

Volume 2, Issue 3

Research Article

Date of Submission: 13 August, 2026

Date of Acceptance: 08 September, 2026

Date of Publication: 16 September, 2026

From Fresh Fruit Bunches to Better Nutrition: Red Palm Oil as a Nutrition-Sensitive Pathway for Inclusive and Sustainable Smallholder Downstreaming in Rural Indonesia

Loso Judijanto* 

IPOSS Jakarta, Indonesia

***Corresponding Author:**

Loso Judijanto, IPOSS Jakarta, Indonesia.

Citation: Judijanto, L. (2026). From Fresh Fruit Bunches to Better Nutrition: Red Palm Oil as a Nutrition-Sensitive Pathway for Inclusive and Sustainable Smallholder Downstreaming in Rural Indonesia. *Lett Econ Res Updates*, 2(3), 01-21.

Abstract

Red palm oil (RPO) presents an unusual development opportunity because its value is simultaneously nutritional and economic. Produced through processing routes that retain naturally occurring carotenoids and vitamin E compounds, RPO may provide a food-based source of provitamin A and other bioactive constituents for nutritionally vulnerable rural populations. At the same time, decentralized RPO processing could enable oil palm smallholders to progress from selling fresh fruit bunches toward processing, product differentiation, branding, and downstream value capture. This qualitative literature review synthesizes peer-reviewed literature published primarily between 2020 and 2026 across nutrition science, food technology, agricultural economics, rural development, value-chain studies, and sustainability research. The evidence indicates that the strongest contemporary human evidence for RPO concerns increased exposure to provitamin A carotenoids, with emerging findings concerning hematological outcomes, intestinal parasite reinfection, xerophthalmia prevention, and gut microbiota. These findings do not justify portraying RPO as a stand-alone solution to stunting or chronic disease. Economically, successful smallholder downstreaming depends on collective action, professional cooperative governance, reliable feedstock, technology, food-safety assurance, working capital, market development, and traceability. The paper proposes a Red Palm Oil Nutrition–Downstreaming Nexus, in which nutrition-sensitive value chains, smallholder value capture, and four-dimensional sustainability—economic, nutritional, social, and environmental—are developed simultaneously. A phased policy architecture emphasizing demonstration clusters, evidence-based nutrition programs, cooperative ownership, professional management, blended finance, sustainability safeguards, and multidimensional monitoring is recommended.

Keywords: Red Palm Oil, Rural Nutrition, Provitamin A, Carotenoids, Tocotrienols, Oil Palm Smallholders, Downstreaming, Cooperatives, Inclusive Value Chains, Sustainability

JEL Classification: I15, O13, Q12, Q13, Q18

Introduction

Rural Nutrition and the Development Paradox of Oil-Palm-Producing Regions

Improving nutritional quality in rural communities is fundamentally more complex than increasing the availability of calories. Malnutrition encompasses inadequate micronutrient intake, poor dietary diversity, impaired child growth, anemia, infection-related nutritional losses, and, increasingly, excessive consumption of energy-dense foods associated with non-communicable disease risks. In Indonesia, child stunting and other manifestations of malnutrition have repeatedly been shown to be associated with factors operating at household, community, and regional levels, including dietary adequacy, maternal characteristics, household socioeconomic status, sanitation, health services, education, and local institutional capacity [1,2]. Consequently, no single commodity or micronutrient should be presented as an isolated cure for a multidimensional nutritional problem.

At the same time, many rural Indonesian communities participate directly in one of the country's most commercially important agricultural sectors: oil palm. Oil-palm cultivation has generated substantial income and welfare benefits for many smallholders, although the distribution and durability of these gains are heterogeneous. Panel-based research has found that participation in oil palm cultivation can raise household consumption and provide some protection from economic risk, while other studies suggest that higher agricultural income can contribute indirectly to improved food access and dietary quality [3,4]. However, benefits depend on production conditions, market access, institutional arrangements, land tenure, gender relations, location, and the wider structure of the value chain.

This produces an important development paradox. Many smallholder households are integrated into the palm oil economy mainly as suppliers of fresh fruit bunches (FFB), whereas a considerable share of processing, formulation, branding, distribution, and product differentiation occurs farther downstream. Participation in primary production therefore does not necessarily provide farmers with substantial influence over downstream value creation. Nor does the presence of oil palm in a region automatically translate into improved local nutrition.

Red palm oil (RPO) provides an interesting point at which these two challenges can potentially intersect. Unlike conventionally refined palm oil, RPO is processed using conditions intended to retain a comparatively high proportion of the naturally occurring carotenoids and vitamin E compounds originally present in crude palm oil. Contemporary food-science literature particularly identifies α - and β -carotenes, tocopherols, and tocotrienols as nutritionally important components of RPO [5].

The initial material supplied for this article reflects the growing Indonesian policy discourse surrounding precisely this dual potential. It highlights the carotenoid, tocopherol, and tocotrienol content of red palm oil and associates these compounds with opportunities for nutrition improvement. The material also proposes product diversification—including more convenient product formats—and connects RPO downstreaming with village cooperatives, rural employment, farmer welfare, and potentially improved FFB price stability.

Those propositions provide an important agenda-setting input, but they should not themselves be treated as clinical or economic proof. Claims that RPO can “solve” stunting, prevent neurodegenerative diseases, or automatically stabilize farmer income require much more careful evidentiary qualification. The present review therefore transforms this development proposition into an academic question: under what conditions can the nutritional characteristics of RPO and smallholder-controlled downstreaming reinforce one another without overstating health benefits, transferring excessive commercial risk to farmers, or generating additional environmental pressure?

Why Red Palm Oil Deserves Renewed Attention

RPO is not simply conventional cooking oil with a different color. Mild refining technologies can retain carotenoids and vitamin E components that are substantially reduced through conventional refining, bleaching, and high-temperature deodorization [5]. Its reddish-orange appearance is therefore closely connected with the very carotenoid fraction that creates much of its nutritional differentiation. Processing, however, becomes nutritionally consequential: inappropriate heating, oxygen exposure, light, and storage can degrade phytonutrients and undermine the product's intended value [6-8].

The contemporary human evidence base has also expanded. Surveys of rural Malaysian schoolchildren documented substantial burdens of malnutrition and vitamin A deficiency in the populations from which recent RPO intervention research was developed [9]. A six-month double-blind randomized trial among vitamin A-deficient rural Malaysian schoolchildren found that biscuits containing red palm olein increased circulating alpha- and beta-carotenes and produced favorable changes in several hematological and iron-related indicators relative to the control product, although retinol outcomes require more nuanced interpretation because improvements occurred in both groups [10]. Related research reported a lower six-month *Ascaris lumbricoides* reinfection rate in the RPO group after anthelmintic treatment, while emphasizing that the effect was parasite-specific and needed confirmation elsewhere [11].

Further research has expanded the potential mechanistic picture. A 2025 randomized trial reported changes in gut microbial composition and network characteristics following RPO-enriched biscuit supplementation in vitamin A-deficient children [12]. Another 2025 cluster randomized trial examined RPO supplementation as a potential strategy for preventing xerophthalmia among vitamin A-deficient primary schoolchildren, adding an ocular-health endpoint to the recent evidence base [13].

These findings make RPO worthy of serious nutritional consideration, but they do not transform it into a universal therapeutic product. Evidence regarding purified tocotrienols, isolated carotenoids, animal models, and cellular experiments cannot automatically be attributed to ordinary RPO consumption. Similarly, promising results in vitamin A-deficient Malaysian schoolchildren cannot automatically be generalized to all Indonesian rural populations.

The Economic Case for Smallholder Downstreaming

The second rationale for renewed attention concerns economic structure. Indonesian oil palm smallholders frequently encounter constraints involving access to finance, high-quality planting material, extension, legal documentation,

certification, traceability, market information, and bargaining power [14-16]. Certification studies further demonstrate that higher sustainability standards do not automatically produce inclusion: participation requires organization, documentation, internal-control systems, technical capacity, and affordable compliance mechanisms, while certification costs and benefits can vary substantially across farmers and implementation contexts [17-20].

RPO downstreaming could potentially alter the position of farmers within this structure. Instead of merely producing FFB and transferring it to an external processor, organized smallholders could participate in aggregation, processing, quality assurance, packaging, product development, branding, and distribution. Recent Indonesian research on cooperative or corporate-farming approaches similarly suggests that collective processing can become one route toward stronger smallholder value-chain participation [21].

Yet downstreaming should not be romanticized. Owning processing equipment is not equivalent to running a viable food enterprise. Smallholder organizations must manage utilization rates, feedstock quality, plant maintenance, working capital, product standards, market development, inventory, distribution, professional staffing, and price risks. An underutilized factory financed by farmer debt can destroy rather than create smallholder value. Therefore, the relevant economic objective is not “processing for its own sake,” but sustainable farmer value capture.

Objectives and Research Questions

This article develops an integrated qualitative synthesis around five research questions. First, what does recent scientific literature indicate about the composition of RPO and the mechanisms through which it could contribute to improved rural nutrition? Second, under what processing, dietary, behavioral, and institutional conditions can biochemical potential translate into meaningful nutritional effectiveness? Third, through what organizational and commercial arrangements could oil palm smallholders participate in downstream RPO production and capture additional value? Fourth, what economic, social, nutritional, and environmental safeguards are required for such downstreaming to be genuinely inclusive and sustainable? Fifth, what integrated policy architecture could connect RPO-based rural nutrition with smallholder-controlled industrial upgrading? Together, these questions motivate the Red Palm Oil Nutrition-Downstreaming Nexus, which conceptualizes RPO simultaneously as a nutrient-preserving food, a differentiated downstream product, a potential vehicle for local industrialization, and a test case for nutrition-sensitive agricultural development.

Literature Review and Conceptual Foundations

Red Palm Oil: Product Definition, Composition, and Processing

Palm fruit naturally contains a complex lipid and phytonutrient matrix. RPO is obtained by processing palm oil under conditions designed to retain substantially more of the naturally occurring carotenoids and vitamin E compounds than conventional refining. The principal fatty acids include palmitic and oleic acids, while its distinctive micronutrient attributes include α - and β -carotene and different tocopherol and tocotrienol homologues [5,22].

This distinction is fundamental. Crude palm oil, conventionally refined palm olein, red palm oil, and red palm olein cannot be treated as identical products. Conventional refining aims to produce neutral flavor, color, stability, and consumer familiarity, RPO processing deliberately preserves a portion of the colored carotenoid fraction. Mild deacidification and deodorization technologies can therefore become part of a nutritional strategy because process severity determines how much of the original phytonutrient profile remains in the final product [5].

Post-processing handling is equally important. Experiments examining thermal treatment demonstrate progressive carotenoid and tocol degradation under prolonged or severe heating, although significant retention is possible under appropriate conditions [6]. Research on RPO-containing bakery products additionally shows that an RPO food vehicle can retain meaningful concentrations of bioactive compounds and remain sensorially acceptable [23]. Storage studies likewise indicate that temperature, oxygen, packaging, and storage duration influence oxidative quality and phytonutrient retention [7,8].

These findings carry a direct policy implication: a program promoting RPO cannot focus only on how much carotenoid exists at the refinery gate. It must consider nutrient retention from processing to consumption. Production technology, packaging, transport, shelf conditions, household storage, and cooking method form one continuous nutritional delivery system.

Provitamin A as the Strongest Nutritional Rationale

The best-established nutritional rationale for RPO is its carotenoid content, especially α - and β -carotene. Beta-carotene is an important provitamin A carotenoid that can be enzymatically converted into retinoids according to physiological requirements, while vitamin A contributes to normal vision, epithelial integrity, immune function, growth, and cell differentiation. Because carotenoids are lipid-soluble and their bioavailability depends on food matrix, dose, host factors, and co-consumed fat, their occurrence in an edible-oil matrix is nutritionally relevant but does not eliminate interindividual variability [5,24-26].

The nutritional proposition is therefore more defensible when formulated as “RPO can serve as a food-based source of provitamin A carotenoids” than when framed as “RPO prevents stunting.” The first proposition follows directly from

food composition and human biomarker evidence. The second jumps across multiple causal stages and overlooks the multidimensional determinants of child growth.

The most informative recent human trial illustrates this distinction. Tan et al. (2024) randomized 651 rural Malaysian schoolchildren with vitamin A deficiency to receive red palm olein-enriched or palm-olein biscuits for six months [10]. Both groups experienced improvement in retinol and retinol-binding protein, and the between-group retinol effect was not uniformly superior for RPO. In contrast, α - and β -carotene levels, iron, and several hematological measures improved more strongly in the experimental group. This pattern demonstrates why outcomes must be interpreted individually rather than using a generalized claim that “RPO improves all nutritional indicators.”

The 2025 xerophthalmia trial provides an additional human-health endpoint and is particularly important because ocular manifestations are directly related to vitamin A deficiency. It strengthens the case for continued research on RPO as part of food-based approaches to vitamin A inadequacy, while still not supporting broad therapeutic extrapolation to unrelated diseases [13].

Vitamin E, Tocotrienols, and the Problem of Evidence Extrapolation

RPO also contains tocopherols and tocotrienols. The broader palm-vitamin E literature reports antioxidant, anti-inflammatory, neurobiological, and metabolic activities associated particularly with tocotrienols [27,28]. Recent narrative assessments similarly identify a wide spectrum of potentially beneficial RPO-associated bioactives while emphasizing substantial heterogeneity in experimental designs and the need for additional human clinical research [29].

This evidence requires careful translation. An intervention using a purified palm tocotrienol-rich fraction at a controlled pharmacological dose is not equivalent to ordinary consumption of RPO. Likewise, molecular effects observed in cell culture or animal models establish biological plausibility, not community-level effectiveness.

The distinction is particularly important for cardiovascular and neurological claims. Reviews of tropical oils show that lipid outcomes depend strongly on the comparator and on which dietary fat is replaced, while a 2024 randomized trial comparing red palm olein with extra virgin olive and coconut oils found distinct carotenoid responses without establishing a simple overall cardiometabolic advantage for red palm olein [30,31]. The appropriate public-health message is therefore not to add unlimited quantities of RPO to existing diets simply because it contains micronutrients. Instead, RPO should be positioned as a nutritionally differentiated edible fat used in appropriate quantities and, where feasible, as a substitution for another culinary fat while preserving overall dietary balance.

RPO, Hematological Outcomes, Infection, and Emerging Microbiome Evidence

Recent RPO research suggests that its relevance may extend beyond circulating provitamin A carotenoids, but the strength of evidence varies considerably. The discussion therefore distinguishes direct human outcomes from exploratory mechanisms so that later policy implications remain proportionate to the evidence.

The 2024 Malaysian trial found favorable changes in iron and erythropoietic indicators among children receiving RPO-enriched biscuits, including reductions in microcytic anemia in the experimental group [10]. These findings could reflect interactions among vitamin A status, inflammatory processes, iron utilization, and overall micronutrient metabolism, but replication and mechanistic clarification are needed.

An associated randomized study investigated soil-transmitted helminth reinfection after albendazole treatment. Six months after treatment, *Ascaris lumbricoides* reinfection was lower among children receiving RPO-enriched biscuits than among controls, whereas the same pattern was not demonstrated consistently for all helminths [11]. A biologically plausible interpretation involves vitamin A-related epithelial integrity and immune function, but this remains an emerging pathway rather than evidence that RPO itself should be prescribed as an antiparasitic intervention.

In 2025, the same broader research program reported modulation of gut microbial composition and microbial network characteristics after six months of RPO-enriched biscuit supplementation. The trial involved 328 vitamin A-deficient children and identified associations between microbial changes and micronutrient or hematological indicators [12]. The microbiome findings are scientifically interesting but should be interpreted as an emerging mechanism rather than as a validated clinical endpoint.

Taken together, these studies reveal a useful hierarchy of claims. Evidence is relatively direct for RPO as a source of provitamin A carotenoids, increasingly suggestive for hematological and ocular outcomes, intriguing but still developing for immunity, parasitic reinfection, and gut microbiota, and insufficient for generalized claims concerning chronic disease prevention.

Food Vehicles, Fortification Logic, and Consumer Acceptability

The biological availability of a nutrient does not guarantee successful nutritional intervention. A product must also be consumed repeatedly, in suitable amounts, by the intended population. Therefore, food format, price, taste, color, convenience, cultural familiarity, and household preparation become critical elements of effectiveness.

RPO has several possible delivery formats. Direct use as household cooking oil has the advantage of fitting an existing food practice but creates uncertainty about dose, heating, and substitution. Incorporation into standardized foods—such as biscuits, bakery products, spreads, complementary food ingredients, or institutional meals—allows more predictable dosing but increases processing and distribution requirements. Controlled bakery research demonstrates that RPO can be incorporated into sensorially acceptable products while retaining carotenoids and vitamin E compounds under suitable conditions [23].

Encapsulation offers another technological pathway. Research on vitamin A fortification increasingly emphasizes encapsulation and stabilization strategies designed to protect oxidation-sensitive compounds during processing and storage [32]. Fortified-oil research also demonstrates why actual nutrient concentrations and physicochemical properties must be monitored through supply chains rather than assumed from formulation targets [33].

The best delivery vehicle may therefore differ by target group. Household RPO may be appropriate for ordinary culinary substitution. A standardized RPO-enriched product may be more suitable for a controlled school-based intervention. A concentrated or encapsulated product could be commercially viable in a nutraceutical market, but it should not automatically replace ordinary food-based nutrition strategies.

Why RPO Should Not Be Framed as a Stand-Alone Stunting Intervention

Stunting is a manifestation of chronic constraints on child growth rather than a specific vitamin A-deficiency disease. Indonesian evidence identifies determinants ranging from inadequate diet and infection to parental socioeconomic conditions, health care, water and sanitation, and local public capacity [1,2]. Dietary diversity and parental nutrition knowledge also remain central to child nutritional quality [34].

Consequently, RPO can contribute to a nutrition-sensitive portfolio, especially where provitamin A inadequacy is relevant, but should not displace breastfeeding support, complementary feeding, dietary diversification, infection control, sanitation, maternal health, immunization, or clinically indicated micronutrient programs. This evidence-calibrated framing improves the academic credibility of the RPO proposition and protects rural communities from exaggerated health marketing.

Agricultural Value-Chain Upgrading and Smallholder Value Capture

The economic argument begins with a distinction between value creation and value capture. Processing FFB into a differentiated RPO product may create additional gross value, but smallholders benefit only when a meaningful share of that value accrues to them after accounting for operating costs, depreciation, finance, management, quality assurance, logistics, marketing, and commercial risk.

Value-chain upgrading literature distinguishes several forms of upgrading. Product upgrading involves producing a higher-quality or more differentiated product. Process upgrading improves efficiency. Functional upgrading occurs when producers acquire new activities such as processing, packaging, logistics, or marketing. RPO downstreaming potentially combines all three.

This is particularly relevant because smallholders face structural disadvantages in conventional palm chains. Institutional research in Sumatra indicates that independent farmers commonly experience weaknesses involving bargaining position, capital, farm management, market information, and collective institutions [14]. Sustainability-certification studies likewise demonstrate that legality, organizational readiness, documentation, training, and group capacity are major barriers to participation [15,16].

Smallholder downstreaming can therefore be understood as an attempt to transform farmers from price-taking raw-material suppliers into partial owners of downstream functions. The critical word is “partial”: farmers need not personally operate every technical process. Ownership, professional operation, strategic partnerships, and equitable distribution of returns can be separated institutionally.

Collective Action, Cooperatives, and Professionalization

Individual smallholders rarely possess sufficient FFB volume, capital, laboratory capacity, marketing expertise, and managerial resources to operate a food-processing enterprise independently. Collective action is therefore central.

A cooperative can aggregate feedstock, distribute fixed costs, strengthen bargaining power, obtain finance, coordinate certification, organize traceability, and create a legal vehicle for collective asset ownership. Research on Indonesian independent smallholders repeatedly identifies organization as a critical precondition for successful certification and market inclusion [16,17,20].

However, farmer ownership and professional management should not be treated as opposites. A cooperative-owned RPO plant requires professional engineering, accounting, procurement, food-safety, sales, and risk-management functions. Democratic governance determines strategic accountability and distribution of benefits, qualified management ensures commercial operation.

This distinction also guards against elite capture. An enterprise can carry the label “cooperative” while decision-making, contracts, information, or benefits remain concentrated among local elites or better-capitalized members. Inclusive downstreaming therefore requires transparency concerning membership, voting, procurement rules, patronage payments, dividends, wages, retained earnings, and debt exposure.

Smallholder Welfare, Resilience, and the Limits of Commodity Dependence

Oil-palm cultivation has contributed positively to many Indonesian farm households. Mehraban *et al.* (2021) found higher household consumption expenditure associated with oil palm cultivation and evidence of risk-reducing effects [4]. Chrisendo *et al.* (2020) similarly demonstrated pathways connecting land-use change, household income, nutrition, and gender roles [3].

Yet dependence on a single primary commodity can produce vulnerability to price cycles, crop aging, production shocks, climate risks, and industrial restructuring. Hendrawan, Chrisendo and Musshoff (2024) emphasize the need to strengthen smallholder resilience to future industrial challenges, while Petri *et al.* (2024) identify substantial obstacles related to replanting aging palms [35,36].

Downstreaming can diversify sources of value without necessarily diversifying the underlying crop. For that reason, it should be combined with household livelihood diversification, improved farm productivity, replanting support, and food-system development. Modern-smallholder research in Indonesia similarly emphasizes diversified livelihood and landscape strategies rather than narrowly maximizing a single commodity flow [37].

Sustainability as a Four-Dimensional Requirement

Sustainable RPO downstreaming requires four simultaneous dimensions that should be treated as complementary rather than interchangeable. Economic sustainability requires competitive conversion costs, adequate capacity utilization, stable feedstock, working capital, demonstrated demand, maintenance capability, and positive farmer returns after full costs. Nutritional sustainability requires nutrient retention, food safety, appropriate consumption levels, evidence-based health communication, and a product that contributes positively to overall dietary quality.

Social sustainability requires equitable access to membership, voice, employment, dividends, and market opportunities while addressing gender and youth participation and preventing excessive concentration of benefits. Environmental sustainability requires traceable and legally produced FFB, avoidance of deforestation and peatland conversion, efficient processing, responsible waste management, and productivity improvement on existing agricultural land. Framing the problem in this way is consistent with food-system scholarship that argues for integrated assessment across social, economic, nutritional, and environmental outcomes rather than optimization of a single value-chain objective [38].

The broader palm oil literature supports this multidimensional framing by documenting substantial economic benefits alongside biodiversity, emissions, land-use, and community trade-offs [39,40]. Certification outcomes are context-dependent rather than automatically positive, and smallholder agribusiness sustainability remains shaped by institutional and farm-level constraints [41,42]. Recent research further suggests that yield-gap closure, replanting, and stronger support for smallholders on existing agricultural land can improve livelihoods while reducing pressure for expansion, although zero-deforestation commitments still reach many Indonesian smallholders unevenly [43-45].

Method

Qualitative Literature Review Design

This study uses a qualitative literature review, not a Systematic Literature Review (SLR). Its purpose is conceptual integration and explanatory synthesis rather than exhaustive study identification, effect-size estimation, or statistically pooled evidence.

Qualitative and narrative review methodologies are particularly useful when a research question spans heterogeneous disciplines, epistemologies, units of analysis, and study designs. Wilson and Anagnostopoulos (2021) conceptualize qualitative reviewing as an interpretive craft in which literature is analyzed relationally rather than simply counted [46]. Kalpokaite and Radivojevic (2021) similarly emphasize transparent qualitative coding and development of an analytically coherent narrative [47]. State-of-the-art and narrative review guidance further demonstrates that rigor does not require transforming every review into a conventional SLR, it instead requires clarity about the purpose, search logic, interpretive process, and limitations of the synthesis [48,49].

Accordingly, this review does not claim PRISMA compliance, exhaustive database capture, formal risk-of-bias scoring across every article, or meta-analytic estimation. No PRISMA flow diagram is presented because doing so would incorrectly imply an SLR design.

Literature Identification and Scope

Literature was identified iteratively from peer-reviewed publications available through major scholarly databases, indexing services, journal platforms, and citation networks. The principal publication window was January 2020 to August 2026, and search combinations covered red palm oil and red palm olein, carotenoids, provitamin A, tocopherols, tocotrienols,

and vitamin A deficiency, processing, heating, storage, stabilization, fortification, and sensory acceptance, rural nutrition, dietary diversity, anemia, stunting, and nutrition-sensitive agriculture, oil palm smallholders, cooperatives and value-chain upgrading, certification, traceability, inclusion, replanting, resilience, and sustainability, and rural industrialization, food hubs, and nutrition-sensitive value chains. Because the review was designed as an integrative qualitative synthesis rather than an SLR, these terms were used iteratively to connect disciplinary evidence streams rather than to implement a single exhaustive search algorithm.

Rather than applying an exhaustive eligibility algorithm, the review used purposive and theoretical sampling. Articles were retained when they materially illuminated one of the research questions or helped explain a causal mechanism, institutional condition, tension, or boundary.

More than 50 peer-reviewed journal articles published since 2020 constitute the principal academic evidence base. Government regulations, standards, and the contextual material that informed the initial research proposition were used to understand Indonesian policy discourse but were not counted toward the journal-article evidence requirement.

Cross-Disciplinary Thematic Analysis

The literature was organized initially into first-cycle domains: RPO composition, nutrient retention, clinical outcomes, processing, food vehicles, nutritional effectiveness, rural livelihoods, collective action, cooperative governance, finance, market structure, certification, inclusion, traceability, environmental impact, and policy. These domains provided a common coding structure across otherwise heterogeneous disciplinary evidence.

Second-cycle interpretation generated nine integrative themes: nutrient retention as a prerequisite for nutritional value, differentiated strength of human nutritional evidence, delivery systems as determinants of real-world effectiveness, downstreaming as functional upgrading and value capture, ownership versus substantive inclusion, the enabling ecosystem required for cooperative industrialization, local nutrition demand as a possible anchor market, economic, nutritional, social, and environmental downstreaming paradoxes, and evidence gaps preventing immediate large-scale replication. This interpretive approach is consistent with qualitative review methodology because themes emerged through comparison among disciplinary evidence streams rather than through calculation of pooled effects.

Evidentiary Safeguards

Three safeguards were applied. First, evidence from human randomized trials was distinguished from animal, in vitro, mechanistic, and narrative evidence. Second, studies on isolated palm-derived compounds were not automatically treated as evidence about whole RPO. Third, positive evidence was read alongside countervailing literature on saturated-fat substitution, certification limitations, farmer exclusion, land use, and environmental risk.

This procedure is important because a credible RPO strategy requires both opportunity identification and boundary setting. Literature was therefore used not only to ask what may work, but also under what conditions, for whom, compared with what, and at what cost or risk. Because the review relies on purposive rather than exhaustive sampling, it cannot eliminate selection bias or estimate pooled effects, its conclusions should therefore be read as an integrative conceptual synthesis rather than a systematic evidence map [48,49].

Results: Thematic Findings

Theme 1: Nutritional Value Is Created—or Lost—Along the Processing Chain

The first major finding is that RPO's nutritional proposition cannot be separated from processing technology. The high carotenoid content that differentiates RPO is vulnerable to the same thermal and oxidative conditions that conventional oil processing and household cooking may impose.

Mild processing can retain substantial β -carotene and vitamin E, whereas conventional bleaching and deodorization can remove much of this nutritional differentiation [5]. Heating studies indicate progressive losses under prolonged thermal exposure, although the degree of loss varies according to cooking method and conditions [6]. Oxidative stability and storage experiments further show that packaging and storage temperature materially influence the trajectory of product quality [7,8].

This relationship can be summarized conceptually as follows: effective nutritional value equals nutrient concentration after production multiplied by retention during distribution and storage, retention after food preparation, the amount actually consumed, and bioavailability. The expression is more useful than relying only on nutrient concentration at the factory because it makes explicit the points at which nutritional value can be lost.

It also means that smallholder processing facilities require food-technological competence. A cooperative cannot legitimately market a carotenoid-rich RPO unless it can measure product quality, standardize processing, control oxidation, maintain hygienic conditions, and verify shelf stability. Nutrition claims and industrial capability are therefore mutually dependent.

Theme 2: Contemporary Human Evidence Is Promising but Outcome-Specific

The second thematic finding concerns the evidence hierarchy. The contemporary evidence base supports RPO most convincingly as a dietary source of provitamin A carotenoids.

In the six-month randomized trial by Tan et al. (2024), RPO-enriched biscuits increased α - and β -carotene exposure and improved several hematological indicators [10]. However, serum retinol improved in both RPO and control groups and the between-group pattern varied according to baseline vitamin A status. This is scientifically important because it cautions against simplifying the trial into a claim that RPO uniformly “corrected vitamin A deficiency.”

The same research program provides additional, increasingly exploratory findings. RPO supplementation was associated with lower *A. lumbricoides* reinfection at six months after deworming but not with equivalent effects on all helminth species [11]. The investigators themselves called for replication in other populations.

A 2025 cluster randomized trial addressing xerophthalmia strengthens the relevance of RPO to vitamin A-deficiency-related ocular outcomes [13]. Meanwhile, microbiome research suggests that six months of RPO-enriched biscuit supplementation can alter microbial-community composition and network properties among vitamin A-deficient children [12].

A responsible synthesis therefore distinguishes several levels of evidence. The relatively strong proposition is that RPO is a carotenoid-rich edible oil capable of increasing dietary provitamin A exposure. A promising but more context-dependent proposition is that appropriately formulated RPO foods may improve selected micronutrient, hematological, or ocular outcomes among deficient populations. Emerging evidence suggests possible effects on infection-related or gut-microbiome pathways, whereas ordinary RPO consumption remains insufficiently supported as a population-level strategy for preventing major cardiovascular, neurodegenerative, or other chronic diseases. This evidence gradient should govern both policy design and marketing communication.

Theme 3: A Nutrient-Rich Product Requires a Delivery System

A third finding is that nutritional effectiveness depends on a system of delivery rather than merely a biochemical property. The relevant question is therefore not only whether RPO contains useful nutrients, but whether those nutrients reach an appropriate population in a stable, acceptable, affordable, and correctly used product.

The RPO product must first reach an appropriate population. Population targeting matters because benefits from additional provitamin A are likely to be greater where inadequate intake or deficiency actually exists. The product must then be affordable, culturally acceptable, palatable, regularly available, and consumed in a form that preserves nutrients.

These delivery constraints create several strategic options. Each model differs in dose control, distribution complexity, regulatory requirements, and ability to match nutritional need with commercial demand.

- A household culinary model would provide RPO through normal village retail channels. Its strengths are low behavioral disruption and broad accessibility. Its limitations include variable dose and unpredictable heating practices.
- A targeted food model would incorporate measured quantities of RPO into biscuits, complementary foods, sauces, or other standardized products. This improves dose consistency and lends itself to school or community distribution, but may raise costs.
- A public-procurement model could link cooperative processors with nutritionally justified institutional demand. However, procurement should follow evidence of safety, effectiveness, price competitiveness, and product acceptance rather than being used primarily to rescue an uncompetitive processing enterprise.
- A commercial functional-food model could target urban and regional consumers willing to pay for differentiated products, potentially generating higher margins that cross-subsidize local markets. That model could also reduce reliance on public procurement, but it would depend on credible product differentiation and evidence-based claims.
- A nutraceutical model may use encapsulation or concentrated formulations. Such products could produce higher-value market niches but require stricter regulatory oversight and should not be conflated with ordinary rural nutrition interventions.

Regional food-hub research offers a relevant conceptual parallel: local aggregation, processing, distribution, and institutional purchasing can strengthen regional food-system linkages when coordination and market demand are sufficiently strong [50]. Nutrition-sensitive food-value-chain scholarship likewise identifies multiple impact pathways through food availability, income, knowledge, women’s agency, and market access rather than a single consumption channel [51]. Recent reviews also emphasize that nutrition-sensitive value-chain interventions need explicit consideration of supply, demand, consumer behavior, unintended dietary effects, and enabling institutions if they are to translate into nutritional outcomes at scale [52,53].

Theme 4: RPO Can Convert Downstreaming from a Volume Strategy into a Differentiation Strategy

Conventional commodity downstreaming frequently focuses on processing greater physical volumes. RPO offers a more differentiated proposition: the objective is not merely to transform FFB into another oil, but to preserve and

commercialize a specific nutritional quality.

This distinction matters for smallholders. Competing directly with large conventional refineries purely on scale and unit cost is unlikely to be the most advantageous strategy for decentralized farmer enterprises. A smallholder RPO business may instead compete through verified carotenoid retention, traceable smallholder origin, local processing, sustainable sourcing, cooperative ownership, culturally relevant product formulation, nutrition-sensitive institutional markets, and differentiated branding. These attributes shift competitive emphasis from throughput alone toward verifiable quality, origin, and social value.

Witjaksono *et al.* (2024) demonstrate the relevance of collective processing and corporate-farming arrangements for improving independent smallholder participation in sustainable palm oil supply chains [21]. The implication for RPO is that downstreaming should be designed around functions that farmers can beneficially own, while specialized activities can be delivered through professional partnerships.

This functional-upgrading logic also reframes farmer returns. Member benefit may arise from several channels: a competitive FFB purchase price, patronage payments linked to volume supplied, dividends on cooperative equity, processing employment, local service opportunities, and retained cooperative assets. A proper business evaluation should calculate all these channels rather than focusing exclusively on the factory's accounting profit.

Theme 5: Farmer Ownership Is Necessary but Not Sufficient for Inclusion

The literature consistently demonstrates that participation is not equivalent to empowerment. Smallholders can be formally included in certified or organized value chains while still experiencing uneven bargaining power, high compliance costs, or limited decision-making influence [15,17,18]. Recent evidence on palm contract farming similarly warns that formal participation can coexist with unequal control over productive assets and returns [54].

This distinction is directly relevant to cooperative RPO, because formal farmer ownership does not by itself guarantee equitable participation. Access inclusion requires that poorer farmers, women, younger producers, and farmers with smaller plots have realistic opportunities to join rather than membership being restricted to well-connected producers, procedural inclusion requires transparent information about debt, prices, contracts, costs, margins, and strategic decisions.

Distributional inclusion requires additional downstream value to be allocated through defensible rules rather than captured disproportionately by managers, intermediaries, or dominant members. Risk inclusion is equally important: financial structures should not transfer an excessive share of commercial risk to farmers or leave them with large debts secured against their principal productive assets.

Certification experience provides an important warning. de Vos *et al.* (2023) show that independent farmers often enter sustainability initiatives with highly unequal pre-certification capacity, while Irawan *et al.* (2024) demonstrate that scaling up group certification can reduce per-farmer costs but still requires organizational capacity and documentation [16,20]. Studies of certification governance and finance similarly indicate that formal standards can create uneven burdens when institutions, implementation rules, or economic incentives are weak or ambiguous [19,55]. Smallholder downstreaming will face similar asymmetries.

Theme 6: A Cooperative Processing Plant Is an Ecosystem, Not a Machine

Many rural industrialization programs underestimate the difference between purchasing equipment and creating a viable enterprise. The literature indicates that sustainable smallholder downstreaming requires a coordinated enabling ecosystem.

- **Feedstock:** RPO facilities require a reliable FFB supply of suitable quality. Because fruit quality deteriorates after harvesting, procurement logistics, harvest schedules, transportation, and processing timeliness matter.
- **Technology:** Equipment must fit realistic throughput rather than political aspirations. Overcapacity increases fixed cost per unit when supply is insufficient, undercapacity constrains growth. Technology should also maximize carotenoid retention, energy efficiency, and food safety.
- **Human Capital:** Professional operators, food technologists, quality-control personnel, accountants, procurement specialists, and marketing professionals are required. Farmer training alone cannot substitute for specialized expertise.
- **Working Capital:** This is frequently overlooked. A processor must pay for FFB, wages, packaging, utilities, inventory, and logistics before receiving revenue from customers. Adequate fixed-asset financing without working capital can still cause enterprise failure.
- **Quality Assurance:** Food-grade products require systematic control of raw-material quality, contaminants, oxidation, microbial safety where relevant, packaging integrity, labeling, and nutrient claims. These controls are also necessary to substantiate nutrient-content claims and reduce the risk that nutritional differentiation becomes merely a marketing assertion.
- **Markets:** Capacity should be built around validated demand rather than assumed demand. Household willingness

to pay, institutional off-take, consumer sensory acceptance, retailer margins, and competing-oil prices should be assessed before major investment.

- **Governance:** The cooperative needs independent audit, transparent procurement, member reporting, conflict-of-interest rules, professional management contracts, and clear distribution policies. Such mechanisms are particularly important where member ownership and professional management are separated, because they clarify accountability between principals and operators.

The institutional literature on oil palm smallholders supports this ecosystem perspective. Raharja *et al.* (2020) emphasize institutional strengthening, Watts *et al.* (2021) document certification barriers, de Vos *et al.* (2023) identify pre-certification capacities, and Hendrawan, Chrisendo and Musshoff (2024) highlight broader resilience requirements [14,16,17,35].

Theme 7: Local Nutrition Demand Could Become an Anchor Market—but Only Conditionally

An attractive feature of the RPO proposition is that local nutritional need may create part of the initial market for local downstream processing. This opportunity is credible only when public-health need is established independently of the commercial need to utilize processing capacity.

Conceptually, a nutrition-sensitive anchor-market strategy could connect farmer cooperatives with village retail, schools, community nutrition services, local food processors, and public institutions. Stable institutional demand can reduce market uncertainty during early industrial development.

However, a crucial sequence must be maintained. The defensible sequence moves from nutritional need to product suitability, then to clinical and nutritional evidence, consumer acceptance, cost-effectiveness, and finally a procurement decision, it should not begin with a processing plant and then seek mandatory nutrition procurement simply to sell its product. Reversing the sequence risks turning a public-health program into an industrial subsidy and can undermine both nutritional and commercial objectives.

Public procurement is most defensible when RPO-based products demonstrate a clear nutritional role compared with realistic alternatives. For example, in a population with inadequate vitamin A intake, decision makers should compare RPO with dietary diversification, fortification, supplementation, biofortified foods, and other interventions in terms of effectiveness, cost, adherence, logistical complexity, and unintended dietary effects.

Agriculture-nutrition research broadly shows that agricultural interventions can influence nutrition through food production, income, women's agency, and food prices, but the pathway is not automatic [56,57]. RPO should therefore be embedded within local food-system strategies rather than promoted as a stand-alone commodity. This is also consistent with implementation reviews showing that context, local structures, governance, acceptability, and adaptive management strongly influence whether nutrition-sensitive agriculture interventions scale successfully [53].

Theme 8: Four “Downstreaming Paradoxes” Must Be Managed

The Economic Paradox

Downstream processing creates more gross value but also adds capital expenditure, technical complexity, market risk, and working-capital requirements. An RPO plant can therefore create less net farmer value than FFB sales if utilization rates and commercial margins are inadequate.

The Nutrition Paradox

RPO can provide valuable carotenoids and vitamin E compounds while still being an energy-dense edible fat. Nutrition promotion that simply adds RPO to an already energy-sufficient diet may be inferior to substituting it for another culinary fat, and evidence concerning tropical-oil consumption reinforces the importance of the dietary comparator [30]. A recent randomized trial comparing red palm olein, extra virgin coconut oil, and extra virgin olive oil found distinct carotenoid and lipid responses without demonstrating a simple overall cardiometabolic superiority for red palm olein, reinforcing this comparator-based interpretation [31].

The Inclusion Paradox

A farmer-owned enterprise can become inequitable if wealthier members provide most capital, dominate governance, and capture preferred procurement or employment opportunities. Cooperative ownership must therefore be supported by governance safeguards, and sustainability rules should be designed with explicit attention to possible tensions between environmental, social, and economic goals [58].

The Environmental Paradox

Successful downstream demand could increase incentives to expand oil palm area. This would undermine a holistic sustainability claim if expansion caused deforestation, peat conversion, or biodiversity loss. Indonesia's historical oil palm expansion has had significant environmental consequences, although recent research also shows opportunities to improve livelihoods through productivity and replanting rather than frontier expansion [43,44,59]. Evidence from Sumatra suggests that replanting unproductive plantations can contribute to multiple development goals, while peatland

restoration research underscores the importance of local acceptance and livelihood considerations in environmental transitions [60,61].

The environmental safeguard should therefore be explicit: additional RPO value should come predominantly from value addition and improved productivity on existing legal agricultural land, not from additional forest conversion. This safeguard is also compatible with sustainability-governance research showing that environmental and social goals can conflict unless support for smallholder transition is built into implementation [58].

Theme 9: Critical Evidence Gaps Remain

Several gaps prevent immediate claims that smallholder RPO should be scaled nationally. These gaps concern both nutrition effectiveness and enterprise design, so they should be resolved before national replication is treated as a policy default.

- First, contemporary human RPO intervention evidence is still geographically concentrated, particularly in Malaysia. Indonesian trials are needed across different age groups, dietary patterns, and baseline nutritional conditions.
- Second, evidence on Indonesian consumer acceptance of RPO at scale remains limited. Color and taste can be assets in some food cultures and barriers in others.
- Third, rigorous techno-economic analysis of cooperative-scale RPO plants is required. Studies should estimate break-even throughput, raw-material radius, extraction rates, capital and working-capital requirements, energy use, labor, packaging, distribution costs, and sensitivity to FFB and product prices.
- Fourth, research should compare alternative ownership models. A fully cooperative-owned plant may not always outperform a joint venture, lease-to-operate arrangement, contract processor, or shared regional facility.
- Fifth, distributional analysis is necessary. Researchers should determine which categories of farmers capture profits, who receives employment, whether women and youth gain meaningful opportunities, and who bears debt.
- Sixth, life-cycle assessment should compare decentralized processing with conventional alternatives, including energy, water, emissions, transport, and residue management. Collectively, these gaps support a pilot-evaluate-adapt-scale strategy rather than immediate blanket expansion, with progression contingent on evidence from each phase.

Discussion and Analysis

The Red Palm Oil Nutrition–Downstreaming Nexus

The evidence synthesized above suggests that the strongest conceptual contribution is not RPO itself but the relationship between nutrient preservation, local industrial upgrading, and smallholder value capture. Treating these objectives jointly makes it possible to identify where a gain in one pathway may be nullified by failure in another.

The proposed RPO Nutrition-Downstreaming Nexus contains two principal causal pathways. The nutrition pathway runs from RPO processing and retention of carotenoids and tocopherols through product acceptability and appropriate consumption to greater micronutrient exposure, intermediate biological responses, and potential nutritional outcomes. The livelihood pathway runs from smallholder FFB through collective aggregation, downstream processing, differentiated products, and market access to greater farmer value capture, income, employment, and potentially improved food access and livelihood resilience.

A reinforcing feedback is possible. Local demand for a nutrition-sensitive product can support the processing enterprise, while increased smallholder income can improve household capacity to purchase a more diverse diet. Yet neither pathway is automatic, and both require institutional safeguards.

Figure 1 synthesizes the article's central argument by demonstrating how the biological value of RPO and the economic value of smallholder downstreaming are connected but mediated by distinct sets of conditions. The figure also makes explicit that environmental sustainability and inclusive governance act as constraints around both pathways rather than as optional additions after economic development.

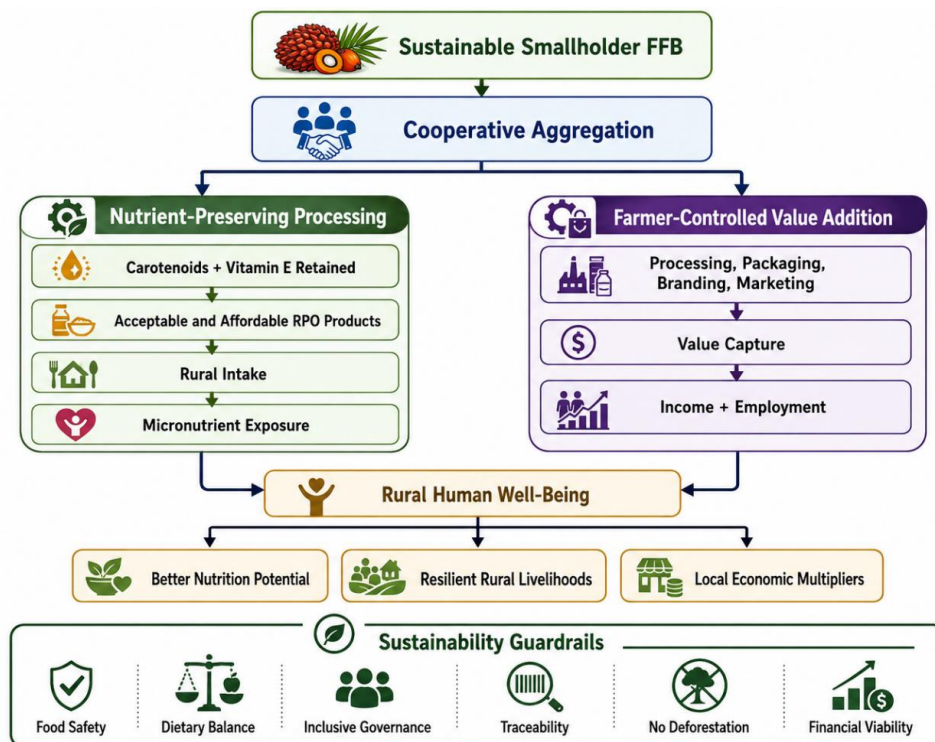


Figure 1: The Red Palm Oil Nutrition–Downstreaming Nexus

Figure 1 highlights that RPO only produces a “dual dividend” when both pathways remain intact. Nutrient losses during processing can sever the nutrition pathway even if the cooperative business succeeds. Conversely, technically excellent RPO can fail to improve farmer welfare if processing ownership and margins are captured outside the smallholder organization. The sustainability guardrails are therefore constitutive conditions of the model. This is consistent with the wider palm oil literature showing that production, welfare, certification, and environmental outcomes are highly dependent on institutional context [39,41,44].

From Nutritional Efficacy to Rural Effectiveness

An important analytical distinction is that between efficacy and effectiveness. Keeping the terms separate prevents controlled-trial outcomes from being assumed to persist unchanged under routine market and household conditions.

Efficacy asks whether an RPO product can generate a measurable effect under controlled conditions. The Malaysian school-based RCTs provide evidence of this type. Effectiveness asks whether the same pathway continues to work when products are purchased, stored, prepared, and consumed under ordinary rural conditions.

Several losses can occur between the two. These losses arise from product, market, household, and implementation factors rather than from biochemical efficacy alone.

A nutritionally appropriate product can fail because households dislike its color or taste. A well-accepted product can fail because carotenoids degrade during storage. A high-quality product can fail because it is unaffordable. An affordable product can fail because it reaches households without the relevant nutritional deficiency. A targeted product can fail because households add it to the diet rather than substituting it for another source of fat. A clinically beneficial product can fail at scale because manufacturing quality becomes inconsistent.

Consequently, RPO nutrition pilots should evaluate not merely biomarkers but a full implementation chain, including product quality at dispatch and point of use, actual consumption, dietary substitution, household acceptability, wastage, affordability, adherence, and unintended consequences. This emphasis is consistent with recent nutrition-sensitive agriculture reviews showing that contextual fit, local institutions, and implementation flexibility are central to successful scale-up [53]. The resulting policy proposition is more modest but more defensible: RPO may be a useful component of context-specific food-based micronutrient strategies, particularly where provitamin A intake is inadequate, and product delivery can be controlled without worsening overall dietary balance.

Can Smallholder Downstreaming Actually Increase Farmer Welfare?

The answer is conditional rather than automatic. Downstream processing creates a welfare gain only when the value retained by farmers exceeds the full incremental costs and risks relative to the best realistic FFB-selling alternative.

Suppose one tonne of farmer FFB generates additional gross product value after processing. Farmers benefit only if that additional revenue exceeds the combined costs of fruit collection and transport, processing losses, labor, energy,

maintenance, quality control, packaging, distribution, management, marketing, depreciation, financing, tax and regulatory compliance, and an adequate risk premium. This full-cost perspective prevents gross processing margins from being mistaken for farmer welfare gains.

The correct counterfactual is not zero income, it is the income farmers would have earned by selling FFB through the best available existing channel. Conceptually, incremental farmer benefit equals total farmer returns under downstreaming minus returns under the realistic FFB-sale counterfactual and minus incremental risks borne by farmers. The calculation should therefore include not only prices and dividends but also debt exposure, delayed payments, and other risks that affect household welfare.

This analytical discipline is important. Downstreaming is justified only when it increases long-term net welfare rather than merely moving activities from one stage of a chain to another.

Mehraban et al. (2021) demonstrate that oil palm cultivation itself can generate significant household-welfare effects [4]. A downstream initiative must therefore demonstrate additionality relative to those baseline gains. Hendrawan, Chrisendo and Musshoff (2024) further show that resilience requires anticipating structural challenges, meaning that cooperative processing should form part of a broader farmer-development strategy rather than operate in isolation [35].

Smallholder-Controlled Value Chain and Points of Value Capture

The distribution of value is clearer when the chain is decomposed by function. This functional view also separates ownership of value-creating activities from the operational responsibility for performing them.

Figure 2 identifies successive functions through which a conventional smallholder who sells only FFB can potentially progress toward partial ownership of downstream value. It also distinguishes economic returns from operational responsibilities, emphasizing that cooperatives do not have to internalize every function to capture value from them.

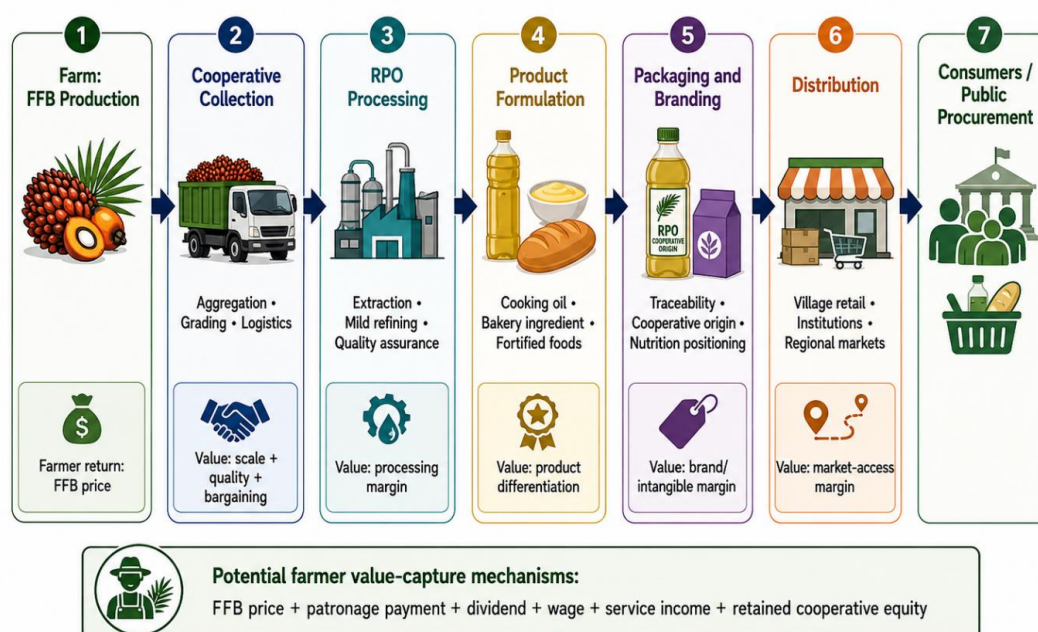


Figure 2: Smallholder-Controlled RPO Value Chain

Figure 2 demonstrates why measuring only FFB prices can underestimate—or overestimate—the effect of downstreaming. A cooperative may intentionally pay members the normal market price for FFB but return additional value through patronage payments or annual dividends. Conversely, an apparently high FFB price may be unsustainable if the processing enterprise accumulates debt. Evaluations should therefore measure total member economic return and risk exposure over time.

Cooperative Ownership with Professional Enterprise Management

The evidence supports a hybrid institutional model in which farmer ownership is combined with specialized management. The cooperative should provide collective ownership, member representation, feedstock coordination, benefit-sharing rules, and long-term strategic control. A professional operating company or management unit should handle food processing, quality control, finance, inventory, sales, and operations according to commercial standards.

Universities and research institutions can provide formulation, food technology, nutrition evaluation, and product-testing support, while government should set and enforce standards, finance public-good capacity, provide enabling

infrastructure, and support innovation rather than routinely guarantee commercial losses. Financial institutions should evaluate business viability and provide appropriately structured working and investment capital. This allocation of functions is consistent with implementation evidence showing that nutrition-sensitive interventions depend on coordinated, cross-sector enabling environments rather than a single lead actor [53].

Private-sector partners can contribute technology, off-take, logistics, or marketing capabilities without necessarily controlling the underlying farmer organization. Community and public-health institutions can evaluate nutritional targeting, educate consumers, and monitor unintended dietary effects. This architecture allows farmers to control strategic assets and share in value without assuming that every smallholder must become a food technologist or marketing professional.

Inclusive Downstreaming Requires Deliberate Distributional Design

Inclusion should be embedded into enterprise design from the beginning. Ex-post redistribution cannot fully correct exclusion if membership, finance, procurement, and information rules are inequitable at the outset.

Membership fees can be structured so that low-asset farmers are not excluded. Equity contributions can combine cash with patronage-based accumulation. Procurement rules should avoid favoring only large-volume suppliers. Information about prices, margins, debts, and management compensation should be accessible to members.

Women should be considered not only as recipients of household-nutrition messages but also as entrepreneurs, workers, cooperative decision makers, food-product developers, and distributors. Chrisendo et al. (2020) demonstrate that agricultural transformation can alter gendered labor and household roles, reinforcing the need for explicit analysis rather than gender-neutral assumptions [3].

Youth inclusion is equally relevant. Downstream activities such as quality testing, digital traceability, equipment maintenance, e-commerce, packaging design, logistics, and data management can create skilled rural occupations that are qualitatively different from plantation labor.

The social objective is thus larger than raising average cooperative income. It is to create accessible pathways into higher-productivity rural economic functions.

Sustainability Without Further Frontier Expansion

A credible RPO strategy cannot separate the nutritional attributes of the final product from the environmental origin of its feedstock. The product's development claim is weakened if nutrient preservation is achieved through a supply chain that shifts environmental costs onto forests, peatlands, or neighboring communities.

The global palm oil literature documents both land-efficiency advantages and severe environmental consequences when expansion replaces forests or peatlands [39,40]. Gaveau et al. (2022) show that deforestation dynamics are connected to changing patterns of oil palm expansion and commodity conditions, while Monzon et al. (2021) demonstrate that improved yields on existing areas could play a substantial role in meeting future production while limiting additional land conversion [43,59]. Recent spatial evidence from Sumatra further indicates that replanting unproductive areas with well-supported smallholder plantations can improve several development outcomes without making frontier expansion the default strategy [60].

Li (2024) further argues that the apparent conflict between smallholder welfare and forest protection can be reduced through more effective support for genuine independent smallholders operating on existing agricultural land [44]. The practical principle for RPO downstreaming should therefore be more value per tonne and more sustainable yield per hectare, not more hectares as the default development pathway. The most defensible feedstock strategy combines land legality, traceability, no-deforestation safeguards, better agronomy, replanting of aging stands, and, where feasible, sustainability certification, these measures reduce the risk that nutritional or industrial gains are achieved by externalizing environmental costs.

Recent evidence adds urgency to the inclusion dimension. Chandra et al. (2026) find that corporate zero-deforestation commitments have limited reach among many Indonesian smallholders [45]. Excluding non-compliant farmers without providing a feasible transition pathway may produce social exclusion without transforming production practices, a tension that echoes broader evidence on the paradoxes of private sustainability governance [58]. Traceability policy should therefore combine credible standards with technical and institutional assistance.

Four-Dimensional Sustainability Framework

Figure 3 presents sustainability as the intersection of four non-substitutable dimensions. A project cannot compensate for weak nutritional performance by generating higher profits, nor justify deforestation because it creates employment. Minimum performance is required across all four dimensions.

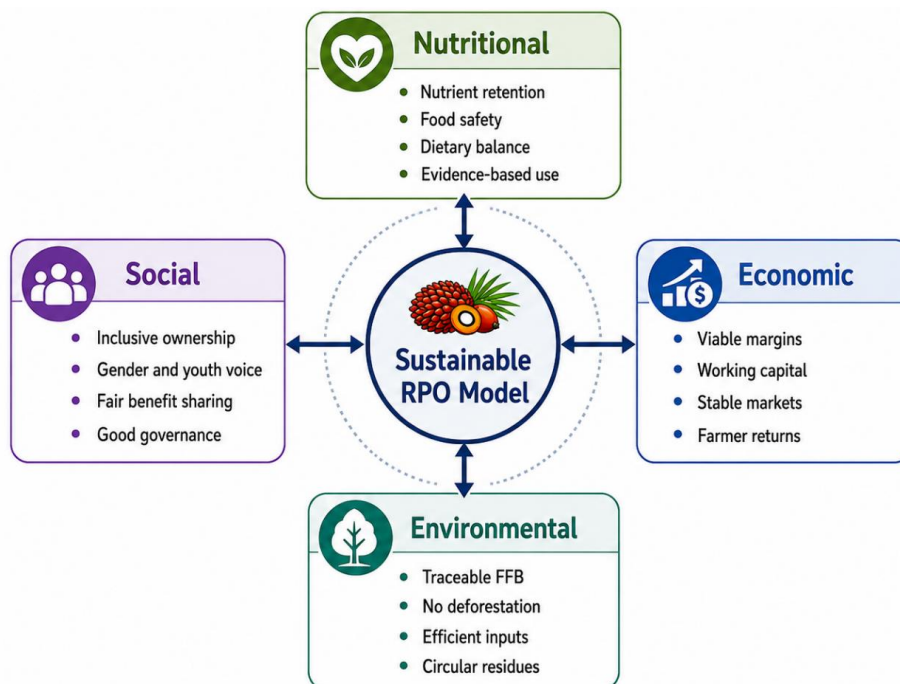


Figure 3: Four-Dimensional Sustainability Framework

The four-dimensional model moves beyond conventional “triple bottom line” reasoning by treating nutritional sustainability as a separate dimension. This is justified because the central value proposition of RPO is partly health-related. A product that retains inadequate carotenoids, promotes excessive energy intake, or relies on misleading health claims may be financially profitable and environmentally traceable yet still fail the primary development rationale.

A Phased Policy Architecture

A national RPO agenda should avoid moving directly from technological enthusiasm to large-scale infrastructure. A staged strategy provides a stronger evidence base.

Phase 1: Evidence and Site Selection

Potential pilot districts should be characterized according to nutritional need, smallholder density, cooperative capacity, FFB availability, infrastructure, processing access, environmental risk, and plausible markets. Site selection should favor places where these conditions overlap rather than districts chosen primarily because equipment or funding is available.

Baseline surveys should assess vitamin A-related dietary intake, dietary diversity, household cooking-oil use, consumer acceptance, prices, and smallholder organization. These data should be collected before product introduction so that nutritional and commercial additionality can be evaluated against a credible baseline.

Phase 2: Technical and Commercial Demonstration

Pilot facilities should test realistic throughput and multiple products. Independent laboratories should verify carotenoids, vitamin E, oxidative stability, contaminants, and shelf life.

Consumer trials should compare formats, package sizes, price points, and sensory characteristics. Business models should be stress-tested against changes in FFB prices, energy costs, interest rates, capacity utilization, and product demand.

Phase 3: Nutrition-Effectiveness Evaluation

Where nutritional targeting is justified, controlled community pilots should measure relevant outcomes. The indicators should depend on the intervention’s mechanism rather than on politically attractive but causally remote endpoints.

For example, an RPO intervention directed toward provitamin A inadequacy should prioritize dietary intake, carotenoid biomarkers, retinol-related indicators where scientifically appropriate, adherence, substitution effects, and product acceptance rather than claiming rapid reductions in stunting. This keeps outcome measurement aligned with the intervention mechanism and avoids evaluating a micronutrient strategy against a distant endpoint dominated by multiple other determinants.

Phase 4: Institutional Market Development

Only successful products should advance into longer-term procurement arrangements. Public procurement can provide predictable demand but must use transparent standards and competitive cost-effectiveness analysis.

Phase 5: Replication

Expansion to new regions should occur only after the demonstration phase has met a defined set of conditions. Replication requires evidence that the enterprise is commercially viable, the product has nutritional usefulness, farmers receive measurable additional value, governance functions effectively, sourcing is environmentally compliant, and replication costs remain reasonable. These criteria make scale a consequence of demonstrated performance rather than an objective pursued independently of performance.

Policy Architecture for a Nutrition-Sensitive Rural Industrial Cluster

Figure 4 illustrates the institutional system required around a farmer-owned RPO enterprise. Its core message is that the cooperative should be central but should not operate in isolation. Different institutions should provide capabilities according to comparative advantage while accountability for smallholder value capture remains explicit.

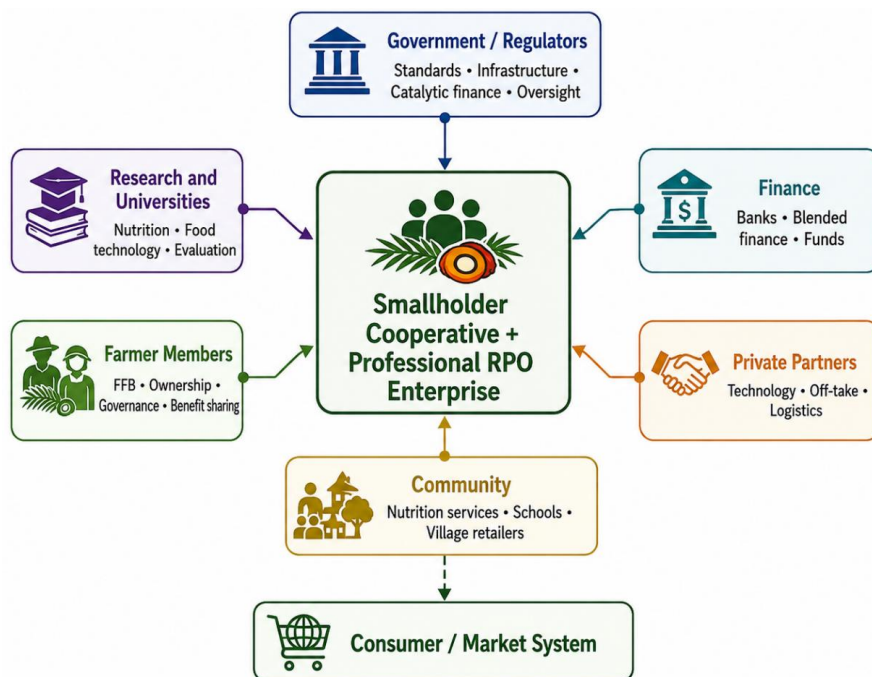


Figure 4: Institutional Architecture for a Smallholder RPO Cluster

The model distributes functions without diluting farmer ownership. Government does not need to manage factories, universities do not need to become distributors, cooperatives do not need to manufacture every input internally. The institutional objective is to assemble a capability network around an enterprise whose strategic purpose remains improved smallholder value capture and credible nutrition-sensitive production.

Financing: From Equipment Subsidy to Enterprise Finance

Financing policy deserves particular attention because rural industrialization often places excessive emphasis on capital equipment. A viable processing plant is a working enterprise rather than a one-off asset purchase, so financing must cover the capabilities and liquidity needed to operate it.

A financially sustainable RPO enterprise requires at least four forms of capital. Fixed investment capital is needed for equipment, buildings, laboratories, storage, and utilities, while working capital is required for FFB procurement, labor, packaging, inventory, and receivables. Human-capital investment must support management, operator training, quality assurance, and product development, and market-development capital must cover certification, product registration, branding, consumer testing, promotion, and distribution.

A blended-finance model may be appropriate. Public or development funds can absorb selected early-stage risks associated with innovation, training, research, and shared infrastructure. Cooperative equity creates ownership commitment, commercial lenders can discipline mature investment decisions, and private partners can contribute technology or off-take under transparent contracts. Subsidies should finance capabilities and public goods rather than permanently conceal negative unit economics.

Measuring Success Beyond Production Volume

Traditional downstreaming programs may celebrate tonnes processed or factories constructed. Those indicators are inadequate.

A multidimensional monitoring framework should contain four groups of indicators. Each group should be interpreted alongside the others so that gains in one dimension do not conceal deterioration elsewhere.

Nutritional Indicators

Nutritional monitoring should track carotenoid and vitamin E retention at production and at the point of consumption, food safety compliance, household or program adherence, dietary substitution rather than uncontrolled additional fat consumption, dietary diversity, and appropriate vitamin A or carotenoid biomarkers in evaluated target groups. Monitoring should also document whether communication remains evidence-based and free of exaggerated therapeutic claims. Together, these indicators test both nutrient delivery and the quality of the intervention's public-health implementation.

Economic Indicators

Economic monitoring should include plant capacity utilization, processing cost per unit, operating margin, farmer FFB prices relative to local alternatives, total member patronage and dividend income, local employment, debt-service coverage, cooperative retained earnings, and the farmer share of final value. These measures should be assessed jointly because a plant can report positive output growth while member returns or financial resilience deteriorate. The central outcome is sustainable net value capture by farmers, not throughput alone.

Social-Inclusion Indicators

Social-inclusion monitoring should disaggregate participation by farm size and track women and youth in governance and skilled employment, voting participation, disclosure of management and financial information, distribution of dividends and patronage payments, and grievance-resolution outcomes. Disaggregation is essential because average cooperative performance can conceal unequal access or benefit capture among member groups. These indicators should therefore be interpreted as distributional as well as governance measures.

Environmental Indicators

Environmental monitoring should measure the percentage of traceable feedstock, land-legality compliance, no-deforestation verification, productivity per existing hectare, energy use, water consumption, waste and by-product utilization, and emissions intensity. Remote-sensing and farm-level assessment tools may complement documentary traceability where they are feasible, especially in fragmented smallholder landscapes [62]. The objective is to verify that additional value is not associated with hidden land-use or resource-efficiency costs.

A project should be regarded as successful only when its improvements are not achieved by systematically degrading another dimension. Trade-offs should be reported explicitly rather than averaged away in a single headline performance measure.

Broader Implications

From Commodity Downstreaming to Nutrition-Sensitive Industrial Policy

The RPO case suggests a broader reinterpretation of agricultural downstreaming. The key shift is from asking how much additional processing occurs to asking what kind of value is created, who captures it, and whether the resulting food and production system is socially and environmentally defensible.

Conventional industrial policy asks how more value can be added domestically, whereas inclusive rural industrial policy asks who captures that additional value. Nutrition-sensitive industrial policy adds the question of whether the resulting product improves or undermines human well-being. Sustainable industrial policy further asks whether environmental and intergenerational consequences are acceptable. Taken together, these questions shift downstreaming from a production-volume agenda toward a multidimensional development framework.

RPO is particularly suitable for illustrating this integrated framework because its differentiation depends on preserving a naturally occurring nutritional characteristic. The very technologies used to create economic value affect nutritional value. The sourcing system that generates rural income affects forests and land use. The ownership architecture affects the distribution of profits. The consumer-use pattern determines whether nutritional benefits materialize.

Thus, nutrition, industry, inclusion, and sustainability cannot be treated as separate policy chapters. They are mutually conditioning dimensions of the same downstreaming strategy.

Reframing the Role of Smallholders

Smallholders are often described either as beneficiaries who need assistance or as upstream producers who need to comply with standards. The RPO downstreaming framework proposes a third position: smallholders as collective economic principals who can own strategic downstream assets and contract professional capabilities.

This framing matters because genuine inclusion is not identical to integrating farmers more efficiently into someone else's supply chain. Integration may improve welfare, but ownership creates additional possibilities for value retention and strategic voice.

Nevertheless, ownership should be chosen where economically sensible. A cooperative need not own a refinery simply to satisfy an ideological conception of empowerment. In some regions, equity participation in a shared processor, contract processing, or cooperative ownership of branding and distribution may generate higher farmer returns with

lower capital risk.

The policy objective should therefore be optimal farmer value capture, not maximum physical asset ownership. Ownership should be expanded where it improves long-term net returns, bargaining power, and strategic voice without imposing disproportionate technical or financial risk.

RPO and Rural Food-System Diversification

The RPO strategy should also avoid deepening monoculture dependence. Its economic gains should support a more diversified rural food system rather than make household nutrition and local livelihoods more dependent on a single commodity.

Income generated from RPO processing can support broader rural food-system development, including horticulture, livestock, legumes, aquaculture, and diverse local foods. This is especially important because nutritional adequacy cannot be reduced to a single oil or nutrient.

Food-hub and nutrition-sensitive-value-chain research suggests that coordinating regional production and markets can strengthen the availability of diverse foods [50,51]. RPO should therefore become one component of a diversified nutrition-sensitive rural economy, not the commodity around which every nutrition objective is reorganized. Recent value-chain scholarship also warns that focusing on one commodity can miss interactions with the wider diet and other sustainability dimensions [38,52].

Policy Recommendations

Based on the qualitative synthesis, ten recommendations are proposed. Together, they prioritize evidence-led pilots, farmer value capture, professional enterprise management, dietary discipline, and sustainability safeguards over rapid infrastructure-led expansion.

- First, establish a limited number of nutrition-sensitive RPO demonstration clusters rather than immediately pursuing nationwide replication. Pilot locations should combine nutritional relevance, strong farmer institutions, reliable legal feedstock, infrastructure, and plausible markets.
- Second, separate the nutritional claim from the industrial policy claim during evaluation. A facility should demonstrate commercial viability, an RPO nutrition intervention should separately demonstrate nutritional usefulness. Success in one dimension should not be used to conceal failure in the other.
- Third, place organized smallholders in the ownership and value-capture structure while professionalizing operations. Cooperative governance and technical enterprise management should be complementary rather than mutually exclusive.
- Fourth, finance the whole business system rather than only processing machinery. Investment packages should include working capital, laboratories, training, quality systems, product development, logistics, and market building.
- Fifth, develop scientifically disciplined RPO nutrition guidance. Claims should emphasize provitamin A carotenoids and substantiated outcomes. RPO should not be marketed as a cure for stunting, cardiovascular disease, Alzheimer's disease, Parkinson's disease, or other conditions in the absence of adequate intervention evidence.
- Sixth, evaluate RPO primarily as dietary substitution rather than indiscriminate additional oil consumption where energy intake is already adequate. This protects the nutritional proposition from becoming an argument for excessive fat intake.
- Seventh, use public procurement selectively and conditionally. School, community, or other institutional markets should purchase RPO products when nutritional suitability, safety, consumer acceptance, cost-effectiveness, and supply reliability have been demonstrated.
- Eighth, require inclusive-governance safeguards. Cooperatives receiving public support should disclose procurement rules, management compensation, debt, operating performance, patronage payments, and dividend distribution and should report participation by gender, age, and farm-size category.
- Ninth, link RPO downstreaming to traceability, legal sourcing, no-deforestation safeguards, and productivity improvement on existing farmland. Higher product value should be achieved predominantly through downstream differentiation and improved productivity, not frontier expansion. The limited current reach of some zero-deforestation initiatives among smallholders reinforces the need to combine standards with practical capacity-building [45].
- Tenth, institutionalize independent monitoring and learning. Universities and independent evaluators should assess nutritional outcomes, business performance, farmer value capture, social inclusion, and environmental indicators before public replication.

Conclusion

Red palm oil occupies an unusual position at the intersection of food science, nutrition, rural development, and agricultural industrialization. Its distinctive value originates from a processing approach that preserves naturally occurring carotenoids and vitamin E compounds, giving it a nutritionally relevant differentiation from conventional refined palm oil. Contemporary randomized trials provide credible evidence that RPO-enriched foods can raise provitamin A carotenoid exposure and influence selected hematological and vitamin A-related outcomes among deficient rural schoolchildren. Emerging findings concerning helminth reinfection, xerophthalmia, and gut microbiota add scientific interest but require

replication and careful interpretation.

The evidence does not justify presenting RPO as a stand-alone solution to stunting or as a general therapeutic agent. Its strongest public-health role is more specific: it may form part of a food-based strategy for increasing provitamin A intake and potentially improving related nutritional outcomes when used in appropriate populations, doses, and dietary contexts.

The economic opportunity is equally conditional. Smallholder processing can potentially transform farmers from predominantly FFB suppliers into participants in processing, formulation, branding, and marketing. Yet constructing a plant does not automatically create farmer prosperity. Genuine value capture requires competitive economics, collective organization, professional management, working capital, food-safety capability, viable markets, transparent benefit sharing, and risk management.

The article therefore proposes the Red Palm Oil Nutrition–Downstreaming Nexus. In this framework, a sustainable strategy creates two mutually reinforcing but independently testable pathways: a nutritional pathway based on phytonutrient preservation and effective consumption, and an economic pathway based on smallholder functional upgrading and value capture. Both operate within four non-negotiable sustainability dimensions: economic viability, nutritional integrity, social inclusion, and environmental responsibility.

The most appropriate policy approach is consequently neither uncritical RPO promotion nor rejection of the opportunity. It is evidence-led experimentation followed by conditional scaling. Demonstration clusters should integrate nutrition assessment, cooperative business development, professional food processing, consumer research, blended finance, traceability, and independent impact evaluation.

If these conditions can be met, RPO could do more than create another palm oil product. It could become an example of how rural agricultural regions move from producing commodities to retaining value, from supplying calories to supporting nutritional quality, and from conventional downstreaming to inclusive and nutrition-sensitive rural industrialization.

References

1. Mulyaningsih, T., Mohanty, I., Widyaningsih, V., Gebremedhin, T. A., Miranti, R., & Wiyono, V. H. (2021). Beyond personal factors: Multilevel determinants of childhood stunting in Indonesia. *PLoS one*, 16(11), e0260265.
2. Indra, J. and Khoirunurrofik (2022) 'Understanding the role of village fund and administrative capacity in stunting reduction: empirical evidence from Indonesia', *PLOS ONE*, 17(1), e0262743.
3. Chrisendo, D., Krishna, V. V., Siregar, H., & Qaim, M. (2020). Land-use change, nutrition, and gender roles in Indonesian farm households. *Forest Policy and Economics*, 118, 102245.
4. Mehraban, N., Kubitz, C., Alamsyah, Z. and Qaim, M. (2021) 'Oil palm cultivation, household welfare, and exposure to economic risk in the Indonesian small farm sector', *Journal of Agricultural Economics*, 72(3), pp. 901–915.
5. Tan, C.H., Lee, C.J., Tan, S.N., Poon, D.T.S., Chong, C.Y.E. and Pui, L.P. (2021) 'Red palm oil: A review on processing, health benefits and its application in food', *Journal of Oleo Science*, 70(9), pp. 1201–1210.
6. Loganathan, R. et al. (2020a) 'Retention of carotenes and vitamin E, and physico-chemical changes occurring upon heating red palm olein using deep-fat fryer, microwave oven and conventional oven', *Journal of Oleo Science*, 69(3), pp. 167–183.
7. Tay, B.Y.P., Che Idris, C.A. and Abd Maurad, Z. (2020) 'Oxidative stability of refined red palm olein under two Malaysian storage conditions', *Journal of Oleo Science*, 69(10), pp. 1209–1218.
8. Teh, S.S., Lau, H.L.N. and Abd Wafti, N.S. (2023) 'Storage stability and degradation kinetics of phytonutrients of red palm-pressed mesocarp olein', *Journal of Oleo Science*, 72(5), pp. 511–520.
9. Tan, P.Y., Mohd Johari, S.N., Teng, K.-T., Loganathan, R., Lee, S.C., Ngui, R., Selvaduray, K.R. and Lim, Y.A.-L. (2023b) 'High prevalence of malnutrition and vitamin A deficiency among schoolchildren of rural areas in Malaysia using a multi-school assessment approach', *British Journal of Nutrition*, 129(3), pp. 454–467.
10. Tan, P.Y., Loganathan, R., Teng, K.-T., Mohd Johari, S.N., Lee, S.C., Selvaduray, K.R., Ngui, R. and Lim, Y.A.-L. (2024) 'Supplementation of red palm olein-enriched biscuits improves levels of provitamin A carotenes, iron, and erythropoiesis in vitamin A-deficient primary schoolchildren: a double-blinded randomised controlled trial', *European Journal of Nutrition*, 63, pp. 905–918.
11. Tan, P. Y., Loganathan, R., Teng, K. T., Lee, S. C., Johari, S. N. M., Selvaduray, K. R., ... & Lim, Y. A. L. (2023). Red palm olein-enriched biscuit supplementation lowers *Ascaris lumbricoides* reinfection at 6-month after anthelmintic treatment among schoolchildren with vitamin A deficiency (VAD). *Acta tropica*, 240, 106860.
12. Tan, K.M. et al. (2025a) 'Red palm olein biscuit supplementation modulates gut microbiota in vitamin A deficient rural Malaysian schoolchildren: a randomised controlled trial', *Nature Communications*.
13. Tan, P.Y., Lim, C.C., Seng, K.B.H. et al. (2025b) 'Red palm olein supplementation as a potential preventive solution for xerophthalmia among vitamin A-deficient primary schoolchildren: a cluster randomized controlled trial', *European Journal of Clinical Nutrition*, 79, pp. 928–936.
14. Raharja, S. et al. (2020) 'Institutional strengthening model of oil palm independent smallholder in Riau and Jambi Provinces, Indonesia', *Helicon*, 6(5), e03875.
15. Apriani, E., Kim, Y. S., Fisher, L. A., & Baral, H. (2020). Non-state certification of smallholders for sustainable palm

oil in Sumatra, Indonesia. *Land use policy*, 99, 105112.

16. De Vos, R. E., Suwarno, A., Slingerland, M., Van Der Meer, P. J., & Lucey, J. M. (2023). Pre-certification conditions of independent oil palm smallholders in Indonesia. Assessing prospects for RSPO certification. *Land use policy*, 130, 106660.
17. Watts, J. D., Pasaribu, K., Irawan, S., Tacconi, L., Martanila, H., Wiratama, C. G. W., ... & Manvi, U. P. (2021). Challenges faced by smallholders in achieving sustainable palm oil certification in Indonesia. *World Development*, 146, 105565.
18. Ogahara, Z., Jespersen, K., Theilade, I., & Nielsen, M. R. (2022). Review of smallholder palm oil sustainability reveals limited positive impacts and identifies key implementation and knowledge gaps. *Land use policy*, 120, 106258.
19. Tey, Y. S., Brindal, M., Hadi, A. H. I. A., & Darham, S. (2022). Financial costs and benefits of the Roundtable on Sustainable Palm Oil certification among independent smallholders: A probabilistic view of the Monte Carlo approach. *Sustainable production and consumption*, 30, 377-386.
20. Irawan, S., Pasaribu, K., Busch, J., Dwiastuti, A., Martanila, H., Retnani, D., ... & Hukom, V. (2024). Cost reduction for upscaling voluntary sustainability standards: the case of independent oil palm smallholders in Central Kalimantan, Indonesia. *Frontiers in Forests and Global Change*, 7, 1418782.
21. Witjaksono, J., Djaenudin, D., Fery Purba, S., Yulianti, A., Fadwiwati, A. Y., Muslimin, ... & Seerasarn, N. (2024). Corporate farming model for sustainable supply chain crude palm oil of independent smallholder farmers. *Frontiers in Sustainable Food Systems*, 8, 1418732.
22. Mozzon, M., Foligni, R., & Mannozi, C. (2020). Current knowledge on interspecific hybrid palm oils as food and food ingredient. *Foods*, 9(5), 631.
23. Loganathan, R., Tarmizi, A. H. A., Vethakkan, S. R., & Teng, K. T. (2020). Thermal stability and sensory acceptance of cupcakes containing red palm olein. *Journal of Oleo Science*, 69(7), 671-676.
24. Bhatt, T., & Patel, K. (2020). Carotenoids: Potent to Prevent Diseases Review: T. Bhatt, K. Patel. *Natural Products and Bioprospecting*, 10(3), 109-117.
25. Böhm, V., Lietz, G., Olmedilla-Alonso, B., Phelan, D., Reboul, E., Bánati, D., ... & Bohn, T. (2021). From carotenoid intake to carotenoid blood and tissue concentrations—implications for dietary intake recommendations. *Nutrition Reviews*, 79(5), 544-573.
26. Yao, Y., Tan, P., & Kim, J. E. (2022). Effects of dietary fats on the bioaccessibility and bioavailability of carotenoids: a systematic review and meta-analysis of in vitro studies and randomized controlled trials. *Nutrition Reviews*, 80(4), 741-761.
27. Zainal, Z., Khaza'ai, H., Radhakrishnan, A. K., & Chang, S. K. (2022). Therapeutic potential of palm oil vitamin E-derived tocotrienols in inflammation and chronic diseases: Evidence from preclinical and clinical studies. *Food Research International*, 156, 111175.
28. Ranasinghe, R., Mathai, M., & Zulli, A. (2022). Revisiting the therapeutic potential of tocotrienol. *Biofactors*, 48(4), 813-856.
29. Madoromae, H., & Lertcanawanichakul, M. (2025). Red palm oil: nutritional composition, bioactive properties, and potential applications in health and cosmetics: a narrative review. *Molecules*, 30(22), 4402.
30. Unhapipatpong, C., Shantavasinkul, P. C., Kasemsup, V., Siriyotha, S., Warodomwichit, D., Maneesuwannarat, S., ... & Thakkinstian, A. (2021). Tropical oil consumption and cardiovascular disease: An umbrella review of systematic reviews and meta analyses. *Nutrients*, 13(5), 1549.
31. Teng, K. T., Loganathan, R., Chew, B. H., & Khang, T. F. (2024). Diverse impacts of red palm olein, extra virgin coconut oil and extra virgin olive oil on cardiometabolic risk markers in individuals with central obesity: a randomised trial. *European Journal of Nutrition*, 63(4), 1225-1239.
32. Patil, R., Singh, A., Mane, S., & Roy, T. (2024). Emerging encapsulation strategies for vitamin A fortification in food sector: an overview: R. Patil et al. *Food Science and Biotechnology*, 33(13), 2937-2951.
33. Begum, R., Hasan, M., Akter, S., & Rahman, M. (2024). Fortified edible oils in Bangladesh: A study on vitamin A fortification and physicochemical properties. *Heliyon*, 10(3).
34. Hendryanti, D. N., Andriani, C., Indriani, S., Gunawan, L., & Sibero, M. T. (2023). Dietary Diversity, Stunting, and the Impact of an Education Program on Parents's Knowledge and Attitudes in West Sumba, Indonesia. *Jurnal Gizi dan Pangan*, 18(2), 79â.
35. Hendrawan, D., Chrisendo, D., & Musshoff, O. (2024). Strengthening oil palm smallholder farmers' resilience to future industrial challenges. *Scientific reports*, 14(1), 12105.
36. Petri, H., Hendrawan, D., Bähr, T., Musshoff, O., Wollni, M., Asnawi, R., & Faust, H. (2024). Replanting challenges among Indonesian oil palm smallholders: a narrative review. *Environment, Development and Sustainability*, 26(8), 19351-19367.
37. Race, D., Suka, A. P., Oktalina, S. N., Bisjoe, A. R., Muin, N., & Arianti, N. (2022). Modern smallholders: creating diversified livelihoods and landscapes in Indonesia. *Small-Scale Forestry*, 21(2), 203-227.
38. Farmery, A. K., Brewer, T. D., Farrell, P., Kottage, H., Reeve, E., Thow, A. M., & Andrew, N. L. (2021). Conceptualising value chain research to integrate multiple food system elements. *Global Food Security*, 28, 100500.
39. Qaim, M., Sibhatu, K. T., Siregar, H., & Grass, I. (2020). Environmental, economic, and social consequences of the oil palm boom. *Annual review of resource economics*, 12(1), 321-344.
40. Ayompe, L. M., Schaafsma, M., & Egoh, B. N. (2021). Towards sustainable palm oil production: The positive and negative impacts on ecosystem services and human wellbeing. *Journal of cleaner production*, 278, 123914.
41. Santika, T., Wilson, K. A., Law, E. A., St John, F. A., Carlson, K. M., Gibbs, H., ... & Struebig, M. J. (2021). Impact of

- palm oil sustainability certification on village well-being and poverty in Indonesia. *Nature Sustainability*, 4(2), 109-119.
42. Suardi, T. F., Sulistyowati, L., Noor, T. I., & Setiawan, I. (2022). Analysis of the sustainability level of smallholder oil palm agribusiness in Labuhanbatu Regency, North Sumatra. *Agriculture*, 12(9), 1469.
 43. Monzon, J. P., Slingerland, M. A., Rahutomo, S., Agus, F., Oberthür, T., Andrade, J. F., ... & Grassini, P. (2021). Fostering a climate-smart intensification for oil palm. *Nature Sustainability*, 4(7), 595-601.
 44. Li, T. M. (2024). Securing oil palm smallholder livelihoods without more deforestation in Indonesia. *Nature Sustainability*, 7(4), 387-393.
 45. Chandra, A., Grabs, J., Meemken, E. M., Hidayat, N. K., Dharmawan, A. H., Mardiyarningsih, D. I., & Garrett, R. D. (2026). Limited reach of zero-deforestation commitments to Indonesian oil palm smallholders. *Nature Sustainability*, 1-14.
 46. Wilson, S. M., & Anagnostopoulos, D. (2021). Methodological guidance paper: The craft of conducting a qualitative review. *Review of Educational Research*, 91(5), 651-670.
 47. Kalpokas, N., & Radivojevic, I. (2021). Adapting practices from qualitative research to tell a compelling story: A practical framework for conducting a literature review. *The Qualitative Report*, 26(5), 1546-1566.
 48. Barry, E. S., Merkebu, J., & Varpio, L. (2022). State-of-the-art literature review methodology: A six-step approach for knowledge synthesis. *Perspectives on Medical Education*, 11(5), 281-288.
 49. Sukhera, J. (2022). Narrative reviews: flexible, rigorous, and practical. *Journal of graduate medical education*, 14(4), 414-417.
 50. Hermiatin, F. R., Handayati, Y., Perdana, T., & Wardhana, D. (2022). Creating food value chain transformations through regional food hubs: a review article. *Sustainability*, 14(13), 8196.
 51. Kumar, S., Das, A., Kasala, K., & Ravula, P. (2022). Micronutrient-sensitive food value chains: A systematic review of intervention strategies and impact pathways to nutritional outcomes. *CABI Reviews*, (2022).
 52. Nicholson, C. F., Monterrosa, E., & Garrett, J. L. (2021). Food value chain interventions and nutritional outcomes: a review of evidence and recommendations for future assessments. *Current Opinion in Biotechnology*, 70, 61-67.
 53. Di Prima, S., Wright, E. P., Sharma, I. K., Syurina, E., & Broerse, J. E. (2022). Implementation and scale-up of nutrition-sensitive agriculture in low-and middle-income countries: a systematic review of what works, what doesn't work and why. *Global Food Security*, 32, 100595.
 54. Snashall, G. B., & Poulos, H. M. (2023). 'Smallholding for Whom?': The effect of human capital appropriation on smallholder palm farmers: GB Snashall and HM Polous. *Agriculture and Human Values*, 40(4), 1599-1619.
 55. Choiruzzad, S. A. B., Tyson, A., & Varkkey, H. (2021). The ambiguities of Indonesian Sustainable Palm Oil certification: internal incoherence, governance rescaling and state transformation: SAB Choiruzzad et al. *Asia Europe Journal*, 19(2), 189-208.
 56. Daum, T., & Birner, R. (2022). The forgotten agriculture-nutrition link: farm technologies and human energy requirements: Farm technologies, physical activity and human energy requirements. *Food Security*, 14(2), 395-409.
 57. Timberlake, T. P., Cirtwill, A. R., Baral, S. C., Bhusal, D. R., Devkota, K., Harris-Fry, H. A., ... & Memmott, J. (2022). A network approach for managing ecosystem services and improving food and nutrition security on smallholder farms. *People and Nature*, 4(2), 563-575.
 58. Grabs, J., & Garrett, R. D. (2023). Goal-based private sustainability governance and its paradoxes in the Indonesian palm oil sector. *Journal of Business Ethics*, 188(3), 467-507.
 59. Gaveau, D. L., Locatelli, B., Salim, M. A., Husnayaen, Manurung, T., Descals, A., ... & Sheil, D. (2022). Slowing deforestation in Indonesia follows declining oil palm expansion and lower oil prices. *PloS one*, 17(3), e0266178.
 60. Fosch, A., Ferraz de Arruda, G., Aleta, A., Descals, A., Gaveau, D., Morgans, C., ... & Moreno, Y. (2023). Replanting unproductive palm oil with smallholder plantations can help achieve Sustainable Development Goals in Sumatra, Indonesia. *Communications Earth & Environment*, 4(1), 378.
 61. Ward, C., Stringer, L. C., Warren-Thomas, E., Agus, F., Crowson, M., Hamer, K., ... & Hill, J. K. (2021). Smallholder perceptions of land restoration activities: rewetting tropical peatland oil palm areas in Sumatra, Indonesia: Smallholder perceptions of land restoration activities: rewetting tropical peatland oil palm areas in Sumatra, Indonesia. *Regional Environmental Change*, 21(1), 1.
 62. Wong, Y. B., Gibbins, C., Azhar, B., Phan, S. S., Scholefield, P., Azmi, R., & Lechner, A. M. (2023). Smallholder oil palm plantation sustainability assessment using multi-criteria analysis and unmanned aerial vehicles. *Environmental Monitoring and Assessment*, 195(5), 577.