

ISRG Journal of Agriculture and Veterinary Sciences (ISRGJAVS)



ISRG PUBLISHERS

Abbreviated Key Title: ISRG. J. Agri.Vet.Sci.

ISSN: 3048-8869 (Online)

Journal homepage: <https://isrgpublishers.com/gjavs/>

Volume – III Issue - V (September-October) 2026

Frequency: Bimonthly



ECONOMIC VALORIZATION OF NUTMEG FRUIT FLESH VIA PECTIN AND ESSENTIAL OIL RECOVERY

Mifta Elfahmi^{1*}, Dian Zalzabila Fahlevi²

¹ Directorate General of Estate Crops, Ministry of Agriculture, Jl. Harsono RM No. 3, Gedung C, Ragunan, South Jakarta 12550, Indonesia

² Department of Agroindustrial Technology, Faculty of Agricultural Technology, Universitas Gadjah Mada, Jl. Flora No. 1, Bulaksumur, Yogyakarta 55281, Indonesia

| Received: 29.09.2026 | Accepted: 03.10.2026 | Published: 05.10.2026

*Corresponding author: Mifta Elfahmi

Abstract

Background: Nutmeg (*Myristica fragrans* Houtt.) fruit flesh is the largest fraction of the fruit but remains economically underutilized relative to the seed and mace, creating a substantial biomass stream with potential for higher-value recovery. **Aims:** This study estimated the gross economic value that could theoretically be generated from nutmeg fruit flesh through pectin and essential-oil recovery and examined the implications of a cascading valorization strategy. **Methodology:** A literature-based secondary data analysis was conducted using peer-reviewed studies, government statistics, trade data, and market-price observations available through September 2026. A mass-balance model used 1,000 kg of fresh mature nutmeg fruit as the functional basis. The flesh fraction was set at 77.8%, pectin yield at 2.588% on a wet basis, and essential-oil yield at 0.71-0.73%. Gross product value was estimated from reference prices and trade unit values; capital expenditure, operating costs, industrial recovery losses, certification, waste treatment, and marketing costs were excluded. **Results/Findings:** One tonne of fresh fruit provides approximately 778 kg of fruit flesh, corresponding theoretically to 20.13 kg of pectin and 5.52-5.68 kg of essential oil. At the reference prices used, pectin generated a gross value of approximately IDR 2.32-5.13 million per tonne of fresh fruit, while essential oil generated approximately IDR 5.30-8.48 million. A theoretical sequential-recovery scenario produced a combined upper-bound gross product value of IDR 7.62-13.61 million, with a midpoint of approximately IDR 10.60 million per tonne. **Conclusion:** Nutmeg fruit flesh has credible potential to shift from a low-value by-product to an industrial feedstock for pectin and essential oil recovery. However, the combined value is exploratory rather than a profitability estimate and requires validation through sequential extraction, product-quality testing, techno-economic analysis, and life-cycle assessment before investment decisions are made.

Keywords: circular bioeconomy, economic valuation, essential oil, *Myristica fragrans*, nutmeg pericarp, pectin

1. INTRODUCTION

Nutmeg (*Myristica fragrans* Houtt.) is a high-value tropical spice native to the Maluku Islands of Indonesia. Commercial utilization has historically centered on two products: the seed kernel and mace, while the fruit flesh, or pericarp, has commanded substantially less market value. This allocation is economically important because the flesh is not a minor fraction. Nirmagustina et al. (2024, pp. 191-200) reported a fruit-flesh proportion of 77.8%, while Rajan and Cherian (2026, Article 25) reported values of approximately 80-85% of the total fresh-fruit mass. Consequently, processing one tonne of mature fresh nutmeg fruit can generate roughly 778-850 kg of flesh, depending on cultivar, maturity, and measurement basis.

Where local markets can absorb the material, nutmeg flesh is processed into candied products, syrup, jam, beverages, or other foods. Nevertheless, the scale and regularity of those outlets may be insufficient to capture the full biomass stream in major production areas. High moisture content also makes the fresh flesh highly perishable, raising handling and transport costs. From a circular-bioeconomy perspective, the resulting mismatch between biological abundance and captured economic value provides a strong case for evaluating higher-value fractions before the biomass is relegated to low-value use or disposal.

Nutmeg pericarp is chemically more diverse than its conventional food uses imply. Reported constituents include pectin, structural carbohydrates, minerals, volatile oils, phenolics, flavonoids, tannins, lignans, and other bioactive compounds. Zhang et al. (2015, pp. 1399-1402) identified antioxidant and anti-inflammatory constituents in nutmeg pericarp, while Antasionasti et al. (2021, pp. 301-310) reported substantial levels of phenolics, flavonoids, and tannins associated with antioxidant activity. Rahman et al. (2018, pp. 183-189) further showed that pericarp processing conditions influence myristicin retention and antioxidant properties, emphasizing that this biomass can be treated as a functional raw material rather than merely as residue.

Two value pathways are particularly suitable for an initial economic assessment: pectin and essential oil. Layuk et al. (2002, pp. 178-183) extracted pectin from nutmeg mesocarp and reported a pectin yield of 20.73% on a dry basis, along with high methoxyl and polygalacturonic acid contents. For mass-balance purposes on fresh material, the same study provides a wet-basis yield of 2.588%. Pectin is a multifunctional hydrocolloid used as a gelling, thickening, stabilizing, and emulsifying agent. Reviews of alternative pectin sources emphasize the increasing interest in recovering pectin from fruit-processing by-products, including tropical fruit residues, although commercial competitiveness depends strongly on extraction efficiency, purity, degree of esterification, energy demand, and downstream purification (Picot-Allain et al., 2022, pp. 282-312; Roman-Benn et al., 2023, Article 100192; Kumar et al., 2023, Article 124332).

Essential oil offers a second pathway with much higher unit value but lower mass yield. Nirmagustina et al. (2024, pp. 191-200) reported nutmeg-flesh oil yields of 0.73% under experimentally favorable conditions and approximately 0.71% at the response-surface optimum. Pericarp oil has also been characterized for possible uses in coating and preservation (Vyshak et al., 2023, pp. 144-152). Broader work on nutmeg essential oil confirms the commercial relevance of its volatile constituents and shows that its composition varies by plant part, origin, and processing conditions

(Ashokkumar et al., 2022, pp. 2839-2851). This distinction is critical because oil produced from fruit flesh cannot automatically be assumed to receive the same price as conventional nutmeg oil from seed material.

Although studies on composition, extraction, bioactivity, and product development are available, relatively little work translates these technical findings into a transparent mass balance and an economic value estimate per unit of fresh fruit. Such an estimate does not replace a feasibility study, but it can clarify the order of magnitude of potentially recoverable value and identify which technical assumptions most strongly influence further research and investment priorities.

Accordingly, this study aimed to: (1) identify technically and commercially relevant value fractions in nutmeg fruit flesh; (2) estimate the theoretical mass of pectin and essential oil obtainable from one tonne of mature fresh nutmeg fruit; (3) estimate gross product value using transparent reference prices; and (4) formulate a cascading-valorization scenario that focuses on higher-value recovery while minimizing double counting. The analysis explicitly represents gross theoretical product value rather than profit because it excludes capital investment, process operating costs, industrial recovery losses, labor, energy, chemicals, purification, certification, waste treatment, distribution, and marketing.

2. MATERIALS AND METHODS

2.1 Study design and data sources

The study used a structured literature review and secondary-data valuation design. Scientific evidence was drawn from peer-reviewed publications on nutmeg fruit flesh or pericarp, pectin recovery, essential-oil extraction, bioactive compounds, and by-product valorization. Contextual evidence was drawn from government statistics and policy documents. Economic parameters were derived from Indonesian market observations for food-grade pectin and trade observations for nutmeg oil available up to September 2026.

Data were grouped into three categories. First, biological and technical parameters included the proportion of fruit flesh, pectin yield, essential-oil yield, and reported functional or bioactive properties. Second, the economic parameters included benchmark pectin prices and nutmeg oil trade unit values. Third, contextual parameters included Indonesian nutmeg production, downstream processing, and circular bioeconomy considerations. Pectin and essential oil were selected for quantitative valuation because both have experimentally reported yields and observable market benchmarks. Other bioactive fractions were discussed qualitatively to avoid double-counting in overlapping extracts.

2.2 Functional unit and mass balance

The functional unit was 1,000 kg of mature fresh nutmeg fruit. The base-case flesh fraction was 77.8% following Nirmagustina et al. (2024, pp. 191-200). Fruit-flesh mass was calculated as:

$$W_p = W_f \times f_p$$

where W_p is the mass of nutmeg fruit flesh (kg), W_f is the mass of fresh nutmeg fruit (kg), and f_p is the fruit-flesh fraction. Thus, 1,000 kg $\times$ 0.778 gives 778 kg of fresh fruit flesh.

2.3 Product-yield calculation

Potential product mass was estimated by multiplying fresh fruit-flesh mass by the reported yield on a compatible mass basis:

$$Y_i = W_p \times r_i$$

where Y_i is the theoretical mass of product i (kg) and r_i is the yield of product i . Pectin was calculated using a 2.588% wet-basis yield derived from Layuk et al. (2002, pp. 178-183). Essential oil was calculated using the 0.71-0.73% range reported by Nirmagustina et al. (2024, pp. 191-200). These values were treated as technical benchmarks, not guaranteed industrial recoveries.

2.4 Economic valuation

Gross product value (GPV) was calculated as the theoretical product mass multiplied by a reference unit price:

$$GPV_i = Y_i \times P_i$$

where P_i is the benchmark price of product i . Food-grade pectin was valued at IDR 115,000-255,000/kg based on Indonesian market observations (Shopee Indonesia, 2026). Nutmeg oil was valued using an observed trade-unit-value range of approximately USD 54.56-84.85/kg (Volza, 2026) and an analytical exchange rate of IDR 17,600/USD, producing an indicative benchmark of approximately IDR 960,000-1,493,600/kg. These prices were used solely as secondary valuation benchmarks and should not be interpreted as assured industrial contract prices.

2.5 Scenario construction and interpretation

Three scenarios were assessed. Scenario A monetized pectin only. Scenario B monetized essential oil only. Scenario C represented a theoretical cascading process in which the volatile fraction is first recovered by distillation and the remaining biomass is subsequently evaluated for pectin recovery. Scenario C was treated as an exploratory upper-bound estimate because the pectin and essential-oil yields originate from separate studies and have not been validated within a single sequential process using the same batch of raw material. This treatment is consistent with circular biorefineries, where the objective is to recover higher-value fractions sequentially while preserving the downstream utility of the residual biomass (Yaashikaa et al., 2022, Article 126126).

Table 1. Mass-balance basis for nutmeg fruit flesh from one tonne of mature fresh fruit

Parameter	Value	Source/assumption
Mature fresh nutmeg fruit	1,000 kg	Functional basis
Fruit-flesh proportion	77.8%	Nirmagustina et al. (2024)
Available fresh fruit flesh	778 kg	Calculated
Alternative literature range	80-85%	Rajan & Cherian (2026)

3. RESULTS AND DISCUSSION

3.1 Nutmeg fruit flesh as the dominant biomass fraction

The base-case mass balance indicates that 778 kg of fruit flesh is generated from one tonne of mature fresh nutmeg fruit. If the 80-85% range summarized by Rajan and Cherian (2026, Article 25) is applied, the potential flesh stream increases to approximately 800-850 kg/t. Therefore, most of the harvested fresh-fruit mass lies in a

fraction that is economically secondary to seed and mace. This creates a structural opportunity to intensify value without increasing plantation area or primary crop output.

The same characteristic that makes the flesh abundant also makes its logistics difficult. Fresh pericarp contains a substantial amount of water and is susceptible to fermentation and quality deterioration. Long-distance transport of unprocessed flesh therefore moves large quantities of water while increasing the risk of spoilage. This supports decentralized or near-source primary processing. Distillation, stabilization, partial drying, or other first-stage operations located near production clusters could reduce deterioration and create a more transport-efficient intermediate product.

This spatial logic is consistent with the broader concept of agro-industrial by-product valorization: the first economic gain is often not only the recovery of a valuable molecule but also the conversion of a bulky, unstable residue into a standardized intermediate that can enter a formal supply chain. Such a transition would require quality specifications, collection schedules, contamination controls, and sufficient throughput to justify the investment in fixed processing assets.

3.2 Pectin as a value-added product

Using the 2.588% wet-basis yield, 778 kg of nutmeg fruit flesh corresponds to approximately 20.13 kg of pectin per tonne of fresh fruit. The underlying study reported pectin with a methoxyl content of about 11.43% and polygalacturonic acid content of about 79.47%, indicating a material with functional potential beyond simple fiber recovery (Layuk et al., 2002, pp. 178-183). At the reference range of IDR 115,000-255,000/kg, the resulting theoretical gross value is approximately IDR 2.32-5.13 million per tonne of fresh fruit.

The strategic importance of pectin is supported by its broad technological functions. Pectin is widely used for gel formation, viscosity control, emulsion stabilization, and texture modification, and it is increasingly investigated for biomedical, pharmaceutical, and biomaterial applications (Roman-Benn et al., 2023, Article 100192). Commercial pectin is still dominated by citrus peel and apple pomace, but reviews of tropical and subtropical by-products show growing technical interest in alternative raw materials, particularly where the by-product is locally abundant and where extraction can be integrated into an existing processing chain (Picot-Allain et al., 2022, pp. 282-312).

Nevertheless, yield alone is insufficient for commercial positioning. Pectin value depends on the degree of esterification, galacturonic acid content, molecular weight, ash, color, residual contaminants, gel strength, and the target application. Nutmeg pectin would therefore require benchmarking against established citrus and apple pectins, and scale-up should examine acid consumption, solvent or alcohol recovery, water demand, drying energy, effluent treatment, and product standardization. Recent pectin valorization reviews emphasize that advanced extraction approaches may improve resource efficiency, but their economic advantage depends on equipment costs and process scale (Kumar et al., 2023, Article 124332).

3.3 Essential-oil potential from nutmeg fruit flesh

Applying the reported yield range of 0.71-0.73% to 778 kg of fresh fruit flesh yields approximately 5.52-5.68 kg of essential oil per tonne of mature fresh fruit. At the benchmark price range of

roughly IDR 960,000-1,493,600/kg, the theoretical gross product value is approximately IDR 5.30-8.48 million per tonne of fresh fruit. Despite the small recovered mass, the high unit value makes essential oil the dominant contributor in the quantitative valuation.

Nirmagustina et al. (2024, pp. 191-200) reported that distillation temperature and time materially affected yield and quality attributes. Their best experimental condition achieved a yield of 0.73%, while the response-surface recommendation yielded approximately 0.71%. This reinforces the need to treat the yield as process-dependent rather than intrinsic to the raw material. Pretreatment, moisture content, particle size, distillation configuration, residence time, and plant-part chemistry may all alter both yield and composition.

The market benchmark requires additional caution. Nutmeg essential oil is not a chemically uniform commodity across all plant parts. Reviews identify substantial variation in key constituents, including sabinene, myristicin, elemicin, and other terpenes (Ashokkumar et al., 2022, pp. 2839-2851). Pericarp oil has demonstrated functional potential, including food-surface applications (Vyshak et al., 2023, pp. 144-152), but a buyer may value it differently from conventional seed-derived nutmeg oil. Therefore, future commercialization should establish gas chromatography-mass spectrometry profiles, marker specifications, safety parameters, sensory characteristics, and buyer acceptance before assuming equivalent pricing.

Table 2. Theoretical pectin and essential-oil potential from one tonne of mature fresh nutmeg fruit

Product	Yield basis	Theoretical mass	Reference price	Gross product value
Pectin	2.588% wet basis	20.13 kg	IDR 115,000-255,000/kg	IDR 2.32-5.13 million
Essential oil	0.71-0.73%	5.52-5.68 kg	IDR 960,000-1,493,600/kg	IDR 5.30-8.48 million

3.4 Bioactive compounds as additional upside potential

Nutmeg pericarp also contains compounds that could support the development of future value-added extracts. Zhang et al. (2015, pp. 1399-1402) identified neolignans, phenylpropanoids, phenolic aldehydes, triterpenoids, sugars, and steroids and reported antioxidant and anti-inflammatory activity. Antasionasti et al. (2021, pp. 301-310) likewise reported high levels of phenolics, flavonoids, and tannins associated with antioxidant activity. Rahman et al. (2018, pp. 183-189) showed that pericarp processing can retain volatile and antioxidant functionality under selected dehydration conditions.

These findings support potential development of standardized botanical extracts, natural preservatives, functional-food ingredients, or nutraceutical intermediates. However, no additional monetary value was assigned to these fractions in the present analysis. The omission is deliberate. Market prices for standardized nutmeg-pericarp extracts are not well established, and some compounds may overlap with those in essential oil or other extractive fractions. Monetizing each identified constituent as an

independent product would create severe double-counting and overstate the feasible value.

3.5 Economic-valuation scenarios

The scenarios show a clear difference between the two quantified value pathways. Pectin alone produces a theoretical gross product value of IDR 2.32-5.13 million/t fresh fruit, whereas essential oil produces IDR 5.30-8.48 million/t. If both could be recovered sequentially without material loss of yield or product quality, the combined gross value would be approximately IDR 7.62-13.61 million/t, with a midpoint near IDR 10.60 million/t.

The combined figure must be interpreted as an upper-bound exploratory estimate, not as an additive cash-flow forecast. Sequential operations can change the chemistry of the remaining biomass. Thermal distillation may alter pectin structure or extractability, while chemical pectin extraction may reduce the suitability of the residual solids for other uses. The central technical question is therefore not whether two yields can be added arithmetically, but whether both yields and the required quality specifications can be achieved in a single integrated process train.

Table 3. Gross product value under alternative nutmeg fruit-flesh utilization scenarios

Scenario	Monetized product(s)	Minimum	Midpoint	Maximum
A	Pectin	IDR 2.32 million	IDR 3.72 million	IDR 5.13 million
B	Essential oil	IDR 5.30 million	IDR 6.89 million	IDR 8.48 million
C	Essential oil + pectin	IDR 7.62 million	IDR 10.60 million	IDR 13.61 million

3.6 Cascading valorization and circular-bioeconomy logic

A more defensible pathway for whole-fruit utilization is a cascading process rather than parallel assumptions that every component can be fully recovered independently. One conceptual sequence is: separation of seed and mace from mature fruit; rapid handling of fresh flesh; recovery of the volatile fraction by distillation; characterization of the spent biomass for pectin extraction; and subsequent routing of the remaining fiber-rich

residue toward biomaterials, compost, selected feed applications, or energy recovery where safety and technical suitability are demonstrated.

This sequence reflects the circular-biorefineries principle of prioritizing high-value fractions before lower-value material or energy uses. Reviews of agro-industrial residue valorization describe cascading use as a means of increasing resource productivity while reducing terminal waste (Yaashikaa et al., 2022,

Article 126126). The pectin literature similarly emphasizes recovery from processing by-products as a route to convert disposal burdens into functional ingredients (Kumar et al., 2023, Article 124332). For nutmeg, the most important next step is experimental: distillation and pectin recovery should be tested sequentially on the same batch to measure true mass recovery, changes in quality, energy consumption, water demand, and residue characteristics.

A cascading design also changes the meaning of process optimization. The objective should not be simply the maximum yield of a single component. A slightly lower essential-oil yield could be economically preferable if it preserves substantially higher pectin quality or reduces energy demand. Conversely, harsher pretreatment that maximizes pectin recovery could be undesirable if it eliminates a higher-value volatile fraction. Integrated optimization therefore requires multi-product economics rather than single-stage yield maximization.

3.7 Implications for downstream development in Indonesia

The results support a shift from seed-centered utilization toward whole-fruit value capture. This does not reduce the importance of seed and mace as primary commercial products; instead, it recognizes that downstream development can increase the value per harvested fruit by monetizing a fraction that is already produced. Such an approach is especially relevant where raw-material expansion is constrained by land, labor, environmental, or market considerations.

Because fresh flesh is bulky and perishable, early-stage processing is likely to be more practical near production areas. Distillation is a plausible entry process because essential-oil technology is already familiar in several Indonesian spice-producing regions and because oil is a compact, higher-value product. Collection or processing could be organized through farmer groups, cooperatives, village-scale enterprises, or area-based processing units. More demanding purification, analytical testing, and pectin finishing could then be consolidated at larger facilities if sufficient volume and quality consistency are achieved.

A staged development pathway may reduce investment risk. The first stage would validate raw-material supply, oil yield, quality, and buyers. A second stage would test pectin extraction from the post-distillation residue and benchmark the product against

commercial pectin specifications. Only after both streams are technically verified should an integrated biorefinery be evaluated. This approach reduces the risk of building capital-intensive infrastructure before feedstock logistics and product markets are proven.

Policy and statistical systems can also improve the quality of decisions. National or regional nutmeg statistics are generally organized around primary commodity output rather than whole fresh-fruit biomass and by-product flows. Biomass accounting that records the proportion and current use of flesh, seed, mace, shells, and other fractions would provide a stronger basis for locating processing facilities and estimating feasible feedstock supply.

3.8 Limitations and future research

This analysis has several limitations. First, the product yields were taken from laboratory or limited-scale studies and should not be interpreted as industrial recovery rates. Second, benchmark prices can vary substantially based on purity, specifications, order size, certification, contract terms, exchange rates, and buyer location. Third, CAPEX and OPEX were excluded; consequently, the results cannot establish profitability, payback period, internal rate of return, or minimum economic scale.

Fourth, the combined scenario uses pectin and essential-oil yields from different studies. There is currently no demonstration that both can be sequentially recovered from the same batch at the full individual yields assumed here. Fifth, the trade price used for nutmeg oil may not be directly transferable to pericarp-derived oil. Sixth, potential values of phenolics and other bioactives were not monetized because doing so would require defined extract specifications and could create double counting.

Future research needs to therefore prioritize sequential-recovery experiments, GC-MS characterization of fruit-flesh oil, pectin quality after distillation, actual mass-recovery measurements, process-water and energy balances, and residue-utilization tests. A complete techno-economic assessment should then incorporate capital expenditure, utilities, labor, chemicals, solvent recovery, maintenance, quality testing, certification, waste treatment, logistics, product losses, and price sensitivity. Life-cycle assessment is also necessary to verify that circular-economy claims correspond to measurable environmental improvements rather than value recovery alone.

Table 4. Scaling of the theoretical combined gross product value

Fresh nutmeg fruit processed	Minimum	Midpoint	Maximum
1 tonne	IDR 7.62 million	IDR 10.60 million	IDR 13.61 million
10 tonnes	IDR 76.2 million	IDR 106.0 million	IDR 136.1 million
100 tonnes	IDR 762 million	IDR 1.06 billion	IDR 1.36 billion
1,000 tonnes	IDR 7.62 billion	IDR 10.60 billion	IDR 13.61 billion

4. CONCLUSION

Nutmeg fruit flesh is a quantitatively dominant but economically underutilized fraction of the fruit. Using a 77.8% flesh proportion, one tonne of mature fresh fruit provides approximately 778 kg of fruit flesh. Based on published experimental yields, this biomass

could theoretically produce about 20.13 kg of pectin and 5.52-5.68 kg of essential oil.

At the benchmark prices used in this study, pectin contributes an estimated gross product value of IDR 2.32-5.13 million/t fresh fruit, and essential oil contributes approximately IDR 5.30-8.48 million/t. A theoretical sequential-recovery scenario produces a

combined upper-bound value of IDR 7.62-13.61 million/t, with a midpoint of about IDR 10.60 million/t. These figures are not profit estimates because they do not include investment, operating costs, industrial recovery losses, energy, labor, purification, certification, waste treatment, distribution, or marketing.

The principal implication is that downstream development of nutmeg need not be limited to increasing seed and mace output. Greater value may also be captured by reorganizing the existing biomass stream through cascading valorization, beginning with high-value volatile recovery, followed by pectin recovery and appropriate uses of the residual. Before commercial investment, this concept requires sequential-process validation, product-standard testing, techno-economic analysis, buyer validation, and life-cycle assessment.

REFERENCES

1. Antasionasti, I., Datu, O. S., Lestari, U. S., Abdullah, S. S., & Jayanto, I. (2021). Correlation analysis of antioxidant activities with tannin, total flavonoid, and total phenolic contents of nutmeg (*Myristica fragrans* Houtt.) fruit precipitated by egg white. *Borneo Journal of Pharmacy*, 4(4), 301-310. <https://doi.org/10.33084/bjop.v4i4.2497>
2. Ashokkumar, K., Simal-Gandara, J., Murugan, M., Dhanya, M. K., & Pandian, A. (2022). Nutmeg (*Myristica fragrans* Houtt.) essential oil: A review on its composition, biological, and pharmacological activities. *Phytotherapy Research*, 36(7), 2839-2851. <https://doi.org/10.1002/ptr.7491>
3. Kumar, S., Konwar, J., Das Purkayastha, M., Kalita, S., Mukherjee, A., & Dutta, J. (2023). Current progress in valorization of food processing waste and by-products for pectin extraction. *International Journal of Biological Macromolecules*, 239, 124332. <https://doi.org/10.1016/j.ijbiomac.2023.124332>
4. Layuk, P., Marseno, D. W., & Haryadi. (2002). Karakterisasi komposit film edible pektin daging buah pala (*Myristica fragrans* Houtt.) dan tapioka. *Jurnal Teknologi dan Industri Pangan*, 13(2), 178-183.
5. Nirmagustina, D. E., Putri Andini, M. M., & Wulandari, Y. R. (2024). Optimization of distillation of nutmeg oil from the flesh using Response Surface Methodology (RSM). *Jurnal Penelitian Pertanian Terapan*, 24(2), 191-200. <https://doi.org/10.25181/jppt.v24i2.3428>
6. Picot-Allain, M. C. N., Ramasawmy, B., & Emmambux, M. N. (2022). Extraction, characterisation, and application of pectin from tropical and sub-tropical fruits: A review. *Food Reviews International*, 38(3), 282-312. <https://doi.org/10.1080/87559129.2020.1733008>
7. Rahman, N., Xin, T. B., Kamilah, H., & Ariffin, F. (2018). Effects of osmotic dehydration treatment on volatile compound (myristicin) content and antioxidants property of nutmeg (*Myristica fragrans*) pericarp. *Journal of Food Science and Technology*, 55(1), 183-189. <https://doi.org/10.1007/s13197-017-2883-2>
8. Rajan, R., & Cherian, E. (2026). The nutmeg pericarp (*Myristica fragrans*) as a functional food ingredient: Phytochemicals, bioactivities and valorization prospects. *Agricultural Products Processing and Storage*, 2, 25. <https://doi.org/10.1007/s44462-026-00059-3>
9. Roman-Benn, A., Contador, C. A., Li, M. W., Lam, H. M., Ah-Hen, K., Ulloa, P. E., & Ravanal, M. C. (2023). Pectin: An overview of sources, extraction and applications in food products, biomedical, pharmaceutical and environmental issues. *Food Chemistry Advances*, 2, 100192. <https://doi.org/10.1016/j.focha.2023.100192>
10. Shopee Indonesia. (2026). Pectin powder food grade 1 kg: Indonesian market-price observation, September 2026.
11. Volza. (2026). Indonesia nutmeg-oil trade data under HSN 33012940: Trade observation accessed September 2026.
12. Vyshak, V. L., Rahila, M. P., Faisal, I., Lukose, S. J., Divya, M. P., Sudhakaran, A., & Rajakumar, S. N. (2023). Extraction and characterization of essential oil of nutmeg (*Myristica fragrans*) fruit pericarp and utilization as a surface coating material to improve the shelf life of paneer. *Journal of Veterinary and Animal Sciences*, 54(1), 144-152. <https://doi.org/10.51966/jvas.2023.54.1.144-152>
13. Yaashikaa, P. R., Kumar, P. S., & Varjani, S. (2022). Valorization of agro-industrial wastes for biorefinery process and circular bioeconomy: A critical review. *Bioresource Technology*, 343, 126126. <https://doi.org/10.1016/j.biortech.2021.126126>
14. Zhang, C. R., Jayashree, E., Kumar, P. S., & Nair, M. G. (2015). Antioxidant and anti-inflammatory compounds in nutmeg (*Myristica fragrans*) pericarp as determined by in vitro assays. *Natural Product Communications*, 10(8), 1399-1402. <https://doi.org/10.1177/1934578X1501000822>