




Strategic Innovation and Bioeconomic Transformation of Nutmeg (*Myristica fragrans*) Agribusiness within the *Dusung* Agroforestry Framework of the Maluku Islands

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Abstract

Nutmeg (*Myristica fragrans*) remains a strategically pivotal spice commodity, characterized by its profound historical, ecological, and economic significance within the Indonesian Maluku Archipelago. Despite Indonesia's enduring comparative advantage in the global spice trade, the long-term sustainability and competitiveness of the nutmeg agribusiness are increasingly compromised by the socio-economic precariousness of smallholder producers and the structural inertia of conventional value chains. This research systematically evaluates the socio-economic profiles of nutmeg smallholders, analyzes the ecological-economic duality of the traditional *dusung* agroforestry system, and formulates strategic bioeconomic innovations to bolster global market positioning. Adopting a descriptive quantitative framework, primary data were elicited from a purposive sample of 75 smallholder farmers situated across primary production epicenters, including the Banda Islands, Leihitu, and West Leihitu sub-districts. The empirical results reveal a demographic skew toward an aging workforce (56% aged 41–60), characterized by extensive hereditary expertise but constrained by limited formal human capital (48% with only primary-level education). This educational deficit significantly inhibits the diffusion of modern technological innovations and complicates adherence to stringent international Sanitary and Phytosanitary (SPS) standards. Furthermore, while the *dusung* system demonstrates high ecological resilience and carbon sequestration potential, it remains ensnared in a low-productivity trap exacerbated by asymmetric market power and price discovery failures. The study concludes that a strategic pivot toward circular bioeconomic downstreaming encompassing volatile compound extraction, pharmaceutical-grade derivatives, and the integration of digital traceability is an absolute imperative. Such a transition is essential to elevate nutmeg cultivation from a subsistence-based legacy practice into a highly competitive, resilient, and sustainable global enterprise.

Keywords: Strategic Innovation, Nutmeg Agribusiness, Socio-Economic Characteristics, *Dusung* Agroforestry, Bioeconomy.

Strategic Innovation and Bioeconomic Transformation of Nutmeg (Myristica fragrans) Agribusiness Based on the Dusung Agroforestry System in the Maluku Islands

Introduction

Nutmeg (*Myristica fragrans*) constitutes a preeminent agricultural and spice commodity of fundamental historical, strategic, and economic significance to Indonesia's real economy, particularly within the Maluku Archipelago. Serving as a genetic epicenter and endemic region widely recognized in global maritime historiography as the Spice Islands the Maluku Archipelago has functioned for centuries as the primary nexus of the global spice trade, a dynamic that fundamentally reconfigured global geopolitical routes (Leunufna, 2022). Within the contemporary economic equilibrium, Indonesia sustains its position as the world's foremost producer and exporter of nutmeg, commanding a global market share that fluctuates between 66% and 77% contingent upon annual supply and demand dynamics. The principal export destinations for this commodity include the European Union, the United States, Vietnam, and Japan (Sujianto et al., 2024).

Despite the critical macroeconomic contributions of nutmeg exports in generating foreign exchange revenues and bolstering the national trade balance, microeconomic realities at the farm-gate level frequently exhibit concerning anomalies and a welfare paradox. The absolute majority of nutmeg plantations in Indonesia (accounting for 99.81%) are managed by smallholder entities that continue to replicate subsistence cultivation practices and traditional, intergenerationally inherited post-harvest techniques (Lontoh et al., 2025).

Fundamental constraints in adopting Good Agricultural Practices (GAP), the weak institutional bargaining position of farmers within the supply chain architecture, and low technological absorptive capacity render the productivity and quality of Indonesian nutmeg highly vulnerable to global price volatility. Furthermore, the viability of this commodity is increasingly threatened by non-tariff barriers (NTBs) specifically Sanitary and Phytosanitary (SPS) standards in developed markets. This is evidenced by the high frequency of Indonesian nutmeg cargo rejections by food safety authorities in the European Union and Japan due to aflatoxin contamination exceeding regulatory thresholds (Purba et al., 2021).

Farm enterprise analysis constitutes a foundational theoretical and applied framework for evaluating the efficiency, productivity, and economic performance of agricultural operations. Within classical economic terminology, farm management is defined as the science of efficient resource allocation aimed at profit maximization over a given time horizon (Ole & Saragih, 2025). According to view Soekartawi (2002:45-50) the success of farm management is not solely predicated on the availability of physical inputs, financial capital, or

agroecological conditions; rather, it is deterministically influenced by the internal characteristics and socio-economic profile of the farmer, who simultaneously acts as the principal manager, strategic decision-maker, and primary labor provider. The inherent socio-economic attributes of the cultivator encompass key variables, including chronological age, level of formal education, accumulated farming experience, landholding size, and the number of family dependents (Gusrati et al., 2023).

The age variable reflects the level of physical, psychological maturity and economic rationality. Soekartawi (2002) elaborating that farmers within the productive age cohort generally possess optimal physical stamina alongside a proactive propensity for risk-taking behavior, which is critical in the adoption of advanced agronomic technologies. Conversely, farmers entering advanced age brackets exhibit a pronounced conservatism toward exogenous changes, electing to preserve traditional production equilibria to avert the risk of crop failure. Concurrently, agricultural experience accumulated over decades constitutes a vital reservoir of indigenous knowledge, which is indispensable for mitigating microclimatic fluctuations and identifying endemic pest cycles (Gusti et al., 2022). However, studies Dewi & Artini (2025) demonstrating that in the absence of commensurate formal education, such empirical experience frequently transmutes into a cognitive bias, thereby obstructing the assimilation of modern scientific methodologies. Education serves as a primary catalyst that broadens cognitive horizons, facilitates the decoding of complex agricultural extension data, and augments the calculative proficiency required to project revenue-to-cost (R/C) ratios. Furthermore, the parameter of landholding size yields a direct indication of the capacity to achieve economies of scale (Soekartawi, 2002:190).

In the context of mediating the agricultural sector's transition from stagnant traditional production systems toward competitive commercial agribusiness entities, the foundational Diffusion of Innovations Theory, conceptualized by Everett M. Rogers, provides a highly precise analytical paradigm. According to Rogers (2003:13-15), innovation is defined as an idea, practice, or object perceived as novel by an individual or other unit of adoption, whereas diffusion constitutes the process through which an innovation is communicated via specific channels over time among the members of a social system. Fundamentally, the innovation adoption process operates as an uncertainty reduction mechanism, wherein individuals continuously seek, process, and validate technical information to evaluate the functional consequences of a technology prior to articulating a final decision to adopt or reject it.

Strategic Innovation and Bioeconomic Transformation of Nutmeg (*Myristica fragrans*) Agribusiness Based on the Dusung Agroforestry System in the Maluku Islands

Rogers (2003:280-282) empirically asserting an asymptotic linear correlation between educational attainment and both the speed and overall rate of adoption. Individuals possessing higher levels of formal education demonstrate superior analytical literacy, a more intensive frequency of exposure to mass media communication channels and change agents, and a more acute economic rationality when evaluating the five principal attributes of an innovation: relative advantage, compatibility, complexity, trialability, and observability.

These characteristics position them within the innovator or early adopter categories. Conversely, the late majority and laggard cohorts are consistently dominated by demographic segments characterized by subsistence-level education, marginal socio-economic status, and communication networks constrained by extreme homophily (exclusive interaction among individuals sharing identical attributes). Within the discourse of Maluku's nutmeg agribusiness, the imperative of innovation diffusion encompasses a broad technological spectrum. This ranges from the utilization of certified clonal seedlings and the application of location-specific liquid organic fertilizers, to the implementation of closed hybrid drying machinery (designed to eliminate exposure to aflatoxin-producing *Aspergillus flavus* spores) and the introduction of mechanized essential oil extraction (Rogers, 2003:37).

To accelerate value creation within an era of global hypercompetition, this study is anchored in the framework of strategic innovation. Strategic innovation denotes the fundamental reengineering of core business models, production processes, and marketing strategies, enabling corporations or agribusiness entities to disrupt existing markets and secure an absolute competitive advantage (Jihad, 2025). Within the paradigm of sustainable agricultural commodities, strategic innovation manifests through a circular bioeconomy approach. The bioeconomy is articulated as the interdisciplinary integration of biotechnology and economics, designed to transform renewable biological resources into a broad spectrum of functional foods, bio-industrial materials, bioenergy, and high-value ecosystem services (Liza et al., 2025).

The operationalization of the bioeconomy within the nutmeg agribusiness cannot be realized without the foundational support of a green accounting system. Green accounting constitutes a managerial accounting innovation that systematically aggregates, analyzes, estimates, and integrates environmental costs into corporate financial performance reporting. By deploying analytical tools such as Material Flow Cost Accounting (MFCA) and Life Cycle Assessment (LCA), nutmeg processing entities can identify material inefficiencies at a granular

level, quantify greenhouse gas emissions originating from logistical processes, and monetize the negative externalities associated with shell waste and distillation effluent. Consequently, such sustainability disclosure transcends its traditional role as a mere regulatory compliance mechanism; it has metamorphosed into a strategic instrument for securing social legitimacy, satisfying global supply chain prerequisites (such as the European Union's carbon emission regulations), and attracting capital inflows from investors driven by Environmental, Social, and Governance (ESG) criteria (Amalia et al., 2025). Furthermore, the integration of digital transformation specifically through the deployment of Internet of Things (IoT) architecture for the precise monitoring of drying chamber humidity, alongside blockchain technology to guarantee transparent commodity traceability constitutes a foundational pillar for inclusive and sustainable economic growth.

A review of the extant literature and prior academic discourse reveals that the majority of studies concerning the nutmeg commodity remain highly fragmented, operating predominantly within narrow disciplinary silos. Studies Rahmanta et al (2025) focusing almost exclusively on competitiveness analyses utilizing indicators such as Revealed Comparative Advantage (RCA), Export Product Dynamics (EPD), or Sustainability-Adjusted Gravity (S-Gravity) models to map international trade flows. Consequently, these macro-level approaches frequently fail to capture the sociological root causes and structural frictions inherent at the grassroots producer level. On the other end of the academic spectrum, studies Girsang et al (2023) agronomic and ecological studies tend to romanticize the biodiversity conservation functions and climate change mitigation potential of endemic agroforestry systems (referred to in the local vernacular as *dusung*). However, this body of literature frequently overlooks critical dimensions of financial viability, economic valuation, and the imperative for innovative business model reengineering.

Departing from these ontological and epistemological gaps, the novelty of this research is manifested through the holistic integration of the cultivators' socio-economic characteristics analysis, the ecological resilience of the *dusung* agroforestry system, and a critical evaluation of the global value chain into a unified "Strategic Innovation and Bioeconomic Transformation" framework. Specifically, this study correlates fundamental socio-demographic variables (encompassing the determinants of age and formal educational attainment) with the adoption capacity for post-harvest technological innovations. Concurrently, it proposes a blueprint for a bioeconomy-based downstreaming strategy that

Strategic Innovation and Bioeconomic Transformation of Nutmeg (Myristica fragrans) Agribusiness Based on the Dusung Agroforestry System in the Maluku Islands

aligns with sustainable economic development priorities, the integration of green accounting, and contemporary business performance.

Building upon the phenomenological context and theoretical imperatives delineated previously, the core research problem of this study investigates how the socio-economic characteristics of nutmeg cultivators in the Maluku Archipelago influence their production capacity and innovative decision-making processes. Furthermore, it examines the extent to which the *dusung* agroforestry system, in conjunction with existing value chain structures, determines the aggregate competitiveness of the nutmeg agribusiness. This inquiry ultimately aims to construct highly precise strategic innovations specifically, bioeconomy-driven downstreaming to transform inherent natural comparative advantages into resilient competitive advantages within global markets. These multidimensional research questions necessitate a comprehensive analytical framework, given the complexity of the nutmeg agribusiness landscape, which encompasses a dynamic intersection of maritime cultural heritage preservation, the ecological sustainability of small tropical islands, and the escalating compliance demands of international trade standards.

As a preliminary conclusion derived from these research findings, it can be firmly asserted that while nutmeg cultivators in the Maluku Archipelago possess profound accumulated empirical experience and robust independent land tenure, their low formal educational attainment and high household dependency ratios act as structural constraints. These frictions severely impede their capacity to adopt modern technologies and penetrate high-value markets. Furthermore, while the endemic *dusung* land management system demonstrates profound ecological superiority, it suffers from economic stagnation due to an absence of product differentiation and value addition. Consequently, the implementation of strategic innovations that operationalize a circular bioeconomy downstreaming approach specifically through essential oil extraction, nutraceutical product formulation, and the valorization of fruit pericarp waste coupled with the institutional strengthening of farmer corporate entities, constitutes an absolute prerequisite. This multifaceted intervention is imperative to elevate cultivator welfare functions and secure Indonesia's sustained dominance within the global spice supply chain architecture.

Research Method

This study is constructed utilizing a quantitative descriptive methodology, which is rigorously elaborated through the triangulation of ecological and economic perspectives.

Grounded in the ontological and procedural definitions articulated by Sugiono (2008:9) quantitative methodology constitutes a scientific approach grounded in the positivist paradigm. It is operationalized to investigate specific populations or samples utilizing standardized data collection instruments, culminating in rigorous statistical analysis aimed at dissecting and reconstructing the objective reality of natural and social phenomena. Furthermore, the quantitative descriptive approach, as described by Nazir (2014:43) entails the empirical collection of field data to precisely, systematically, and factually describe, dissect, and explicate the socio-economic characteristics of the target population, without the intent to inferentially test complex associative or comparative hypotheses.

The spatial design of this research was conducted within the most historically significant and productive nutmeg production centers in Maluku Province. Administratively, these include the Banda Islands (the endemic center of superior quality *Myristica fragrans*), as well as the Leihitu and West Leihitu Districts on Ambon Island. The site selection was determined purposively, based on the rationale that these areas represent a small-island agroecosystem typology that implements the *dusung* local wisdom system and contributes the highest percentage to the aggregate nutmeg production in Central Maluku. The population for this empirical observation encompasses all productive nutmeg cultivators residing within the selected regions. The sampling technique was executed using a simple random sampling method, justified by purposive conditions, resulting in a final sample size of 75 farmer respondents.

The data collection architecture is multidimensional, encompassing both primary and secondary data acquisition. Primary data were gathered directly from the research subjects through non-reactive participant observation, in-depth interviews, and the distribution of structured questionnaires that have undergone rigorous construct validity and internal reliability testing. The measured independent variables include chronological age, formal educational attainment, duration of empirical farming experience, equivalent landholding size, the juridical status of land tenure, household dependency ratios, seasonal production volume, income streams, and the degree of market accessibility. As a complementary instrument, secondary data were accumulated through a bibliometric literature review of high-impact international journal articles indexed in the Scopus database, macroeconomic indicator publications from the Indonesian Central Bureau of Statistics (BPS), and annual reports from the Maluku Provincial Department of Agriculture and Plantation.

Strategic Innovation and Bioeconomic Transformation of Nutmeg (*Myristica fragrans*) Agribusiness Based on the Dusung Agroforestry System in the Maluku Islands

During the data processing phase, the previously recorded raw quantitative data were subsequently analyzed in accordance with central descriptive statistical procedures. Citing the analytical basis from Ghozali (2018) Descriptive statistics serve as a systematic methodological apparatus to transform observational data matrices into tabulations, frequency distributions, percentage calculations, and measures of central tendency (e.g., mean, median, and mode), thereby yielding comprehensive, intuitive, and highly interpretable demographic profiles. Once these socio-economic profiles are mapped with high fidelity, the study integrates rationality evaluations through qualitative instruments, including the Value Chain Analysis (VCA) framework and macro-level competitiveness indicators such as Revealed Comparative Advantage (RCA). This elaborative process aims to synthesize and formulate a relevant, actionable strategic innovation roadmap for the advancement of nutmeg agribusiness bioeconomics in Indonesia.

Result

1. Socio-Economic Characterization of Nutmeg Smallholders in the Maluku Archipelago, Indonesia

The demographic configurations and economic architectures of nutmeg cultivators are of paramount importance in determining farm operational efficiencies and the sustainability trajectories of innovation. Based on an empirical survey of 75 nutmeg (*Myristica fragrans*) farmer respondents in the primary production centers of the Banda Islands, Leihitu, and West Leihitu, a comprehensive mapping of socio-economic characteristics has been developed, as detailed in Table 1.

Table 1. Socio-Economic Characteristics of Nutmeg Smallholders in the Maluku Archipelago

Characteristics	Category	Frequency (n)	Percentage (%)
Chronological Age (Years)	< 40	18	24
	41 – 60	42	56
	> 60	15	20
Formal Educational Attainment	Primary School	36	48

	Junior High School	20	27
	Senior High School	15	20
	Higher Education	4	5
Farming Experience	< 10 Years	12	16
	10 – 20 Years	39	52
	> 20 Years	24	32
Arable Landholding Size (Ha)	< 1 Ha	47	62
	1 – 2 Ha	21	28
	> 2 Ha	7	10
Land Tenure Status	Self-owned	58	77
	Family Inheritance	13	17
	Leased / Tenant System	4	6
Household Dependency Ratio	1 – 3 Dependents	29	39
	4 – 6 Dependents	38	51
	> 6 Dependents	8	10

An analytical examination of the age metrics presented in Table 1 unveils a demographic phenomenon warranting strategic consideration. It is observed that a dominant majority of the farmers (56%) are situated within the 41 to 60-year age cohort. Conceptually, within the frameworks of biology and labor sociology, this age range is categorized as a mid-productive phase, characterized by the capacity to leverage optimal cognitive and physical labor utilities in managing farm operational cycles (Simanjorang et al., 2020). Nevertheless, the absolute dominance of this age strata, when juxtaposed with the scant participation of the younger cohort under 40 (representing only 24%), serves as a robust indicator of a crisis in decelerating agricultural regeneration. This social disruption, manifested through escalating rural-to-urban migration where coastal youth from Maluku’s small islands are increasingly siphoned off into extractive industries (notably massive nickel mining in North Maluku) or the service-based

Strategic Innovation and Bioeconomic Transformation of Nutmeg (*Myristica fragrans*) Agribusiness Based on the Dusung Agroforestry System in the Maluku Islands

tourism sector, both of which are perceived to provide immediate income liquidity injections triggers the structural phenomenon of the "aging farmer" (Rahmawati & Alhaqi, 2025).

A logical corollary of this aging phenomenon is the progressive degradation of the physical capacity required to perform labor-intensive farm intensification activities. These tasks demand extreme physical endurance, particularly the arduous process of harvesting from towering nutmeg tree canopies situated across rugged, hilly topographies. Affirming the postulate Soekartawi (2002:45-50), a corresponding increase in the chronological age of farmers stimulates a shift toward conservative risk-aversion in capital management. Concurrently, it diminishes the strategic aggressiveness and elasticity required for the adoption of agronomic technological instruments, particularly those perceived to entail high-uncertainty variables.

Examined through the lens of human capital capacity, the formal educational landscape of nutmeg cultivators remains at a highly subsistent equilibrium. Notably, 48% nearly half of the total respondent population reported formal educational attainment limited to the primary school level, with only a marginal fraction (5%) successfully accessing higher education. The deterministic correlation between formal educational attainment and the trajectory of farm transformation is empirically substantiated by Rogers' (2003:280-282) *Diffusion of Innovations* theory. This foundational framework postulates that cohorts with a higher accumulation of academic knowledge possess cognitive superiority in selecting, decoding, and formulating precise scientific and innovative information.

The brief duration of formal educational attainment induces cognitive rigidity among these cultivators. Consequently, they experience substantial difficulty in synthesizing the rational correlation between farm sanitation hygiene, the precision of post-harvest drying engineering, and the stringent quality expectation parameters of the European export market (Lontoh et al., 2025). This constraint in critical literacy is, in turn, exploited by supply chain oligopolists (intermediaries) to dictate information asymmetry, artificially manipulate bean grading, and depreciate the welfare margins that should rightfully accrue to the producers.

Notwithstanding the deficiencies in formal educational attainment, nutmeg smallholders in Maluku possess a profound reservoir of intellectual capital derived from extensive empirical experience. The data indicates that a majority (52%) of these cultivators have dedicated between 10 to 20 years to managing the nutmeg commodity, while an additional 32% boast a track record spanning over two decades. Within the rural sociological constructs of the Banda

and Ambon Islands, nutmeg cultivation transcends mere reduction to a commercial economic livelihood; rather, it constitutes a living cultural heritage intrinsically interwoven with customary legal frameworks (*hukum adat*) and communal value systems (Rais et al., 2026).

This iterative experiential learning embeds invaluable ecological wisdom, enabling cultivators to intuitively map the archipelago's agroclimatological cycles. Furthermore, it empowers them to select superior nutmeg phenotypes guided by historical genetic memory and to adaptively respond to the volatile fluctuations of endemic pest populations (Agustina et al., 2024). However, in the contemporary era of global climate disruption, extreme precipitation anomalies driven by the divergence of ENSO (El Niño/La Niña) circulation are severely disrupting the floral initiation and fructification phases of the nutmeg tree, study by Sujianto et al (2024) rendering historical experience alone fundamentally inadequate as a mitigation instrument. Consequently, the integration of precision agro-climatological technological interventions emerges as an unavoidable imperative.

A deeper analysis of the agrarian structure reveals that the spatial configuration of the plantations is overwhelmingly dominated by micro-scale ownership units (smallholdings). A substantial majority of the respondents (62%) operate on landholdings of less than one hectare. This constrained operational scale creates a structural bottleneck, significantly degrading the probability of achieving industrial economies of scale. Furthermore, such marginal land sizes severely constrict the capital accumulation margin, thereby extinguishing any fiscal incentives for farmers to invest in capital-intensive fixed assets, such as the construction of solar dryer domes or the installation of integrated, village-level essential oil distillation extractors (Wattimena et al., 2023).

Despite confronting these spatial restrictions, a crucial positive anomaly emerges within the agrarian institutional indicators: a substantial 77% of the land is operated under absolute private ownership, supplemented by 17% held under customary inheritance (*tanah dati*) or extended family communal rights. The solidity of these secure land property rights engenders a profound sense of ontological security. Consequently, it guarantees the cross-generational investment certainty that is absolutely vital for the sustainability of perennial woody crops such as nutmeg, which typically only reaches its ecological break-even point after seven years of vegetative growth (Girsang et al., 2023). Conversely, a latent structural challenge emerges from the demographic dimension of the household dependency ratio; a significant 51% of these smallholders function as the sole economic providers for four to six structural family members.

Strategic Innovation and Bioeconomic Transformation of Nutmeg (Myristica fragrans) Agribusiness Based on the Dusung Agroforestry System in the Maluku Islands

The acute pressure of continuous household liquidity outflows compels these cultivators to execute fatalistic economic strategies. These include forward selling of standing crops (*jual tebas*) or the premature liquidation of commodity yields in a high-moisture, immediate post-harvest state a classic manifestation of distress selling. Ultimately, this subsistence-driven defensive mechanism destructively destabilizes the equilibrium of supply elasticity, thereby severely eroding the farmers' price bargaining power against village-level intermediary aggregators (Savitri et al., 2026).

2. Ecological Dualism and the Bioeconomic Valuation of the Dusung Agroforestry System

The agricultural landscape of the Maluku Archipelago is endowed with a masterpiece of land-use biodiversity engineering, internationally recognized as the *dusung* system. Conceptually, the *dusung* represents a high-precision polyculture agroforestry architecture. It weaves a functional coexistence between large protective woody canopy stands, premier commercial plantation crops (nutmeg, clove, and coconut), and an understory stratum of annual crops, all integrated within a singular ecological boundary that is transmitted intergenerationally (Wattimena et al., 2023).

From the perspective of environmental ecological restoration, the spatial design of the *dusung* establishes a vertically stratified silvicultural simulation of a natural tropical forest canopy. The uppermost dominant canopy stratum is occupied by protective overstory species, such as *kanari* (*Canarium indicum*) and forest durian. These trees are strategically employed as windbreakers against cross-sea storm gales and function as microclimate regulators that mitigate evapotranspiration an essential prerequisite for optimizing photosynthetic efficiency *Myristica fragrans* (Girsang et al., 2024).

Meanwhile, the intermediate canopy layer is occupied by moderate-density stands of nutmeg and clove trees. Concurrently, the forest floor stratum is blanketed by rhizomatous vegetation, herbaceous plants, and intercropped food staples. This robust ground cover effectively eliminates the threat of surface run-off, mitigates latent erosion risks within the steep, hilly archipelagic morphology, and sequesters exceptionally high carbon stock deposits with biomass sequestration estimated to reach 275.092 tons C/ha within the Ambon Island ecoregion (Latumahina et al., 2021). Furthermore, this ecological approach facilitates biomass nutrient regeneration through periodic leaf litter decomposition cycles. This natural process provisions the archipelagic alluvial soils with essential organic nutrients, thereby averting a

pathological dependency on commercial synthetic fertilizers (effectively functioning as a *de facto* local organic farming system) (Wawan et al., 2025).

Ironically, when analyzed through the lens of aggregate commercial viability and bioeconomics, the orthodox management of the *dusung* system faces an asymptote of stagnation. Empirical data reveals that the metric yield productivity of nutmeg in conventional *dusung* areas on Ambon Island remains trapped at severely low levels, fluctuating erratically between 0.39 and 0.77 tons per hectare per annum. This failure to escalate production volumes is exacerbated by the irregular spatial geometry of the mixed stands, the complete absence of maintenance canopy pruning which induces interspecific competition for photosynthetic solar radiation and the retention of senescent nutmeg populations that have far surpassed their peak genetic productivity (>60 years). Furthermore, this stagnation is compounded by a persistent reluctance to adopt integrated pest management protocols for lethal pathogens, including infestations by stem borer insects, progressive stem canker, and microbiological wet fruit rot (Kesaulya et al., 2021).

The cultivators are entrenched in a conservative mental paradigm that positions *dusung* commodities merely as instruments of "passive natural savings," rather than as biological manufacturing entities requiring precise engineering of their input-output ratios. Macroeconomically, this renders the nutmeg supply curve at the primary producer (farm-gate) level almost perfectly inelastic (rigid). Consequently, when the global demand curve experiences an exponential outward shift resulting in skyrocketing equilibrium prices, these farmers are alienated from the ensuing momentum of wealth creation. They remain physiologically and agronomically paralyzed, fundamentally incapable of instantaneously multiplying harvest volumes to capture market surges.

3. Export Competitiveness Indicators and the Disruption of Non-Tariff Barriers in the Global Market

An evaluation of the export competitiveness of the Republic of Indonesia's nutmeg commodity within the globalized arena of the international spice trade exposes a highly critical dichotomous divergence. On one end of the spectrum, cross-country econometric estimations utilizing Revealed Comparative Advantage (RCA) and Symmetric Revealed Comparative Advantage (SRCA) indices consistently ratify the postulate that Indonesia retains an absolute hegemony. It exercises an undeniable natural comparative advantage in monopolizing the

Strategic Innovation and Bioeconomic Transformation of Nutmeg (Myristica fragrans) Agribusiness Based on the Dusung Agroforestry System in the Maluku Islands

product classifications for both homogeneous whole nutmeg seeds and ground nutmeg powder derivatives (Rahmanta et al., 2025).

In terms of aggregate statistical volume, Indonesia dictates the global supply market by commanding an overwhelmingly dominant market share. This supply quota fluctuates within an elastic range of 66%, reaching a culmination point of 77% across various trade reporting fiscal years (Sujianto et al., 2024). The indigenous endemic genotype of the Banda Nutmeg (botanical species *Myristica fragrans*) commands an undisputed supremacy within the global flavor and fragrance industries. This elevated status is directly attributed to its exceptionally abundant concentration ratio of pure volatile oils, coupled with a profoundly sharp and exotic aromatic compound signature. Crucially, this unique profile is biomolecularly impossible for competing synthetic substitute commodities to artificially replicate.

Nevertheless, the equilibrium matrix of contemporary global competition has undergone a radical transformation. The determinant parameters of competitiveness are no longer myopically concentrated on the struggle for low-margin commodity price dominance. Instead, they have migrated toward a fierce battleground defined by Quality Assurance dimensions, ecological Sustainability footprint audits, and uncompromising demands for biomedical and phytosanitary food safety protocols. Quantitative simulation analyses, utilizing the extended equation of the Sustainability-Adjusted Gravity (S-Gravity) Model, have successfully demonstrated that the stability of Indonesia's export volume curves and value trajectories suffers from chronic vulnerability to asymmetric shocks driven by exchange rate volatility. Furthermore, and far more perilously, these trajectories remain perpetually distorted and held hostage by discriminatory technical non-tariff barriers (NTBs) orchestrated by the bureaucracies of advanced industrialized importing nations (Rahmanta et al., 2025).

The European Food Safety Authority (EFSA) and Japanese regulatory authorities have a long, documented history of unilaterally executing dozens of port rejections and mandating the destruction of Indonesian nutmeg export consignments. The justification for the rejection of these multi-billion-rupiah cargoes uniformly stems from the detected presence of aflatoxin contamination an acute carcinogenic secondary mycotoxin synthesized by the hyphal spores of the *Aspergillus flavus* mold. Furthermore, these rejections are predicated on microbiological contamination loads (microbiological counts) that allegedly breach the stringent maximum tolerance thresholds enforced by the European consumer protection regulatory regime (Hafif, 2021).

This pathological reality the specter of lethal contamination is rooted entirely in the underdeveloped, primary post-harvest processing malpractices at the smallholder institutional level (smallholders' negligence). The essential dehydration process required to reduce the moisture content of the nutmeg seeds (which are frequently still encased within their wet shells) is conventionally executed on open-air tarpaulins. Consequently, the harvest is highly vulnerable to humid precipitation anomalies and suffers from a critical lack of constant, artificial thermal air circulation. Ironically, the drying beans are still frequently spread out in direct conductive contact with soil-borne pathogenic microbes on earthen floors lined merely with woven mats (Hafif, 2021).

4. Value Chain Asymmetry and the Distortion of Marketing Channels

Shifting to the anatomical architecture of the domestic supply chain mapping, the deep penetration of information asymmetry and the formation of exploitative oligopsonistic market structures have triggered a severe depression of the financial profit margin surplus among the peasantry. The logistical flow of marketing distribution trajectories is generally initiated in a linear and hierarchical fashion: originating from the upstream point of smallholder producers in remote small-island centers, flowing asymmetrically into the hands of predatory village-level intermediary collectors (sociologically termed as *tengkulak*), and subsequently transmitted to the buffer warehouses of large-scale accumulators in urban provincial capitals and commercial transit ports (concentrated within the bays of Ambon or the harbors of Ternate). Ultimately, this trajectory culminates at the massive exporter installations located in the deep-water ports of Surabaya or Tanjung Priok, Jakarta (Jelliani & Raidayani, 2020).

Due to the cultivators' socio-economic precariousness, driven by the acute liquidity pressures of escalating inflation in primary household consumption costs (as validated by the high dependency ratio within family demographics), their option to defer sales transactions is effectively non-existent. There is no negotiating leverage for these smallholders to engineer price speculation strategies or to extend the "waiting time" for warehouse-delayed inventory; the capacity for holding stock to await better market conditions is entirely absent.

The syndicate of intermediary collecting agents despotically monopolizes the privilege of dictating price compensation standards. These purchase prices are set based solely on unilateral, asymmetric claims regarding the degradation of commodity quality indicators. Frequently, these intermediaries "scapegoat" specific parameters, such as the moisture yield

Strategic Innovation and Bioeconomic Transformation of Nutmeg (Myristica fragrans) Agribusiness Based on the Dusung Agroforestry System in the Maluku Islands

percentage claiming it has not been sufficiently reduced to absolute dryness or arbitrarily devaluing the physical aesthetic grading of the shelled nutmeg seeds.

The poverty of information literacy regarding real-time global spice commodity terminal prices within isolated archipelagic rural epicenters results in an autocratic and skewed price discovery failure. This predatory supply chain theorem serves as a rational analytical foundation and valid empirical confirmation as to why despite the astronomical surge in the currency-converted auction valuations of dried nutmeg at European commodity exchange terminals the linear trend of the financial welfare indicators for nutmeg-producing farming communities across the Maluku peninsula remains characterized by persistent stagnation and multi-layered poverty over time (Salampessy et al., 2017).

5. Strategic Innovation: The Imperative of Bioeconomic Downstreaming and Corporate Sustainability

a. The Urgency of Strategic Innovation in Nutmeg Agribusiness

Nutmeg agribusiness in Maluku must be transformed from subsistence-based legacy practices into highly competitive and sustainable global business entities. This transition necessitates strategic innovation, defined as the fundamental re-engineering of core business models, production processes, and marketing strategies to disrupt existing markets and secure an absolute competitive advantage.

b. Circular Bioeconomic Downstreaming

The tactical execution of this strategic innovation is realized through a circular bioeconomy approach. This framework integrates biotechnological and economic disciplines to convert renewable biological resources into functional food products, bio-industrial materials, energy, and high-value ecosystem services. The bioeconomic downstreaming of nutmeg commodities encompasses:

- 1) The extraction of volatile compounds into high-purity essential oils;
- 2) The formulation of pharmaceutical or nutraceutical derivatives;
- 3) The valorization of nutmeg pulp (pericarp) waste to generate added value and facilitate product differentiation.

c. Corporate Sustainability: Green Accounting and Digitalization

Bioeconomic downstreaming cannot be realized without the support of sustainable corporate operational systems that adhere to rigorous international standards:

- 1) The implementation of Green Accounting serves as a managerial accounting innovation designed to integrate environmental costs into corporate financial performance reports. By deploying Material Flow Cost Accounting (MFCA) and Life Cycle Assessment (LCA) frameworks, business entities can systematically identify material inefficiencies, quantify greenhouse gas (GHG) emissions, and monetize waste externalities.
- 2) Fulfilling Global and ESG Requirements: Sustainability reporting has metamorphosed into a strategic instrument for meeting global supply chain prerequisites such as EU carbon regulations and is critical for attracting capital flows from investors governed by Environmental, Social, and Governance (ESG) criteria.
- 3) Digital Technology Integration: Leveraging the Internet of Things (IoT) for the precision monitoring of post-harvest moisture levels, alongside the deployment of blockchain to guarantee transparent commodity traceability, constitutes a foundational pillar for inclusive growth.

d. Institutional Synergy and Collaborative Governance

The implementation of this bioeconomy blueprint establishes the institutional strengthening of farmer corporations as an absolute prerequisite. It requires an intensified institutional policy synergy between state entities, research institutions, and farmer corporations themselves to act as a catalyst for orchestrating a resilient, efficient, and equitable economic sustainability agenda.

Conclusion

Based on the empirical and analytical exploration presented, this study concludes that the socio-economic characteristics of nutmeg farmers in the Maluku Archipelago predominantly an aging demographic with limited formal education and high dependency ratios function as structural constraints that hinder the assimilation of precision post-harvest technologies.

Strategic Innovation and Bioeconomic Transformation of Nutmeg (Myristica fragrans) Agribusiness Based on the Dusung Agroforestry System in the Maluku Islands

Furthermore, while the *dusung* polyculture agroforestry system demonstrates ecological superiority through biodiversity conservation and carbon sequestration, it remains ensnared in a marginal economic productivity trap, exacerbated by information asymmetry within an oligopsonistic value chain. To transcend these structural weaknesses, the integration of strategic innovations centered on circular bioeconomic downstreaming namely volatile compound extraction, nutraceutical formulation, and the implementation of green accounting and digital traceability is an absolute imperative to reclaim the absolute competitive advantage of Indonesian nutmeg in the global spice market. Ultimately, an aggressive institutional policy synergy among state entities, research institutions, and farmer corporations is required as the primary catalyst to orchestrate a resilient, efficient, and equitable economic sustainability agenda.

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Strategic Innovation and Bioeconomic Transformation of Nutmeg (Myristica fragrans) Agribusiness Based on the Dusung Agroforestry System in the Maluku Islands

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