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Sustainable valorization of pineapple peel into nata de pina through physicochemical and economic evaluation

Pemanfaatan bernilai tambah kulit nanas menjadi nata de pina melalui evaluasi fisikokimia dan ekonomi

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ABSTRACT

Pineapple peel is an abundant agro-industrial residue with considerable potential for conversion into value-added products within a sustainable waste management framework. This study investigated the production of nata de pina from pineapple peel and evaluated its physicochemical characteristics and economic performance. Pineapple peel extract was inoculated with *Acetobacter xylinum* and fermented for 14–15 days under controlled laboratory conditions. The resulting nata contained 95.06% moisture, 0.05% ash, 1.56% fat, 0.47% protein, 0.56% crude fiber, and 8.91 mg/100 g reducing sugars. Most physicochemical parameters complied with Indonesian National Standards (SNI); however, the moisture content exceeded the maximum allowable limit (80%), indicating the need for improved post-fermentation handling to enhance product stability, safety, and shelf life. Economic evaluation per production cycle revealed an added value of Rp265,600 with a value-added ratio of 98.37%, while total production costs of Rp390,500 generated a profit of Rp267,000 per cycle. These results demonstrate that pineapple peel is a technically feasible and economically efficient substrate for nata production, supporting its potential application in sustainable, community-based agro-industrial development.

ABSTRAK

Kulit nanas merupakan limbah agroindustri yang melimpah dan memiliki potensi besar untuk dikonversi menjadi produk bernilai tambah dalam kerangka pengelolaan limbah yang berkelanjutan. Penelitian ini mengkaji produksi nata de pina dari kulit nanas serta mengevaluasi karakteristik fisikokimia dan kinerja ekonominya. Ekstrak kulit nanas diinokulasikan dengan *Acetobacter xylinum* dan difermentasi selama 14–15 hari dalam kondisi laboratorium yang terkendali. Nata yang dihasilkan memiliki kadar air sebesar 95,06%, abu 0,05%, lemak 1,56%, protein 0,47%, serat kasar 0,56%, dan gula pereduksi 8,91 mg/100 g. Sebagian besar parameter fisikokimia telah memenuhi Standar Nasional Indonesia (SNI); namun kadar air melebihi batas maksimum yang diperkenankan (80%), sehingga menunjukkan perlunya perbaikan penanganan pascafermentasi untuk meningkatkan stabilitas produk, keamanan, dan umur simpan. Evaluasi ekonomi per siklus produksi menunjukkan nilai tambah sebesar Rp265.600 dengan rasio nilai tambah 98,37%, sementara total biaya produksi sebesar Rp390.500 menghasilkan keuntungan Rp267.000 per siklus. Hasil penelitian ini menunjukkan bahwa kulit nanas merupakan substrat yang layak secara teknis dan efisien secara ekonomi untuk produksi nata, serta berpotensi mendukung pengembangan agroindustri berbasis masyarakat yang berkelanjutan.

INTRODUCTION

Innovation in agricultural waste management plays a critical role in improving sustainability, efficiency, and productivity within the agricultural sector. Inadequate handling of agricultural residues, including by-products from crop processing, contributes significantly to environmental degradation and inefficient resource utilization (Mindarta et al., 2023).

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Consequently, transforming agricultural waste into value-added products has emerged as a strategic approach to simultaneously reduce environmental burdens and enhance farmers' economic welfare (Sukaria et al., 2024).

Among various agricultural wastes, pineapple peel represents a biomass resource with substantial utilization potential. Despite its abundance, pineapple peel is often underutilized, leading to increased organic waste accumulation. It contains carbohydrates, fiber, and bioactive compounds that make it suitable as a substrate for microbial fermentation, particularly for the production of nata de pina (Syauqi & Inasari, 2020). Nata de pina is a gel-like fermented product produced by acetic acid bacteria, characterized by a chewy texture and a distinctive sweet–sour flavor (Ayuningtyas et al., 2024). However, previous studies have predominantly focused on pineapple flesh or juice, while the utilization of pineapple peel through fermentation remains relatively underexplored.

In major pineapple production centers such as Kediri, East Java, where honey pineapple cultivation and small- and medium-scale processing industries are prominent, large volumes of pineapple peel are generated annually (Lisanty et al., 2024). This condition highlights the urgent need for sustainable waste management strategies that not only mitigate environmental impacts but also promote product diversification and community-based agro-industrial development.

Economic feasibility is a critical component of sustainable product innovation. Value-added analysis provides important insights into cost structures, profit distribution, and overall supply chain efficiency (Papilo et al., 2020). Unequal profit distribution among supply chain actors may hinder modernization efforts and threaten long-term industry sustainability (Yusmiati et al., 2023). Nevertheless, studies that integrate fermentation performance, physicochemical characteristics, and economic evaluation—particularly using the Hayami value-added framework—for nata de pina produced specifically from pineapple peel are still limited.

Therefore, this study aims to produce nata de pina from pineapple peel waste and to comprehensively evaluate its physicochemical properties and economic value addition. The novelty of this research lies in its integrated assessment approach, combining biological processing and economic analysis to demonstrate the technical feasibility and economic efficiency of pineapple peel utilization. The findings are expected to support the development of environmentally friendly food products and contribute to sustainable, community-based agro-industrial systems (Sutanto, 2012).

MATERIALS & METHODS

Time and location of research

This research was conducted from May to October 2024 at the Laboratory of the Faculty of Agriculture, Universitas Kadiri, Kediri, Indonesia. All experimental procedures, including nata production, physicochemical analyses, and economic evaluation, were performed under controlled laboratory conditions to ensure reproducibility and data reliability.

Nata de pina production process

The production of nata de pina followed established nata fermentation procedures using agricultural waste substrates, with minor modifications (Rahayu et al., 2023). Pineapple peel was washed thoroughly, cut into small pieces, and extracted using soaking and heating to obtain a carbohydrate-rich substrate. The extract was filtered and pasteurized to eliminate unwanted microorganisms.

After cooling to room temperature, the substrate was inoculated with a starter culture of *Acetobacter xylinum*. Fermentation was carried out at room temperature (28–30 °C) for 14–15 days in sterile containers. During fermentation, bacterial cellulose formed a gel-like nata layer on the surface of the liquid medium. Upon completion of fermentation, the nata was harvested and washed repeatedly with clean water to remove residual acidity before further analysis and packaging. The overall production process, including substrate preparation, fermentation, and post-fermentation handling, is illustrated in Figure 1.

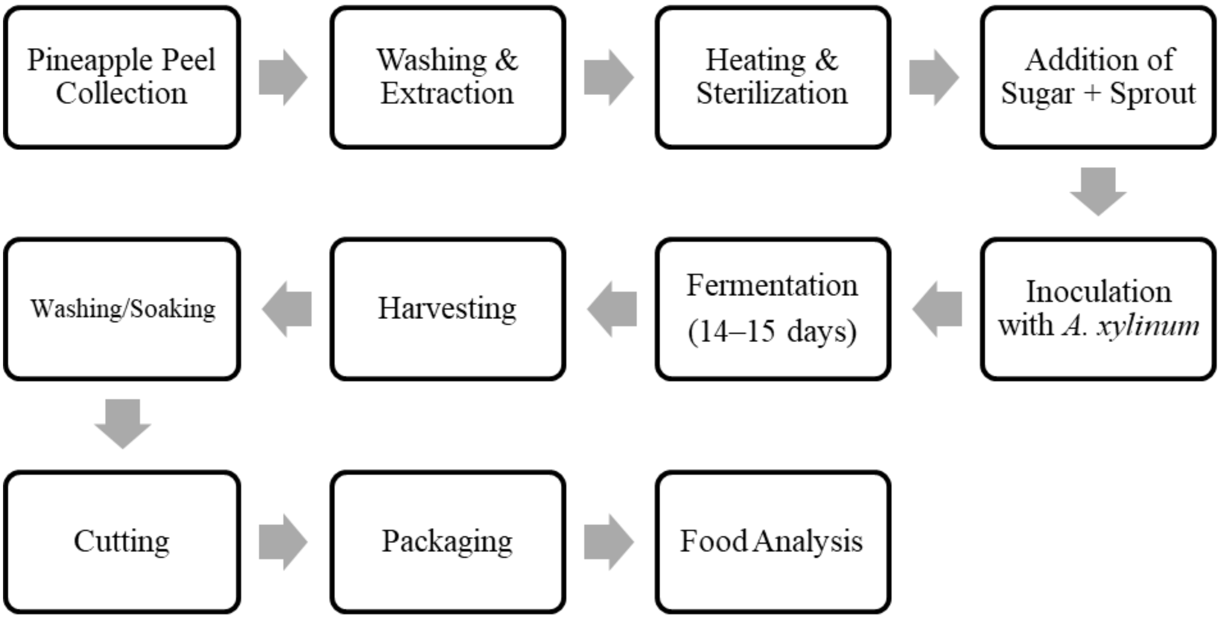

Figure 1. Flowchart of nata de pina production from pineapple peel, including substrate preparation, fermentation, and post-fermentation handling.

Physicochemical analysis

Physicochemical properties of nata de pina were analyzed to assess product quality. Moisture content was determined using the gravimetric method. Ash content was analyzed according to SNI 3751:2009. Fat content was measured using the Soxhlet extraction method, protein content was determined using the Kjeldahl method, crude fiber content was analyzed using the Weende method, and reducing sugar content was measured using a photometric method. All analyses were performed in triplicate to ensure analytical accuracy.

Economic data collection

Economic data were collected to evaluate the value-added performance of nata de pina production. Primary data included quantities of raw materials, labor input, production output, selling prices, and operational costs obtained directly from the production process. Cost components comprised raw material costs, operational costs (electricity and transportation), labor wages, and equipment depreciation costs. Equipment depreciation was calculated based on the economic lifespan of each item used in the production process. Secondary data were obtained from relevant scientific literature to support the analytical framework (Nurainun et al., 2018).

Economic value-added analysis

The economic performance of nata de pina production was evaluated using the Hayami value-added method (Hidayat et al., 2012). This method quantifies added value, value-added ratio, labor remuneration, profit, and production margin based on input–output relationships in agro-industrial processing. The framework of the economic value-added analysis using the Hayami method is illustrated in Figure 2.

The Hayami analysis was conducted in three stages: (1) calculation of output, input, and price variables; (2) estimation of income and profit; and (3) assessment of remuneration for production factors, including labor and other inputs. The calculation procedure and variables used in this analysis are summarized in Table 1. Although the analytical framework follows the original Hayami method, its application in this study was adjusted to reflect the specific characteristics of nata de pina production from pineapple peel, particularly in terms of raw material input, labor allocation, and local cost structure.

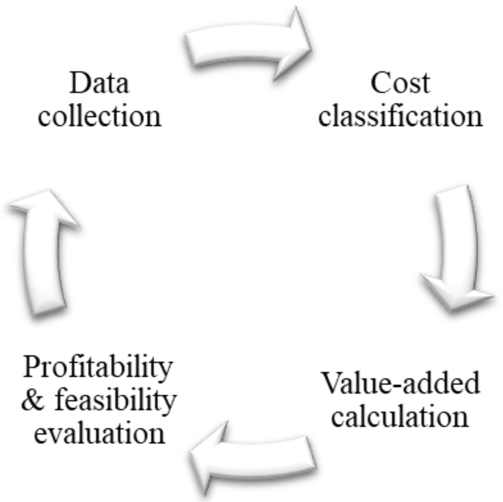

Figure 2. Framework of economic value-added analysis using the Hayami method.

Table 1. Procedure for calculating added value using the Hayami method (adapted from Hidayat et al., 2012).

No	Variable	Mark
I	**Output, Input, Price**	
1.	Output (kg/production)	A
2.	Raw materials (kg/production)	B
3.	Labor (man-days (HOK)/production)	C
4.	Conversion factor	D = A/B
5.	Labor coefficient	E = C/B
6.	Output price (Rp/kg/production)	F
7.	Average labor wages (Rp/man-days)	G
II	**Income and Profit (Rp/kg/production)**	
8.	Price of raw materials	H
9.	Other input contributions (per kg of raw material)	I
10.	Output Value	J = D × F
11.	Value-added	K = J – (I + H)
	Value-added ratio	L% = (K/J) × 100%
12.	Employee benefits	M = E × G
	Labor section	N% = (M/K) × 100%
13.	Profit	O = K – M
	Profit level	P% = (O/K) × 100%
III	**Production Factors Remuneration**	
14.	Margin	Q = J – H
	Profit	R = (O/Q) × 100%
	Labor (HOK/production)	S = (M/Q) × 100%
	Other inputs	T = (I/Q) × 100%

Note. A: Output or total production generated by the agroindustry in one production run; B: Input or raw materials used to produce nata de pina; C: Labor used in producing nata de pina calculated in man-days in one analysis period; F: The product price that applies in one analysis period; G: The average amount of wages received by workers in each production period calculated based on wages per man-days (HOK); H: Price of nata raw material input per kg during the analysis period; I: Other input contributions/costs consisting of costs of auxiliary raw materials, depreciation costs, and packaging costs per kg of raw materials.

RESULTS & DISCUSSIONS

Fermentation outcome and production yield of nata de pina

Fermentation of pineapple peel extract using *Acetobacter xylinum* successfully produced nata de pina characterized by a compact gel structure and uniform appearance. In one production batch, 10 kg of pineapple peel waste yielded approximately 50 bottles of nata de pina, each weighing 200 g, indicating effective conversion of raw material into a marketable product. The fermentation process was completed within 14–15 days without visible contamination, confirming that pineapple peel extract is a suitable substrate for bacterial cellulose formation. The production outcome is illustrated in Figure 1.

The fermentation duration and cellulose formation observed in this study are consistent with previous reports showing that *A. xylinum* effectively utilizes carbohydrate-rich fruit substrates for nata production within 10–15 days (Azzahra et al., 2022; Rahayu et al., 2023). In addition, the suitability of pineapple peel as a fermentation substrate aligns with findings by Kunda et al. (2024), who reported that pineapple peel contains sufficient carbohydrates and fiber to support bacterial growth and stable nata formation.

Comparison between nata de pina and nata de coco

Nata de pina and nata de coco are cellulose-based fermented food products produced through microbial fermentation involving *Acetobacter xylinum*, yet they differ in raw material sources, nutritional characteristics, sensory attributes, and production costs (Jose et al., 2024). In this study, nata de pina was produced from pineapple peel extract supplemented with additional nutrients as described in the Methods section, whereas nata de coco represents a conventional nata product derived from coconut water and is used here as a comparative reference.

Table 2. Differences between nata de coco and nata de pina

Description	Nata de coco	Nata de pina
Raw material	100% Coconut Water	75% Pineapple Peel Juice Extract 25% Coconut water
Aroma	coconut aroma	pineapple aroma
Texture	Dense and chewy	More dense and chewy
Calories	High	Low
Number of calories	210 kcal	45-50 kcal
Production cost	Rp356,430.00	Rp595,250.00
Production process	The procedure for making nata de coco begins with boiling fresh coconut water to kill microorganisms, then mixing it with *Acetobacter xylinum* bacteria. This mixture is then poured into a flat container and left at room temperature for 5 to 14 days, during which time the bacteria convert sugar into acid and produce a chewy gel.	The process of making nata de pina begins by heating the juice extracted from pineapple skins to eliminate microbes. After the juice cools down, a bacterial starter culture of *Acetobacter xylinum* is added. This mixture is then poured into a flat container and left to ferment at room temperature for 14 to 15 days. During fermentation, the bacteria convert sugars into acids, producing a chewy gel that characterizes nata de pina. After fermentation is complete, the nata is harvested and ready for packaging.
Product characteristics	• Transparent color • Neutral taste	• Cream or light yellow color • Sweet and sour taste

Source: primary data processed in 2024

As summarized in Table 2, nata de pina exhibited a distinctive pineapple aroma and a slightly sweet–sour taste, while nata de coco showed a more neutral sensory profile. Both products demonstrated a dense and chewy texture; however, nata de pina tended to be more compact, which may be associated with differences in substrate composition and carbohydrate availability during fermentation.

From a nutritional perspective, nata de pina showed a clear advantage in terms of lower caloric content. The energy value of nata de pina ranged from 45–50 kcal, substantially lower than that of nata de coco (210 kcal), making it more suitable for consumers seeking low-calorie food alternatives (Ayuningtyas et al., 2024). In addition, nata de pina contained 8.91 mg/100 g of reducing sugars and 0.56% crude fiber, which contribute to rapid energy availability and support digestive health (Ayuningtyas et al., 2024).

Although the protein content of nata de pina was relatively low (0.47%; Table 3), this characteristic is consistent with nata products in general, which are primarily composed of microbial cellulose rather than protein-rich components. Compared to nata de coco, nata de pina offers a combination of lower caloric value and moderate fiber content, supporting its potential positioning as a healthier fermented food option.

In terms of economic aspects, nata de pina exhibited higher production costs than nata de coco (Rp595,250.00 versus Rp356,430.00). This difference is mainly attributed to additional processing requirements and supplementary inputs associated with pineapple peel extraction and pre-fermentation handling. Nevertheless, the nutritional advantages and waste valorization potential of nata de pina suggest that it remains competitive, particularly within health-oriented and sustainability-driven food markets.

Physicochemical characteristics of nata de pina and compliance with SNI standards

The physicochemical characteristics of nata de pina produced in this study were evaluated and compared with the Indonesian National Standard (SNI) for packaged nata products, as summarized in Table 3. The moisture content of nata de pina reached 95.06%, exceeding the maximum limit of 80% specified by SNI. High moisture content has important implications for product quality, shelf life, and microbiological safety, as excessive water content increases water activity (aw), which accelerates deterioration during storage and reduces structural stability. Nata-based products with high moisture content are more susceptible to microbial contamination when storage and post-fermentation handling are not adequately controlled (Srimiati et al., 2023).

Table 3. Physicochemical properties of nata de pina and their compliance with Indonesian National Standards (SNI)

Parameter	Results	SNI Nata Products	Information
Water content	95.06%	Max 80%	Exceeding SNI standards
Ash Content	0.05%	Max 0.5%	According to SNI standards
Fat Content	1.56%	Max 2%	According to SNI standards
Protein Content	0.47%	Max. 1%	According to SNI standards
Crude Fiber	0.56%	Max. 1%	According to SNI standards
Reducing Sugar	8.91 mg/100 g	Max. 10 mg/100 g	According to SNI standards

Source: primary data processed in 2024

To address this issue, appropriate post-fermentation treatments are required to reduce moisture content and improve shelf life. Such treatments may include draining and pressing, reheating, repeated soaking with periodic water replacement, or packaging in sugar solutions with controlled concentrations. Similar observations were reported by Srimiati et al. (2023), who noted that nata products with moisture content above the recommended standard tend to deteriorate more rapidly under ambient storage conditions.

Table 4. Equipment inventory and depreciation costs for nata de pina production

No	Name	Note	Unit (Rp)	Amount Economic (Rp)	Life (years)	Depreciation (Rp)
1	Blender	1	665,000	665,000	4	100,000
2	Juicer	1	705,000	705,000	4	100,000
3	Pan	2	60,000	120,000	2	20,000
4	Scales	1	35,000	35,000	2	10,000
5	Stove	1	160,000	160,000	4	25,000
6	Spatula mixer	3	15,000	45,000	2	15,000
7	Spoon stirrer	1 dzn	15,000	15,000	2	4,000
8	Funnel	1	25,000	25,000	2	7,500
9	Knife	2	30,000	60,000	2	15,000
10	Measuring Cup 1000 ml	1	80,000	80,000	4	7,500
11	10 ml Measuring Cup	1	30,000	30,000	4	3,750
12	Beaker glass 1000 ml	2	176,000	352,000	4	35,000
13	Burette	2	155,000	310,000	4	35,000
14	Cup	2	25,000	50,000	4	7,500
15	Erlenmeyer 500 ml	1	60,000	60,000	4	10,000
16	Plastic Bucket	2	50,000	100,000	2	25,000
17	Hemocytometer	1	350,000	350,000	4	50,000
18	60 cm tripod	1	85,000	85,000	5	8,000
19	Clamp holder	1	35,000	35,000	5	4,000
20	Aluminum foil	3	15,000	45,000	2	7,500
21	Drop pipette	2	10,000	20,000	2	5,000
22	Tray	2	35,000	70,000	4	7,500
23	10 ml measuring flask	1	57,000	57,000	4	7,500
24	Filter paper 58 cm x 58 cm	2	10,000	20,000	2	5,000
25	60 mm watch glass	1	15,000	15,000	1	10,000
26	Reflux	1	400,000	400,000	4	50,000
27	Bottle	71	1,000	71,000	2	15,500
Total			3,299,000	4,980,000		590,250

The ash content of nata de pina was 0.05%, which is well below the SNI maximum limit of 0.5% (Table 3). Ash content reflects the mineral fraction of a food product, and the low value observed indicates that nata de pina contains relatively low mineral levels. This finding is consistent with previous reports stating that nata products derived from fruit extracts and coconut water are predominantly carbohydrate-based rather than mineral-rich (Sutanto, 2012).

The fat content of nata de pina was 1.56%, remaining within the SNI limit of 2%, confirming that nata de pina can be categorized as a low-fat food product. Low fat content is characteristic of nata products, as the fermentation process primarily produces microbial cellulose without the incorporation of lipid-rich components. The protein content was 0.47%, which also complies with SNI standards but remains relatively low. This result is expected because nata products are not designed as protein sources but rather as refreshing food products with textural appeal, consistent with the general characteristics of microbial cellulose-based foods (Sutanto, 2012).

The crude fiber content of nata de pina reached 0.56%, which is still below the SNI maximum limit of 1% (Table 3). Dietary fiber contributes to digestive health by supporting bowel function and preventing constipation. Although the fiber content of nata de pina is moderate, it provides additional functional value compared to many gelatinous desserts that typically contain negligible fiber levels. In terms of reducing sugar content, nata de pina contained 8.91 mg/100 g, which is below the SNI threshold of 10 mg/100 g, indicating that the product is not excessively sweet and may be suitable for consumers seeking lower-sugar snack alternatives.

Cost structure and production economics of nata de pina

The cost structure of nata de pina production was evaluated to assess production efficiency and economic feasibility at the laboratory scale. The total production cost per cycle amounted to IDR 390,500, indicating that nata de pina can be produced with a relatively modest investment while still generating positive economic returns. The cost components consisted of fixed costs, variable costs, and labor costs, each contributing differently to the overall production economics.

Fixed costs were associated with equipment investment and depreciation, covering tools used for extraction, fermentation, analysis, and packaging processes. As presented in Table 4, the total depreciation cost reached IDR 590,250, reflecting the capital intensity required to support stable and hygienic production. Adequate equipment availability is essential to maintain process efficiency and consistent product quality, particularly in fermentation-based agro-industrial activities.

Table 5. Raw material and operating costs per production cycle of nata de pina

No	Name	Information	Unit price (Rp)	Amount (Rp)
Raw Material Cost				
1	Pineapple skin	10 kg	3,000	30,000
2	Bean sprout extract (Vinegar)	3 bottles	4,000	12,000
3	Sugar	5 kg	15,000	75,000
4	Nitrogen source (ZA Food Grade)	0.5 kg	65,000	65,000
5	*A. xylinum* bacteria	1 bottle	96,000	96,000
6	Pineapple	10 kg	10,000	100,000
7	Coconut water	2.5 liters	5,000	12,500
Operating costs				
8	Electricity cost	4 times	50,000	200,000
9	Transportation costs	4 times	37,500	150,000
Total			285,500	740,500

Variable costs comprised raw materials and operational expenses. The breakdown of raw material and operational costs is shown in Table 5, with a total variable cost of IDR 740,500. Raw materials included pineapple peel, sugar, starter culture (*Acetobacter xylinum*), and auxiliary ingredients, while operational costs covered electricity and transportation. These components represent the most flexible cost elements and directly influence production scalability and cost control. Proper management of variable costs is therefore critical to maintaining economic efficiency in small-scale agro-processing systems.

Labor costs constituted another important component of the production economics. As summarized in Table 6, total labor expenditure amounted to IDR 150,000 per production cycle, covering activities from raw material preparation to packaging and marketing. Labor input plays a crucial role in fermentation-based processing, where careful handling and monitoring significantly affect product quality and yield.

Table 6. Labor requirements and labor costs in nata de pina production

No	Type of activity	Amount worker	Working h/day	Amount (Rp)
1	Production Input	1 person	8	50,000
	Shopping for materials			
	Washing			
	Cutting			
	Cooking			
	Mixing			
2	Production process	1 person	8	50,000
	a. Fermentation			
	b. Harvesting			
	c. Cutting			
	d. Immersion			
	e. Water change			
	f. Washing			
3	Production Output	1 person	8	50,000
	a. Packaging			
	b. Marketing			
Total				150,000.00

The classification of production costs into fixed, variable, and labor components provides a clear picture of cost distribution and economic performance. This approach is consistent with previous studies emphasizing that structured cost grouping facilitates efficiency evaluation and supports competitive pricing strategies in agro-industrial enterprises (Jakaria et al., 2024; Damayanti et al., 2024). The observed cost structure indicates that nata de pina production from pineapple peel waste is economically manageable and suitable for further development at the community or small-enterprise scale (Bunkaew et al., 2023).

Value-added analysis using the Hayami method

The economic value-added of nata de pina production from pineapple peel waste was evaluated using the Hayami method to assess processing efficiency and income generation in agro-industrial activities. The results of the value-added analysis are presented in Table 7, which summarizes input–output relationships, cost components, and profit distribution per production cycle.

The analysis indicates that processing 10 kg of pineapple peel waste generated 90 kg of nata de pina, yielding an added value of IDR 265,600 per production cycle. This corresponds to a value-added ratio of 98.37%, demonstrating a highly efficient conversion of low-value agricultural waste into a product with substantial economic worth. A high value-added ratio reflects the effectiveness of processing activities in enhancing the economic value of raw materials through technological and managerial inputs (Widiastuti et al., 2020).

The selling price of nata de pina was IDR 30,000 per kg, resulting in a total profit of IDR 267,000 per cycle, as shown in Table 7. Labor remuneration accounted for 15.06% of the added value, indicating that a portion of the economic benefit was distributed to labor while maintaining a dominant share for enterprise profit. Such a distribution pattern is considered favorable for small-scale agro-industrial enterprises, as it supports both income generation and business sustainability.

The high added value achieved in this study can be attributed to the low cost of raw materials, efficient fermentation performance, and relatively simple processing requirements. According to the Hayami framework, added value reflects the success of processing activities in transforming raw inputs into outputs with higher market value (Hidayat et al., 2012).

When the value-added ratio exceeds 40%, the activity is generally classified as having high economic potential, placing nata de pina production firmly within this category.

Table 7. Value-added analysis of nata de pina production using the Hayami method

No	Variable	Mark
I	**Output, Input, Price**	
1.	Output (kg/production)	90
2.	Raw materials (kg/production)	10
3.	Labor (HOK/production)	8
4.	Conversion factor (output/raw materials)	9
5.	Labor coefficient (Labor/raw materials)	0.80
6.	Output price (Rp/kg/production)	30,000
7.	Average labor wages (Rp/HOK)	50,000
II	**Income and Profit (Rp/kg/production)**	
8.	Price of raw materials (Rp)	3,000
9.	Other input contributions (per kg of raw material) (Rp)	1,400
10.	Output Value (Rp)	270,000
11.	Value-added (Rp)	265,600
	Value-added ratio ((value-added/output value) × 100%)	98.37
12.	Employee benefits (Rp)	40,000
	Labor section ((employee benefits/value-added) × 100%)	15.06
13.	Profit (Rp)	225,600
	Profit level ((profit/output value) × 100%)	84.93
III	**Production Factors Remuneration**	
14.	Margin (Rp)	267,000
	Profit ((profit/margin) × 100%)	84.49
	Labor (HOK/production)	14.98
	Other inputs (Other input contributions/output value)	0.52

These findings suggest that nata de pina production from pineapple peel waste is not only technically feasible but also economically attractive. The combination of high added value, favorable profit margins, and efficient resource utilization highlights its potential for application in community-based agro-industrial development and waste valorization initiatives. By converting agricultural residues into marketable food products, this approach contributes to both economic sustainability and environmental management.

CONCLUSIONS

This study demonstrates that pineapple peel waste can be effectively converted into nata de pina through fermentation using *Acetobacter xylinum*, resulting in a value-added food product with promising technical and economic performance. The physicochemical characteristics of the produced nata de pina complied with most Indonesian National Standard (SNI) requirements, and the Hayami value-added analysis revealed a high added value and profitability, supporting its feasibility as a sustainable agro-industrial product. The primary limitation identified was the high moisture content (95.06%), which exceeded the SNI threshold for packaged nata products, indicating the need for improved post-fermentation handling to enhance shelf life and product stability. Addressing this limitation through optimized dehydration or preservation strategies is essential for future product development. These findings highlight the potential of nata de pina production as an alternative pathway for agro-industrial waste valorization, particularly for small-scale and community-based enterprises aiming to promote sustainable food processing and circular bioeconomy practices.

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