), which are excessively produced during prolonged inflammation in wounds. Wound healing itself is a complex biological process consisting of hemostasis, inflammation, proliferation, and remodeling phases. Excessive ROS accumulation can trigger oxidative stress, inhibit fibroblast activity and collagen synthesis, and delay the transition to the proliferative phase, ultimately causing chronic wounds (Shi et al., 2023; Dong & Wang, 2023). Therefore, antioxidant-based wound therapies are considered highly important to enhance tissue regeneration and accelerate wound closure (Comino-Sanz et al., 2021).

Besides oxidative stress, chronic wound formation is also associated with excessive activity of proteolytic enzymes, particularly matrix metalloproteinases (MMPs). Under normal conditions, MMPs function in extracellular matrix remodeling; however, uncontrolled MMP activity in chronic wounds leads to excessive tissue degradation, impaired collagen integrity, and inhibition of re-epithelialization (McCarty & Percival, 2013). This condition causes wounds to remain in the inflammatory phase and delays complete healing. Consequently, protease inhibition has emerged as a promising therapeutic strategy for maintaining extracellular matrix stability and supporting tissue repair. Recent studies suggest that combining antioxidant agents with protease inhibitors provides a more effective multi-target therapy because it simultaneously reduces oxidative stress and controls excessive proteolytic activity (Comino-Sanz et al., 2021). Therefore, natural materials such as snake fruit seed waste, which potentially possess both antioxidant and protease inhibitor activities, offer promising opportunities for the development of innovative and environmentally friendly biomedical products.

3. Method

This research is a laboratory experimental study utilizing a quantitative and descriptive approach, aimed at testing the antioxidant activity and protease inhibition of the SALACCA-TAN bioactive gel formulated from snake fruit (*Salacca zalacca*) seed waste. This design follows commonly used antioxidant testing procedures in phytochemical studies (Puspitasari & Ningsih, 2016) and protease enzyme activity testing

procedures based on plant bioactive studies (Chandra et al., 2025). This study is a Research and Development (R&D) project aimed at developing an innovative product named SALACCA-TAN—an eco-friendly bioactive gel based on snake fruit seed extract with dual activity as an antioxidant and protease inhibitor.

The development model used is a modification of Borg and Gall, simplified into six stages:

1. Identification of potential and problems
2. Data collection
3. Product design
4. Product manufacturing
5. Product testing
6. Result evaluation

This R&D approach is suitable for producing new biotherapeutic products based on natural bioactive compounds (Hosseinkhani et al., 2017). The experimental design used during the product testing phase is a Completely Randomized Design (CRD) with a single treatment factor: variations in the concentration of snake fruit seed extract (0 mL, 5 mL, and 8 mL). These variations serve as controls to test their impact on pH parameters, organoleptic properties, browning levels (apple browning), spreadability, and homogeneity. This approach is frequently employed in food and pharmaceutical product development research to assess the effects of formulation variations on physical and organoleptic quality (Vhangani & Van Wyk, 2023).

The research process begins with the collection of snake fruit seeds from student food waste. The seeds are cleaned and dried at a low temperature to preserve the antioxidant content, then ground into powder. A total of 60 grams of snake fruit seed powder is macerated using 70% ethanol for 48 hours to obtain the active extract. Subsequently, the extract is formulated into a gel using Na-CMC, glycerin, and propylene glycol with three extract concentration variations: 0 mL, 5 mL, and 8 mL.

Product Testing

The resulting product is then tested using several parameters:

1. Product pH Test pH measurement is conducted using a pH meter calibrated with standard buffer solutions of pH 4 and pH 7. Five grams of gel are dissolved in 25 mL of distilled water; the pH meter electrode is then immersed in the solution until a stable result is obtained. The ideal pH value for topical preparations ranges from 4.5–6.5 to prevent skin irritation (Naibaho et al., n.d.).
2. Organoleptic Test This involves a panel of 10 judges to assess color, aroma, texture, and overall preference attributes. This study uses a scale of poor, fair, good, and very good.
3. Apple Browning Test This test is conducted to determine the product's ability to inhibit enzymatic browning reactions. Apple slices are soaked in the sample solution, and color changes are observed over a specific period. A lower browning level indicates higher antioxidant activity in the product.
4. Homogeneity Test The homogeneity test is performed by placing approximately 1 gram of the gel preparation between two glass plates and observing it under light. The preparation is declared homogeneous if it appears uniform and no coarse particles or lumps are visible on the gel surface (Saraung et al., 2018).
5. Spreadability Test 0.3 grams of snake fruit seed extract gel is placed on a transparent glass, then covered with another glass and left for one minute. A spreadability of 2.5–3.5 cm indicates that the gel has an ideal semi-solid consistency and is comfortable to use (Saraung et al., 2018).

4. Results and Discussion

The research results indicate that the SALACCA-TAN bioactive gel possesses good physical quality and high antioxidant activity. In the pH test, all gel formulations yielded values between 5.4–5.8, which are consistent with the skin's physiological pH, making it safe for use without causing irritation. Organoleptic test results showed that the gel has a yellowish-brown color with a natural aroma characteristic of snake fruit seeds and a soft texture that is easily spread on the skin surface. Respondent assessments also indicated a good to very good level of acceptance, particularly for formulations containing the extract.

In the apple browning test, the gel containing snake fruit seed extract was able to slow down the browning process compared to the control, demonstrating antioxidant activity in inhibiting the action of the polyphenol oxidase (PPO) enzyme. Furthermore, homogeneity test results showed that all gel preparations were evenly mixed without the presence of coarse particles or lumps. The spreadability test also revealed that as the extract concentration increased, the spreadability of the gel also increased, from 2.5 cm in the control to 3.0 cm in the 8 mL formulation; however, the gel texture remained stable and comfortable for use as a semi-solid preparation.

Table 1. Results of Physical Tests and Antioxidant Activity of SALACCA-TAN Gel

Parameter	0 ml	5 ml	8 ml	Description
pH	5,7	5,8	5,4	Skin safety
Color	Good	Very good	Good	Brownish-yellow
Odor	Good	Good	Good	Distinctive Salak Seed Aroma
Texture	Good	Very good	Very good	Soft and spreads easily
Apple Browning Test	Low	Moderate	High	Increased Antioxidant Activity
Homogenity	Homogeneous	Homogeneous	Homogeneous	No coarse particles
Spreadability	2,5 cm	2,8 cm	3,0 cm	Spreads more easily

The results of the study indicate that snake fruit seed waste (*Salacca zalacca*) can be utilized to create SALACCA-TAN bioactive gel with favorable physical characteristics, characterized by a homogeneous texture, a natural light brown color, and no pungent odor. This demonstrates that the extraction and gel formulation processes were optimal and have the potential to be developed as an eco-friendly product based on natural materials (Chandra et al., 2025).

The antioxidant activity of the SALACCA-TAN gel is related to the content of phenolic compounds, flavonoids, and tannins, which act as electron donors to neutralize free radicals, thereby inhibiting oxidative stress. This finding is consistent with research reporting significant antioxidant activity in the extract of the fruit, skin, and seeds of the snake fruit using the DPPH method (Puspitasari & Ningsih, 2016; Rejeki et al., 2024). Additionally, SALACCA-TAN gel also shows potential as a protease inhibitor, which is thought to stem from the interaction of polyphenol and tannin compounds with protease enzymes, thus reducing their activity. The combination of antioxidant activity and protease inhibition indicates that SALACCA-TAN has a dual-action mechanism that provides protection against cell damage.

Utilizing snake fruit seeds as a raw material for bioactive gel also supports the principles of zero waste and sustainability, as organic waste that was previously underutilized can be processed into a value-added product (Puryono & Rahayenda, 2015).

5. Conclusion

Based on the results of the research and testing conducted, it can be concluded that snake fruit seed extract (*Salacca zalacca*) has the potential to be developed as an active ingredient in eco-friendly bioactive gel preparations. The formulated SALACCA-TAN gel demonstrates favorable physical characteristics, including a pH level that aligns with the skin's physiological pH, uniform homogeneity, spreadability that meets semi-solid preparation standards, and organoleptic properties that are well-accepted by panelists. Furthermore, the results of the apple browning test indicate that the gel enriched with snake fruit seed extract is capable of inhibiting the enzymatic browning process, signifying potent antioxidant activity. A higher concentration of snake fruit seed extract correlates with enhanced antioxidant capacity. Consequently, SALACCA-TAN represents a promising innovation in bioactive gels derived from agricultural waste, which not only holds economic value but also possesses significant potential for further development as a skincare product and supportive therapy for wound healing based on green biotechnology principles.

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