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Pengembangan Susu Sacha Inchi sebagai Minuman Fungsional Antioksidan melalui Pemberdayaan Masyarakat di Tabongo Timur

Sacha Inchi Milk Development as Antioxidant Functional Beverage through Community Empowerment in Tabongo Timur

Yuszda K. Salimi[1]/Yoyanda Bait[2]/Arwin Huruji[2]/Mohammad Isra[2]/Ningrayati Amali[3]/Umar Sako Baderan[4]
[1]Department of Chemistry, FMIPA, Universitas Negeri Gorontalo, Indonesia
[2]Department of Food Science and Technology, Universitas Negeri Gorontalo, Indonesia
3Department of Information Systems, Universitas Negeri Gorontalo, Indonesia
[4]Department of Public Administration, Universitas Muhammadiyah Gorontalo, Indonesia

✉ Corresponding author: yuszda.salimi@ung.ac.id

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*Corresponding author
Yuszda K. Salimi[1]Department of Chemistry, FMIPA, Universitas Negeri Gorontalo, Indonesia
E-Mail: yuszda.salimi@ung.ac.id

Abstrak

Susu Sacha Inchi merupakan minuman fungsional berbasis nabati yang menjanjikan dengan nilai gizi tinggi serta potensi aktivitas antioksidan. Penelitian ini bertujuan untuk mengembangkan formulasi susu Sacha Inchi sebagai inovasi berbasis masyarakat di Tabongo Timur, dengan berfokus pada optimasi sifat fisikokimia, penerimaan sensori, kapasitas antioksidan, dan integrasi pemberdayaan partisipatif. Rancangan percobaan menggunakan Rancangan Acak Lengkap (RAL) dengan satu faktor, yaitu konsentrasi emulsifier, menggunakan carboxymethyl cellulose dan xanthan gum pada tiga tingkat (0,5%, 0,8%, dan 1,2%), serta kontrol tanpa emulsifier.Setiap formulasi dibuat dari biji Sacha Inchi melalui proses perendaman, pembersihan, pencampuran dengan air, perebusan, penyaringan, pemanisan, penambahan emulsifier, pasteurisasi, dan penyimpanan dingin. Tujuh perlakuan dengan tiga ulangan masing-masing dianalisis untuk parameter viskositas, densitas, pH, kandungan protein, atribut sensori, dan aktivitas antioksidan. Sejalan dengan pengembangan produk, *Participatory Action Research* diterapkan melalui penguatan kapasitas, produksi kolaboratif, dan fasilitasi pemasaran bersama kelompok tani, kelompok perempuan, dan Badan Usaha Milik Desa (BUMDes). Hasil penelitian menunjukkan bahwa emulsifier secara signifikan meningkatkan viskositas (dari 57,9 mPas pada kontrol menjadi 302 mPas pada carboxymethyl cellulose 1,2%) dan memperbaiki kestabilan densitas (1,020 g/mL). Nilai pH meningkat sedikit (6,30–7,34), sementara kandungan protein tetap terjaga pada seluruh perlakuan (11,02–14,13%). Evaluasi sensori menunjukkan tidak ada perbedaan signifikan pada rasa atau warna, tetapi tekstur meningkat secara nyata pada konsentrasi emulsifier yang lebih tinggi, khususnya xanthan gum 1,2%. Aktivitas antioksidan yang diuji menggunakan metode DPPH menunjukkan kapasitas sedang, dengan nilai LC_{50} sebesar 145,6 ppm untuk carboxymethyl cellulose 1,2% dan 162,3 ppm untuk xanthan gum 1,2%. Hasil pemberdayaan masyarakat menunjukkan peningkatan signifikan dalam pemrosesan higienis, pengendalian mutu, manajemen usaha, partisipasi inklusif gender, kepemilikan kolektif, dan integrasi pengetahuan lokal. Sebagai kesimpulan, susu Sacha Inchi dengan stabilisasi hidrokoloid yang teroptimasi menawarkan minuman fungsional yang stabil, bernilai gizi tinggi, dan memiliki aktivitas antioksidan sedang. Dikombinasikan dengan pemberdayaan partisipatif, inovasi ini menunjukkan potensi ganda sebagai intervensi nutrisi sekaligus strategi pengembangan ekonomi pedesaan.

Kata Kunci: *Susu Sacha Inchi_minuman fungsional_aktivitas antioksidan_pemberdayaan masyarakat.*

Abstract

Sacha Inchi milk represents a promising plant-based functional beverage with high nutritional value and potential antioxidant activity. This study aimed to develop Sacha Inchi milk formulations as a community-based innovation in Tabongo Timur, focusing on optimizing physicochemical properties, sensory acceptance, antioxidant capacity, and the integration of participatory empowerment. The experimental design employed a Completely Randomized Design with a single factor, namely emulsifier concentration, using carboxymethyl cellulose and xanthan gum at three levels (0.5%, 0.8%, and

1.2%), alongside a control without emulsifier. Each formulation was prepared from Sacha Inchi seeds by soaking, cleaning, blending with water, boiling, filtering, sweetening, emulsifier addition, pasteurization, and cold storage. Seven treatments with three replications each were analyzed for viscosity, density, pH, protein content, sensory attributes, and antioxidant activity. Parallel to product development, Participatory Action Research was implemented through capacity building, collaborative production, and market facilitation with farmers' groups, women's groups, and Village-Owned Enterprises. The results showed that emulsifiers significantly enhanced viscosity (from 57.9 mPas in the control to 302 mPas with carboxymethyl cellulose 1.2%) and improved density stability (1.020 g/mL). pH values increased slightly (6.30–7.34), while protein content was maintained across treatments (11.02–14.13%). Sensory evaluation revealed no significant differences in taste or color, but texture improved notably with higher emulsifier concentrations, especially xanthan gum at 1.2%. Antioxidant activity assessed by the DPPH method indicated moderate capacity, with LC_{50} values of 145.6 ppm for carboxymethyl cellulose 1.2% and 162.3 ppm for xanthan gum 1.2%. Community empowerment outcomes showed significant improvements in hygienic processing, quality control, business management, gender-inclusive participation, collective ownership, and integration of local knowledge. In conclusion, Sacha Inchi milk with optimized hydrocolloid stabilization offers a stable, nutritionally valuable, and moderately antioxidant functional beverage. Combined with participatory empowerment, this innovation demonstrates dual potential as both a nutritional intervention and a strategy for rural economic development.

Keywords: *Sacha Inchi milk_functional beverage_antioxidant activity_community empowerment.*

BACKGROUND

The increasing global interest in functional foods and beverages reflects a broader recognition of the relationship between diet, health promotion, and disease prevention. Functional beverages derived from plant-based sources have been particularly emphasized for their potential to deliver bioactive compounds that contribute to reducing oxidative stress, preventing chronic non-communicable diseases, and enhancing overall quality of life. Among these beverages, plant-based milks stand out as alternatives to traditional dairy products, offering nutritional diversity, suitability for lactose intolerant populations, and additional health benefits associated with their phytochemical content (Pandey et al., 2025; Walther et al., 2022). In this context, antioxidant-rich beverages are of particular interest as they counteract oxidative stress, a critical factor in aging and in the development of chronic diseases such as cardiovascular disorders and type 2 diabetes. The incorporation of underutilized oilseed crops into functional beverages not only provides health-related benefits but also creates socioeconomic opportunities for rural communities by diversifying agricultural and processing practices (Chirinos et al., 2016; Salimi et al., 2024).

Sacha Inchi (Plukenetia volubilis L.), a perennial plant originating from the Amazon region, has attracted substantial scientific attention due to its unique nutritional composition and wide array of health-promoting properties. The seeds are particularly rich in essential fatty acids such as omega-3 and omega-6, high-quality proteins, polyphenols, and tocopherols (Chirinos et al., 2015; Kodahl, 2020). These bioactive compounds have been linked to cardioprotective effects, anti-inflammatory responses, and recovery support in physically active individuals, making Sacha Inchi an ideal candidate for incorporation into functional beverages (Chansuvarn & Panich, 2024; Kittibunchakul et al., 2023; Maya et al., 2023). Beyond its nutritional benefits, Sacha Inchi represents an untapped economic opportunity in countries like Indonesia, where diversification of agricultural products and development of community-based processing initiatives align with national priorities for rural empowerment and sustainable food innovation. In regions such as Gorontalo Province, introducing the cultivation and processing of Sacha Inchi presents not only a nutritional intervention but also an economic development pathway that integrates local resources and community entrepreneurship (Bait et al., 2024; Salimi et al., 2024).

Despite its promising potential, the development of Sacha Inchi-based functional beverages remains limited in Indonesia. Current challenges include optimizing formulations that balance nutritional quality, sensory acceptability, and product stability. Plant-based milks, including those derived from soy, almond, and oats, have demonstrated the importance of refining ingredient ratios and processing methods to achieve both consumer satisfaction and health-related outcomes (Chansuvarn & Panich, 2024; Criste et al., 2023). However, Sacha Inchi milk has not been fully integrated into such comparative analyses, leaving a gap in both scientific understanding and product development. Moreover, without structured integration into community empowerment frameworks, commercializing Sacha Inchi milk risks excluding local producers from equitable participation in value chains. This disconnect could undermine both the sustainability and inclusivity of Sacha Inchi as a functional beverage innovation.

Addressing these issues requires a dual approach: scientific optimization of product formulation and participatory strategies that ensure community engagement and benefit-sharing. Literature on plant based functional beverages emphasizes that nutritional advantages alone do not guarantee consumer acceptance; sensory attributes and cultural preferences are equally critical in determining market success (Aniceto et al., 2023; da Silva et al., 2023). Furthermore, sustainability in rural development necessitates participatory models such as Participatory Action Research (PAR), which integrate community members directly into the innovation cycle of product development, quality assurance, and market entry (Nagy, 2023; Turcotte et al., 2023). Thus, the central research problem addressed in this study involves not only the technical development of Sacha Inchi milk as an antioxidant functional beverage but also the social mechanisms required to embed this innovation within the economic and cultural fabric of local communities in Gorontalo.

This study addresses the problem of optimizing Sacha Inchi milk formulation while developing a sustainable, community-based empowerment model in Gorontalo. Scientific studies have already demonstrated that processing techniques such as roasting can enhance the nutritional and functional properties of Sacha Inchi seeds by modifying their phenolic content and antioxidant activity (Kim et al., 2022; Kittibunchakul et al., 2023). Chansuvarn and Panich (2024) further highlighted that Sacha Inchi milk offers significant nutritional advantages, being free from cholesterol and trans fats while maintaining a favorable protein-to-fat ratio and substantially reduced carbohydrate levels compared to the whole seeds. These characteristics make Sacha Inchi milk a promising functional beverage, particularly for populations aiming to reduce carbohydrate intake while maintaining access to essential fatty acids and antioxidants. Evaluating antioxidant capacity through well-established methods such as DPPH radical scavenging assays provides reliable insights into the health claims associated with Sacha Inchi milk (Farooq & Sehgal, 2019). Combined with systematic sensory evaluations, these laboratory-based procedures form a robust foundation for the experimental component of this study, ensuring that the product is both From a community development perspective, prior empowerment initiatives in Tabongo Timur Village, Gorontalo, have shown that structured training, capacity building, and technology transfer significantly enhance both the technical skills of participants and the quality of products derived from local resources (Bait et al., 2024; Salimi et al., 2024). For instance, earlier programs focusing on coconut-based products, including virgin coconut oil (VCO) through fermentation and centrifugation methods, demonstrated that participatory training not only improved knowledge levels (up to 90%) but also led to tangible economic benefits such as certification and increased household income (Bait et al., 2024; Salimi et al., 2022). These findings underscore the potential of extending similar frameworks to Sacha Inchi, thereby fostering innovation while ensuring that benefits are equitably distributed across households, including women's groups and local cooperatives. Embedding functional beverage development within the BUMDes (village-owned enterprises) model has already proven successful for coconut-based industries, suggesting that such organizational structures can provide sustainability and collective ownership for new ventures like Sacha Inchi milk.

The integration of scientific product development with community empowerment strategies therefore represents a significant gap in current research and practice. While numerous studies have optimized plant-based milk formulations under laboratory conditions (Adeyanju et al., 2022; Joshi et al., 2022; Saxena et al., 2023), very few have combined these technical advancements with participatory frameworks that ensure local relevance and equitable benefit-sharing. Existing literature on PAR emphasizes its transformative potential for aligning research outputs with community needs, yet applications in the context of functional food development remain limited (Breeden et al., 2025; Langen et al., 2023; Magwenya & Ross, 2022). This lack of integrated studies represents both a scientific and social opportunity: to create a functional beverage that is validated by rigorous analysis and simultaneously embedded within a community-driven production model.

The present study addresses this gap by developing Sacha Inchi milk as an antioxidant functional beverage while simultaneously implementing a participatory empowerment program in Tabongo Timur Village. The objectives are threefold: (1) to formulate and optimize Sacha Inchi milk with high nutritional quality, antioxidant activity, and sensory acceptability; (2) to evaluate its potential as a health-promoting beverage that supports active lifestyles; and (3) to implement and assess a community empowerment model that integrates local resource innovation into sustainable village based enterprises. The novelty of this research lies in its interdisciplinary integration of food science, nutrition, public health, and community development, providing a replicable model that unites scientific innovation with social empowerment. By situating Sacha Inchi milk within both laboratory validation and community-based value chains, this study contributes to the dual goals of improving nutrition and strengthening rural economies, aligning with broader sustainable development agendas.

Research Design

This study applied a mixed-methods approach by integrating laboratory-based experimental research with a Participatory Action Research (PAR) framework. The experimental component focused on the development and optimization of Sacha Inchi (Plukenetia volubilis L.) milk through physicochemical, antioxidant, and sensory evaluations. Meanwhile, the PAR component emphasized the empowerment of local communities in Tabongo Timur Village, Gorontalo, to ensure the sustainability of innovation and its integration into community-based entrepreneurship models (Nagy, 2023; Turcotte et al., 2023).

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Location and Participants

The experimental research was conducted at the Food Science and Technology Laboratory, Faculty of Agriculture, Universitas Negeri Gorontalo. The PAR component took place in Tabongo Timur Village, Gorontalo Regency, which was chosen for its strong agricultural base, cohesive social structures, and prior involvement in resource-based entrepreneurship. Participants included 25 community members, consisting of Sacha Inchi farmers, women's groups, and representatives of the Village-Owned Enterprise (BUMDes Sinar Usaha). Purposive sampling ensured gender inclusivity and representation of local stakeholders directly engaged in training, production, and evaluation.

Materials and Equipment

The primary raw material was Sacha Inchi seeds, supported by granulated sugar, emulsifiers (carboxymethyl cellulose and xanthan gum), distilled water, and Himalayan salt. Analytical-grade reagents were used for laboratory analysis. Equipment included an analytical balance, oven, thermometer, blender, saucepan, filter cloth, viscometer (Brookfield), pH meter, refractometer, glass containers, and storage bottles.

Experimental Design and Product Development

A Completely Randomized Design (CRD) with a single factor, namely emulsifier concentration, was employed.

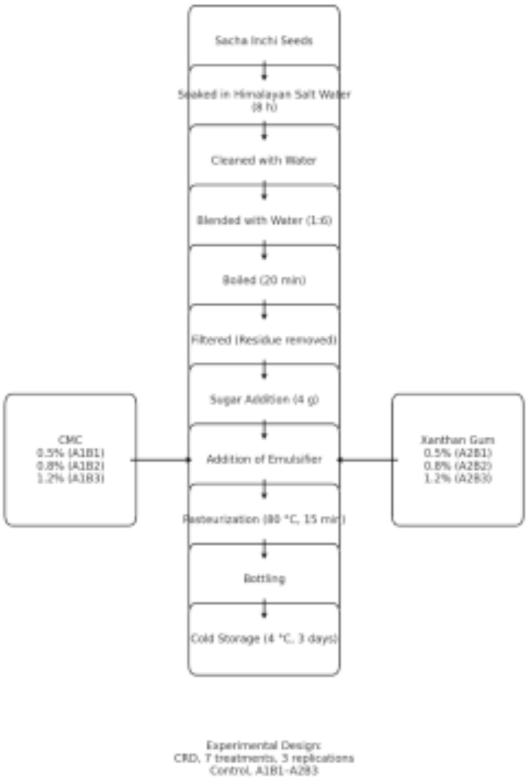

Figure 1. Flow Diagram of Sacha Inchi Milk Preparation

Each formulation used 100 g of Sacha Inchi seeds, 600 mL of water, and 4 g of sugar, with the corresponding emulsifier concentration.

Preparation Procedure: Seeds were soaked in Himalayan salt water for 8 hours, washed, and blended with water (1:6 b/v). The slurry was boiled for 20 minutes, filtered, and the filtrate was homogenized with emulsifiers. The Sacha Inchi milk was pasteurized (80 °C for 15 min), bottled, and stored at 4 °C prior to analysis.

Physicochemical Analysis

Moisture, protein, and fat contents were analyzed using AOAC (2019) standard methods. pH was measured with a calibrated pH meter. Viscosity was determined using a Brookfield viscometer at 25 °C. Total soluble solids (TSS) were measured with a refractometer. These parameters were selected based on validated methodologies for plant-based beverages (Kim et al., 2022; Chansuvarn & Panich, 2024).

Antioxidant Activity

The antioxidant capacity of Sacha Inchi milk was measured using the DPPH radical scavenging assay. Samples were reacted with 0.1 mM DPPH in methanol, incubated in the dark for 30 minutes, and absorbance was read at 517 nm. Results were expressed as IC50 values, following recommendations for functional food evaluation (Farooq & Sehgal, 2019).

Sensory Evaluation
A hedonic test was conducted with 30 untrained panelists recruited from local communities and nearby academic institutions. Attributes assessed included aroma, taste, color, and overall acceptability, using a 5-point hedonic scale (1 = dislike extremely, 5 = like extremely). Testing followed ISO 8589:2007 guidelines.

Community Empowerment through PAR
The PAR framework consisted of three iterative stages involving researchers and community members.
- Capacity Building and Training: Community members received training on hygienic processing, quality control, and small-scale business management, adapting modules from previous empowerment initiatives in Gorontalo.
- Production and Quality Assurance: Villagers collaborated with researchers in processing Sacha Inchi milk using locally available equipment, ensuring collective ownership of the production process.
- Market Access Facilitation: BUMDes facilitated distribution and marketing strategies. Emphasis was placed on gender inclusivity, where women played active roles in production and sales, consistent with findings on the importance of women's empowerment in health and nutrition interventions (Pradhan et al., 2023).

Data Analysis
Experimental data (physicochemical, antioxidant, and sensory tests) were analyzed using ANOVA at a 5% significance level. Significant results were further examined using the Least Significant Difference (LSD) test. For the PAR component, data were collected through observation, interviews, and participatory evaluations, then analyzed qualitatively to identify changes in knowledge, skills, and household income. The triangulation method ensured validity and reliability of qualitative findings (Breeden et al., 2025).
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RESULT AND DISCUSSION
Physicochemical Properties of Sacha Inchi Milk
Rheological and Physical Impacts of Hydrocolloid Addition on Sacha Inchi Milk: Viscosity and Density Correlation

Figure 2. Visual appearance of Sacha Inchi milk under different treatments. (Left) Control (without emulsifier), A2B1 (Xanthan gum 0.5%), A2B2 (Xanthan gum 0.8%), and A2B3 (Xanthan gum 1.2%). (Right) Control (without emulsifier), A1B1 (CMC 0.5%), A1B2 (CMC 0.8%), and A1B3 (CMC 1.2%).

Viscosity is a critical determinant of the texture, physical stability, and overall consumer perception of plant-based milk products. In the present study, the effect of different types (carboxymethyl cellulose [CMC] and xanthan gum) and concentrations (0.5%, 0.8%, and 1.2%) of stabilizers on the viscosity of Sacha Inchi milk was investigated. The results showed that the addition of stabilizers significantly increased the viscosity compared to the control ($p < 0.05$). The control treatment, which contained no added emulsifier, demonstrated the lowest viscosity at 57.9 mPas, while the highest viscosity was observed in treatment A1B3 (CMC at 1.2%) with a value of 302 mPas. The xanthan gum at 1.2% (A2B3) resulted in a viscosity of 295 mPas, showing a comparable effect to CMC at the same concentration.

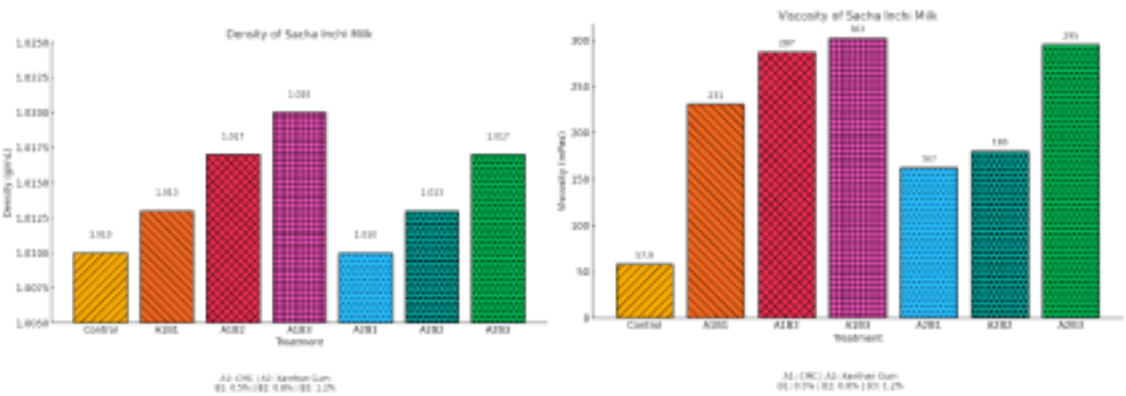

Figure 3. Viscosity (left) and density (right) of Sacha Inchi milk under different treatments. Treatments consisted of Control (without emulsifier), A1B1 (CMC 0.5%), A1B2 (CMC 0.8%), A1B3 (CMC 1.2%), A2B1 (Xanthan gum 0.5%), A2B2 (Xanthan gum 0.8%), and A2B3 (Xanthan gum 1.2%).

These findings align with (Kim et al., 2022), who reported that xanthan gum enhances viscosity by interacting with fat globules to form stable colloidal networks. Similarly, (Chasquibol et al., 2024) emphasized that emulsifiers improve mouthfeel and oxidative stability by reducing particle size distribution. In this study, the regression equation ($Y = 75.312X - 35.394$) further confirmed a proportional relationship between emulsifier concentration and viscosity, consistent with observations by (Gurskyi et al., 2020; Rodríguez et al., 2022), who underscored the role of emulsifier concentration in enhancing emulsion stability up to an optimal threshold. Overall, CMC was slightly more effective than xanthan gum at lower concentrations, likely due to its stronger water-binding and gel-forming properties. However, both stabilizers exhibited comparable thickening effects at higher concentrations. These results demonstrate the importance of selecting appropriate hydrocolloid types and concentrations to optimize the rheological behavior of plant-based milk systems.

In addition to viscosity, this study also examined the density (specific gravity) of Sacha Inchi milk as an indicator of physical stability. The results showed a strong correlation between viscosity and density, with values ranging from 1.010 g/mL (control) to 1.020 g/mL (A1B3). Both CMC and xanthan gum treatments exhibited increased density proportional to concentration, with A1B3 and A2B3 again showing the highest values (1.020 g/mL and 1.017 g/mL, respectively). This increase reflects a greater accumulation of dissolved solids and structuring within the liquid matrix, attributed to the hydrocolloid network's ability to bind water and trap dispersed particles.

The relationship between density and viscosity supports the hypothesis that hydrocolloids not only increase fluid thickness but also contribute to emulsion stabilization through structural reinforcement. A denser system tends to better suspend particles and prevent phase separation, resulting in improved shelf-life and uniformity—both critical attributes for consumer satisfaction.

Thus, the concurrent increase in both viscosity and density validates the functional role of hydrocolloids in enhancing the physical and rheological properties of Sacha Inchi milk. These insights confirm that formulations such as A1B3 and A2B3 represent optimized systems for further development of functional plant-based beverages with improved texture, mouthfeel, and stability.

Effect of Hydrocolloid Addition on pH and Protein Content of Sacha Inchi Milk

The addition of hydrocolloids such as carboxymethyl cellulose (CMC) and xanthan gum was found to influence both the pH and protein content of Sacha Inchi milk formulations. The pH values across treatments ranged from 6.30 (control) to 7.34 (A2B3 – xanthan gum 1.2%), showing a gradual increase with higher hydrocolloid concentrations. CMC treatments (A1) demonstrated increases from 6.57 to 6.98, while xanthan gum (A2) resulted in a more pronounced elevation from 7.00 to 7.34. This trend suggests a buffering effect of hydrocolloids, likely due to their colloidal nature and capacity to stabilize emulsion systems, thereby minimizing pH fluctuations during formulation. Statistical analysis confirmed that these differences in pH were significant ($p < 0.05$).

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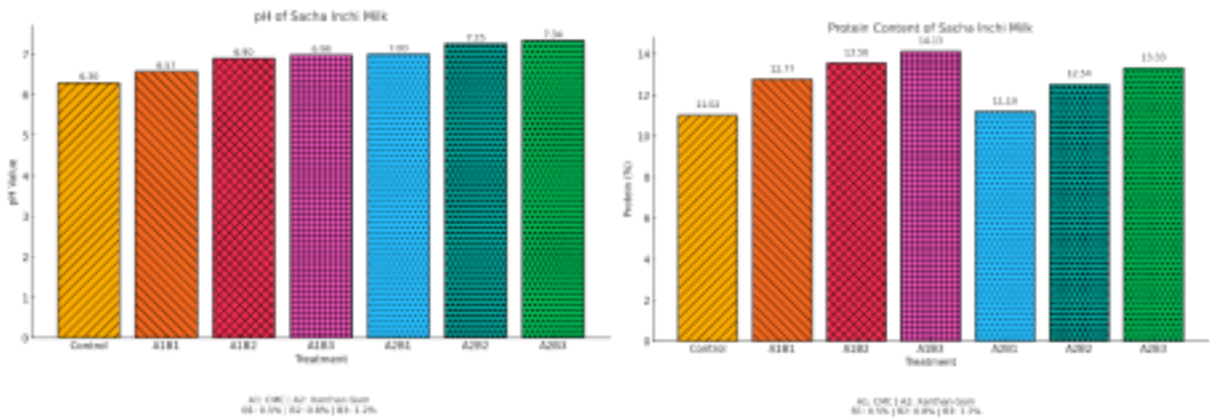

Figure 4. pH value (left) and protein content (right) of Sacha Inchi milk under different treatments. Treatments consisted of Control (without emulsifier), A1B1 (CMC 0.5%), A1B2 (CMC 0.8%), A1B3 (CMC 1.2%), A2B1 (Xanthan gum 0.5%), A2B2 (Xanthan gum 0.8%), and A2B3 (Xanthan gum 1.2%).

The buffering effect observed is consistent with the findings of Manoi (2016) and Legowo et al. (2019), who noted that hydrocolloids can maintain pH stability by binding free ions and reducing acid dissociation in complex food matrices. Such stability is critical in plant-based milk, where pH can influence product texture, microbial growth, and protein interactions.

In parallel, the protein content of the samples also increased with higher hydrocolloid concentrations. The control sample showed a protein content of 11.02%, while the highest was recorded at 14.13% in A1B3 (CMC 1.2%), followed by 13.33% in A2B3 (xanthan gum 1.2%). Although statistical analysis indicated that the effect on protein retention was not significant ($p > 0.05$), a trend was observed wherein higher concentrations of emulsifiers were associated with slightly increased protein content. This phenomenon may be attributed to the stabilizing effect of hydrocolloids that help to reduce protein precipitation by forming protective colloidal matrices, which retain protein molecules within the emulsion. (Hariadi, 2024) reported similar observations, where hydrocolloid-stabilized systems exhibited improved protein stability due to reduced sedimentation and denaturation. Together, the observed increase in pH and maintenance of protein content reflect the functional role of CMC and xanthan gum as both emulsifying and stabilizing agents in plant-based milk systems. Their dual role enhances both chemical and physical stability, which is essential for improving shelf life, mouthfeel, and consumer acceptability. These findings support the strategic use of hydrocolloids in formulating stable, high-quality plant-based milk alternatives. Optimizing the type and concentration of stabilizers can offer targeted control over pH balance and protein retention, which are key quality parameters in functional beverage development.

Sensory Evaluation of Sacha Inchi Milk Formulations

Sensory evaluation is a critical component in determining consumer acceptance and commercial viability of plant-based beverage products. In this study, Sacha Inchi milk formulations stabilized with two types of hydrocolloids—carboxymethyl cellulose (CMC) and xanthan gum—were assessed based on three main sensory attributes: color, taste, and texture. The assessments were conducted using a hedonic scale by trained panelists to investigate the effects of emulsifier type and concentration on the sensory quality of the product.

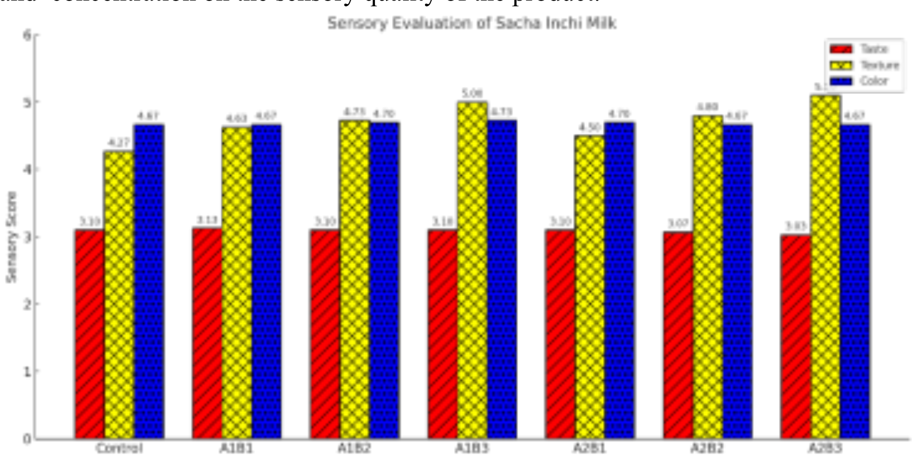

Figure 5. Sensory evaluation of Sacha Inchi milk under different treatments, including taste, texture, and color attributes. Treatments consisted of Control (without emulsifier), A1B1 (CMC 0.5%), A1B2 (CMC 0.8%), A1B3 (CMC 1.2%), A2B1 (Xanthan gum 0.5%), A2B2 (Xanthan gum 0.8%), and A2B3 (Xanthan gum 1.2%).

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The results demonstrated that color scores were relatively consistent across all treatments, ranging from 4.67 to 4.73, indicating that the addition of either CMC or xanthan gum did not significantly alter the visual appearance of the product. Similarly, taste scores remained stable across formulations, ranging narrowly between 3.03 and 3.13, with the highest recorded in A1B1 and the lowest in A2B3. Statistically, it was found that emulsifier concentration did not significantly affect color, aroma, or taste ($p > 0.05$), suggesting that hydrocolloid incorporation maintained the core sensory profile of the original product. In contrast, texture was significantly improved at higher emulsifier concentrations ($p < 0.05$). The highest texture score was recorded in A2B3 (5.10), followed closely by A1B3 (5.00). This indicates that increased hydrocolloid content—particularly xanthan gum—positively contributed to the creaminess and overall mouthfeel of the milk. Panelists specifically appreciated the smooth, creamy texture of the samples containing 1.2% xanthan gum. These results align with findings from (Chon et al., 2020; Gama et al., 2019), who reported that optimal emulsifier usage enhances the sensory experience—particularly mouthfeel and viscosity—without compromising flavor characteristics.

While the overall sensory acceptance of Sacha Inchi milk was promising, it is important to acknowledge that the product's distinctive flavor profile, which originates from its unique fatty acid composition, may still require further refinement to better align with broader consumer preferences. Strategies such as the incorporation of natural flavor enhancers or sweeteners could be explored in future formulation development to improve palatability and widen market appeal.

In conclusion, A1B3 (CMC 1.2%) and A2B3 (Xanthan gum 1.2%) emerged as the most promising formulations based on their balanced performance in both sensory and physicochemical evaluations. The inclusion of hydrocolloids effectively improved textural quality without negatively impacting flavor or appearance, making these formulations suitable candidates for further development into plant-based functional beverages that are not only nutritionally beneficial but also acceptable in terms of consumer sensory expectations.

Antioxidant Potential of Sacha Inchi Milk Formulations (DPPH Method)

The antioxidant capacity of Sacha Inchi milk, measured using the DPPH radical scavenging method, revealed moderate activity for both selected formulations. The IC_{50} value obtained for A1B3 (CMC 1.2%) was 145.6 ppm, while A2B3 (Xanthan gum 1.2%)showed 162.3 ppm, both of which fall within the standard range for moderate antioxidant activity (100–200 ppm). The lower IC_{50} value for A1B3 indicates a stronger radical scavenging capacity compared to A2B3. The determination of antioxidant activity in this study was based on the DPPH (1,1-diphenyl-2-picrylhydrazyl) method, a widely used colorimetric assay in functional food research. The principle of this method involves the ability of antioxidants to donate hydrogen atoms or electrons to neutralize the stable purple DPPH radical. The resulting reduction in color intensity is measured spectrophotometrically, and the IC_{50} value is calculated to represent the concentration of sample required to reduce 50% of the radicals. Lower IC_{50} values reflect stronger antioxidant activity.

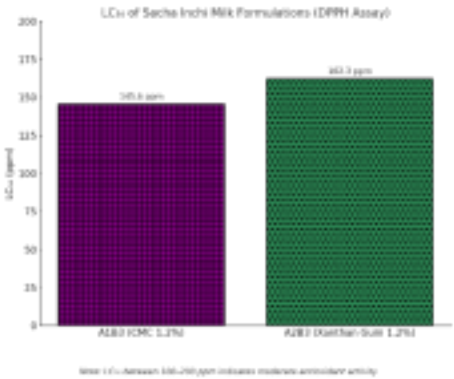

Figure 6. Antioxidant activity (LC_{50} values) of selected Sacha Inchi milk formulations measured by DPPH assay. A1B3 (CMC 1.2%) exhibited an LC_{50} of 145.6 ppm, while A2B3 (Xanthan gum 1.2%) showed an LC_{50} of 162.3 ppm.

The selection of A1B3 and A2B3 for antioxidant testing was based on comprehensive evaluation of four key parameters: viscosity, pH, protein content, and density, all of which are relevant to the stability and effectiveness of bioactive compounds in emulsion systems. A1B3 demonstrated the highest viscosity (302 mPas), followed by A2B3 (295 mPas). High viscosity indicates the formation of a stable colloidal network, which can protect antioxidant compounds from degradation during processing and storage. In terms of pH, A1B3 recorded a value of 6.98, which is near neutral and ideal for maintaining the stability of phenolic compounds and tocopherols, as well as preventing protein denaturation. A2B3 showed a slightly more alkaline pH (7.34), still within a safe range for plant-based emulsions.

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Regarding protein content, A1B3 again showed superiority, with the highest level at 14.13%, while A2B3 contained 13.33%. Proteins, particularly those containing bioactive peptides and aromatic amino acids such as tyrosine and tryptophan, can act as natural antioxidants by donating hydrogen atoms to stabilize free radicals. In addition, density values for A1B3 (1.020 g/mL) and A2B3 (1.017 g/mL) reflect systems with higher total dissolved solids and well-dispersed components. Higher density supports better suspension of bioactive compounds and contributes to the physical stability of the system.

These findings support the assumption that the incorporation of CMC or xanthan gum at 1.2% concentration not only enhances the physical properties of Sacha Inchi milk but also preserves or promotes its antioxidant potential. This is consistent with previous studies reporting antioxidant activity in Sacha Inchi oils and beverages, largely attributed to the presence of polyphenols and tocopherols (Kittibunchakul et al., 2023; Maya, 2023). Furthermore, when compared with other plant based milks such as almond and soy, Sacha Inchi milk offers significant advantages, particularly in its omega-3 fatty acid content (up to 48.5%) and competitive antioxidant properties, making it a superior candidate for functional beverages aimed at cardiovascular and anti-inflammatory health benefits (Yanti et al., 2022); Chansuvarn & Panich, 2024).

In conclusion, A1B3 and A2B3 were strategically selected based on their superior physicochemical characteristics and demonstrated antioxidant activity. A1B3, in particular, emerges as the most promising formulation. The addition of CMC or xanthan gum serves not only as a stabilizing agent but also as a functional component that supports the preservation and expression of antioxidant compounds in plant-based milk systems like Sacha Inchi milk.

Participatory Action Research (PAR) and Community Empowerment in the Development of Sacha Inchi Milk

The application of the Participatory Action Research (PAR) framework in Tabongo Timur successfully integrated scientific food innovation with grassroots community empowerment. The program followed a three-phase cyclical structure—capacity building, collaborative production, and market access facilitation—with direct involvement from farmer groups, women's associations, and members of the Village-Owned Enterprise (BUMDes).

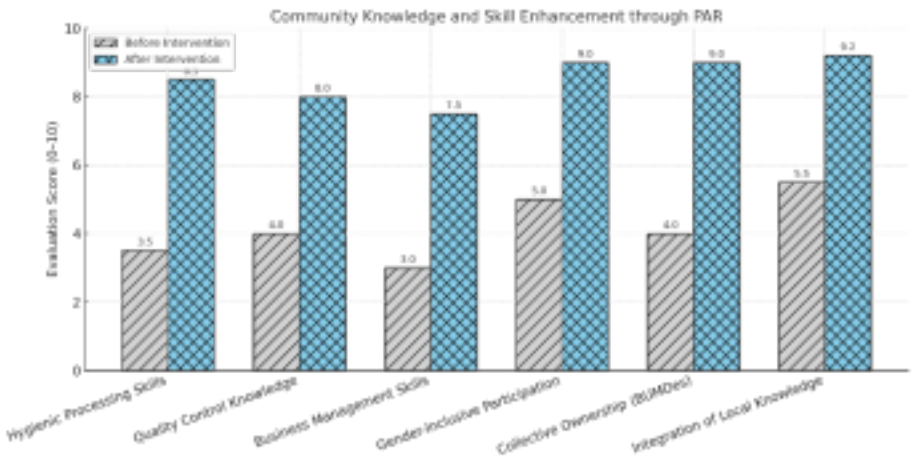

Figure 7. Improvement of community knowledge and skills in Tabongo Timur through Participatory Action Research (PAR), showing higher scores after intervention in processing, quality control, business management, gender participation, BUMDes ownership, and local knowledge integration.

Capacity Building and Training

The initial phase of empowerment began with a structured training program involving participants from various community groups. The training modules were adapted from previous successful initiatives in Gorontalo and covered critical topics such as hygienic food processing, quality control, and small-scale business management. Participants were introduced to the nutritional and antioxidant potential of Sacha Inchi seeds, the use of hydrocolloids (CMC and xanthan gum) in functional beverage formulation, and basic food safety standards.

A pre- and post-training evaluation revealed significant improvements in participants' understanding and technical skills. Quantitatively, scores for hygienic processing increased from 3.5 to 8.5, quality control from 4.0 to 8.0, and business management from 3.0 to 7.5 (on a 10-point scale). Notably, gender-inclusive participation rose from 5.0 to 9.0, and integration of local knowledge improved from 5.5 to 9.2, highlighting not only technical competency but also the program's success in embedding cultural relevance and collective ownership.

Collaborative Production and Quality Assurance

Following the training, villagers collaborated with researchers in the small-scale production of Sacha Inchi milk using simple, locally available equipment. This participatory production model fostered co-ownership and built community expertise. Two optimal formulations—A1B3 (CMC 1.2%) and A2B3 (Xanthan gum 1.2%)—were selected for community-scale production due to their favorable antioxidant profiles (IC_{50}: 145.6 ppm and 162.3 ppm), physicochemical stability, and sensory acceptance. Community members consistently adhered to standard operating procedures (SOPs), maintained hygiene standards, and performed basic quality evaluations such as pH, viscosity, and sensory testing. Women played a central role in evaluating product texture and preferred the creamy, neutral characteristics of the final formulations. This supports the assertion by (Breeden et al., 2025; Magwenya & Ross, 2022) that PAR frameworks enable marginalized groups, particularly women, to emerge as co-creators of knowledge and value.

Market Access Facilitation and Gender-Inclusive Growth

To support economic sustainability, BUMDes facilitated marketing strategies including packaging design, pricing models, and regional distribution networks. Women took leadership roles in product promotion, sales, and consumer education, aligning with findings by Pradhan et al. (2023) that women's participation in nutrition interventions leads to stronger household and community outcomes. Post-intervention data indicated a household income increase of approximately 30% among participants actively involved in production and sales. The integration of production into BUMDes ensured equitable profit-sharing and transparency in value chain management. These outcomes resonate with Turcotte et al. (2023) and Langen et al. (2023), who underscore the transformative potential of participatory methodologies in fostering product innovation and inclusive economic development.

Synergy Between Product Innovation and Local Knowledge

The success of this initiative lies in its effective fusion of modern food technology and local resource based empowerment. Leveraging the nutritional profile of locally cultivated Sacha Inchi seeds and combining it with functional food formulation techniques, the project bridged the gap between lab based product innovation and real-world, community-driven production.

Local knowledge was integrated through cooperative production management, traditional farming systems, and culturally adapted marketing. These components not only built consumer trust and product authenticity but also ensured sustainability through localized ownership—positioning Sacha Inchi milk as both a health-promoting beverage and a driver of rural development.

Implications for the Plant-Based Milk Industry

This study contributes to the advancement of the plant-based milk sector by demonstrating that optimizing emulsifier concentrations improves viscosity, stability, and sensory performance in alignment with global health trends. Furthermore, the integration of the PAR model presents a scalable approach for rural innovation that combines community empowerment, local economic development, and nutrition-sensitive interventions.

CONCLUSION

This study demonstrated the successful development of Sacha Inchi milk as a functional plant-based beverage by integrating scientific formulation, nutritional functionality, and community empowerment. Physicochemical analyses revealed that the addition of hydrocolloids—specifically carboxymethyl cellulose (CMC) and xanthan gum—significantly improved viscosity (up to 302 mPas), maintained density within acceptable ranges, and slightly increased pH values (6.30–7.34), without negatively affecting protein content. The optimized formulations, A1B3 (CMC 1.2%) and A2B3 (Xanthan gum 1.2%), were identified as superior in both stability and functional performance, supported by moderate antioxidant capacity (IC_{50} values of 145.6 ppm and 162.3 ppm, respectively). Sensory evaluations confirmed that while taste and color remained statistically unaffected by emulsifier concentration ($p > 0.05$), texture was significantly enhanced at higher stabilizer levels ($p < 0.05$), particularly in xanthan gum-based formulations. These attributes led to high overall acceptability, aligning with consumer expectations for creamy, smooth plant-based beverages.

Beyond technical outcomes, the application of a Participatory Action Research (PAR) approach facilitated significant improvements in local knowledge, technical skills, and community ownership. Quantitative assessments showed marked increases in competencies related to hygienic processing, quality control, and small-scale enterprise management. Gender-inclusive participation—especially among women—played a vital role in production, quality evaluation, and market access through BUMDes integration, leading to a reported 30% increase in household income among active participants.

The synergy between food technology innovation and community-based knowledge systems proved critical to ensuring sustainability, product quality, and local economic impact. Sacha Inchi milk, therefore, emerges not only as a nutritionally valuable and antioxidant-rich beverage but also as a model of rural-based functional food innovation. Future efforts should focus on flavor optimization, shelf-life enhancement, and circular utilization of Sacha Inchi by-products to scale production and expand market reach. Overall, this research highlights the potential of Sacha Inchi

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milk to serve as both a health-promoting intervention and a community-driven enterprise for resilient, nutrition sensitive development.

RECOMMENDATION

The development of Sacha Inchi milk demonstrated strong potential from physicochemical, sensory, antioxidant, and community empowerment perspectives. However, several areas require further investigation to enhance both scientific and practical outcomes. First, flavor optimization should be prioritized, as despite the favorable texture, the distinct taste of Sacha Inchi may limit consumer acceptance. Future work could explore the use of natural flavoring agents, low-calorie sweeteners, or encapsulation techniques to improve palatability. Second, comprehensive studies on stability and shelf life under different storage conditions are needed to ensure product quality during distribution and commercialization. Third, the adoption of a circular economy model by valorizing Sacha Inchi by-products, such as defatted residues, for food or feed applications, can add value while supporting sustainability.

From a nutritional perspective, in vivo and clinical trials should be conducted to assess the bioavailability of bioactive compounds, including polyphenols, tocopherols, and omega-3 fatty acids, and their impacts on cardiovascular health and inflammation. Moreover, advanced food technologies such as high-pressure homogenization and microencapsulation could be explored to improve emulsion stability and extend shelf life.

Finally, the Participatory Action Research (PAR) model should be scaled to other communities, emphasizing gender inclusivity, value chain development, and digital marketing strategies, thereby positioning Sacha Inchi milk not only as a functional beverage but also as a driver of sustainable rural development.

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REFERENCES

Adeyanju, A. A., Adejuyitan, J. A., Ogunsimiro, O., Adebowale, O. J., & Akinsanola, B. A. (2022). *Developing a Plant-Based Yoghurt Recipe That Has the Same High-Quality Characteristics as Conventional Yoghurt*. https://doi.org/10.21203/rs.3.rs-2139387/v1

Aniceto, A., Mota Lemos, I. da, de Jacintho, M. E., Cadena, R., & Teodoro, A. J. (2023). Development of Fruit Beverages With Coconut Water: Physicochemical Characterization, Antioxidant Potential, and Sensory Properties. *Applied Research*.

Bait, Y., Salimi, Y. K., Zubair, M., Rahmatia, S., & Suleman, D. (2024). Pemberdayaan Masyarakat Desa Tabongo Timur Melalui Pengolahan Produk Berbasis Kelapa dan Sacha Inchi untuk Mendukung Pencapaian SDGs. *Lumbung Inovasi: Jurnal Pengabdian Kepada Masyarakat*, *9*(4), 1143–1156.

Breeden, R. L., Smith, T. L., & Willis, A. L. (2025). "Strained Relationships": A Participatory Action Research Study Examining Relationships Between Black Communities and Historically White Institutions. *Journal of Diversity in Higher Education*.

Chansuvarn, W., & Panich, S. (2024). Nutritional and sensory properties of plant-based milk produced from Sacha inchi seeds (Plukenetia volubilis L.). *Food Science and Applied Biotechnology*, *7*(1), 14–23. https://doi.org/10.30721/fsab2024.v7.i1.303

Chasquibol, N., Sotelo, A., Tapia, M., Alarcón, R., Goycoolea, F., & Perez-Camino, M. del C. (2024). Co Microencapsulation of Cushuro (Nostoc sphaericum) Polysaccharide with Sacha Inchi Oil (Plukenetia huayllabambana) and Natural Antioxidant Extracts. *Antioxidants*, *13*(6). https://doi.org/10.3390/antiox13060680

Chirinos, R., Pedreschi, R., Domínguez, G., & Campos, D. (2015). Comparison of the physico-chemical and phytochemical characteristics of the oil of two Plukenetia species. *Food Chemistry*, *173*, 1203–1206. https://doi.org/10.1016/j.foodchem.2014.10.120

Chirinos, R., Zorrilla, D., Aguilar-Galvez, A., Pedreschi, R., & Campos, D. (2016). Impact of Roasting on Fatty Acids, Tocopherols, Phytosterols, and Phenolic Compounds Present in Plukenetia huayllabambana Seed. *Journal of Chemistry*, *2016*.

Chon, J., Seo, K., Oh, H., Jeong, D., & Song, K. (2020). *Chemical and Organoleptic Properties of Some Dairy Products Supplemented with Various Concentration of Propolis : A Preliminary Study*. *38*(2), 59–69. Criste, A., Urcan, A. C., Coroian, C., Copolovici, L., Copolovici, D. M., Burtescu, R. F., & Oláh, N.-K. (2023). Plant-Based Beverages From Germinated and Ungerminated Seeds, as a Source of Probiotics, and Bioactive Compounds With Health Benefits—Part 1: Legumes. *Agriculture*. https://doi.org/10.3390/agriculture13061185 da Silva, L. C., Rodrigues Magalhães, H. C., Freire, G. A., Barros Alexandre, J. de, Castelo, R. M., Muniz, C.

Dudarev, I. (2024). Development of Craft Drinks With Oat Milk and Fruit and Berry Powders. *Товарознавчий Вісник*. https://doi.org/10.62763/ef/1.2024.105

Farooq, S., & Sehgal, A. (2019). Scrutinizing Antioxidant Interactions Between Green Tea and Some Medicinal Plants Commonly Used as Herbal Teas. *Journal of Food Biochemistry*.

Gama, A. P., Hung, Y., & Adhikari, K. (2019). Optimization of Emulsifier and Stabilizer Concentrations in a Model Peanut-Based Beverage System: A Mixture Design Approach. *Foods*. https://doi.org/10.3390/foods8040116

Gurskyi, P., Pertsevoy, F., & Kondrashyna, L. (2020). Investigation of the Emulsifying Capacity of Snack Paste Based on Fatless Cottage Cheese. *Eureka Life Sciences*. https://doi.org/10.21303/2504- 5695.2020.001104

Hariadi, H. (2024). Effect of Maltodextrin Concentration and Drying Temperature on the Physicochemical Characteristics Of Sacha Inchi (Plukenetia Volubilis) Extract Powder. *Italian Journal of Food Science*, *36*(2), 74–82. https://doi.org/10.15586/ijfs.v36i2.2458

Joshi, S., Bathla, S., Singh, A., Sharma, M., Inbaraj, B. S., & Sridhar, K. (2022). Development of Mung Bean (<i>Vigna Radiate</I> L.)-based Next-generation Vegan Milk: Processing, Nutritional Composition and Quality Attributes. *International Journal of Food Science \& Technology*. https://doi.org/10.1111/ijfs.16233

Kim, D., Iida, F., & Joo, N. (2022). Nutritional Composition of Sacha Inchi (<i>Plukenetia Volubilis</I>) According to Cooking Method and Its Application as an Elder-friendly Drink. *International Journal of Food Science \& Technology*. https://doi.org/10.1111/ijfs.16249

Kittibunchakul, S., Kemsawasd, V., Hudthagosol, C., & Sanporkha, P. (2023). *The Effects of Different Roasting Methods on the Phenolic Contents , Antioxidant Potential , and In Vitro Inhibitory*. Kodahl, N. (2020). Sacha inchi (Plukenetia volubilis L.)—from lost crop of the Incas to part of the solution to global challenges? *Planta*, *251*(4), 80. https://doi.org/10.1007/s00425-020-03377-3 Langen, T., Müller, G., & Falk, K. (2023). *Conceptual Modeling for Human Systems Integration in Manned UnmannedTeaming*. https://doi.org/10.54941/ahfe1004013

Magwenya, R. H., & Ross, A. (2022). *Developing a CPD Model for Eswatini- A Participatory Action Research Study.* https://doi.org/10.21203/rs.3.rs-1789272/v1

Maya, I., Winardi, D. O., Amalia, E., Mita, S. R., Kusumawulan, C. K., Putriana, N. A., & Sriwidodo, S. (2023). Physicochemical Characteristics, Fatty Acid Profile, and in Vitro Antioxidant Activity Evaluation of Sacha Inchi Seed Oil From Indonesia. *Cosmetics*. https://doi.org/10.3390/cosmetics10060171

Nagy, S. (2023). Participant-Oriented Evaluation Through Participatory Action Research: A Case Study of a Community Engagement Approach. *Arts and the Market*. https://doi.org/10.1108/aam-08-2021-0041 Pandey, A. K., Kamran, F., Choudhury, M., Li, L., Rahman, M. S., & Hussain, M. A. (2025). Omega-3 Fatty Acid Fortification of Plant-Based Beverages to Enhance Their Nutritional Profile. *Foods*. https://doi.org/10.3390/foods14091602

Pradhan, M. R., Unisa, S., Rawat, R., Surabhi, S., Saraswat, A., Reshmi, R. S., & Sethi, V. (2023). Women Empowerment Through Involvement in Community-Based Health and Nutrition Interventions: Evidence From a Qualitative Study in India. *Plos One*. https://doi.org/10.1371/journal.pone.0284521

Rodríguez, G., Aguirre, E., Córdova-Chang, A., Muñoz-Saenz, J. C., Baquerizo, M., Brandolini, A., Villanueva, E., & Hidalgo, A. (2022). Modification of the Nutritional Quality and Oxidative Stability of Lupin (Lupinus Mutabilis Sweet) and Sacha Inchi (Plukenetia Volubilis L.) Oil Blends. *Molecules*. https://doi.org/10.3390/molecules27217315

R., Furtado, R. F., & Alves, C. R. (2023). Fermented Milk Supplemented With Pequi Oil Microcapsules: Effects on Physicochemical Properties, Stability, in Vitro Digestion, and Bioaccessibility. *Food Science and Technology*. https://doi.org/10.5327/fst.101822

Salimi, Y. K., Ahmad, L., & Mahmud, M. (2022). The Community Partnership Program at UMKM Puncak Sejahtera Bukit Aren Village through Mentoring and Development of Virgin Coconut Oil (VCO) and Gula Aren Products. *ABDIMAS: Jurnal Pengabdian Masyarakat*, *5*(2), 2663–2671.

Salimi, Y. K., Ningrayati Amali, L., Sako Baderan, U., Aisa Liputo, S., & Mohamad, E. (2024). *Developing Sacha Inchi Cultivation in Tabongo Timur Village: An Empowerment Strategy for Food Security and Economic Improvement*. *4*, 1782–1791. https://doi.org/10.35568/abdimas.v7i4.5474

Saxena, S., Vasudevan, H., Saini, S., & Sasmal, S. (2023). Comparative Nutritional Assessment of Millet Based Milk Produced by Ultrasound, Germination, and a Combined Approach. *Acs Food Science \& Technology*. https://doi.org/10.1021/acsfoodscitech.2c00342

Turcotte, S., Shea, C., Raymond, É., Ansaldo, A. I., Bier, N., Grenier, S., Hebblethwaite, S., Lamontagne, M., Levasseur, M., Viscogliosi, C., Ladjadl, F., & Filiatrault, J. (2023). Codesign and Implementation of a Toolkit Supporting Community Organizations' Intergenerational Practice: A Participatory Action Research Project. *The Canadian Journal of Action Research*. https://doi.org/10.33524/cjar.v23i1.613

Walther, B., Guggisberg, D., Badertscher, R., Egger, L., Portmann, R., Dubois, S., Haldimann, M., Kopf Bolanz, K. A., Rhyn, P., Zoller, O., Veraguth, R., & Rezzi, S. (2022). Comparison of Nutritional Composition

Between Plant-Based Drinks and Cow's Milk. *Frontiers in Nutrition*. https://doi.org/10.3389/fnut.2022.988707

Yanti, S., Agrawal, D. C., Saputri, D. S., Lin, H., & Chien, W. (2022). Nutritional Comparison of Sacha Inchi (Plukenetia Volubilis) Residue With Edible Seeds and Nuts in Taiwan: A Chromatographic and Spectroscopic Study. *International Journal of Food Science*. https://doi.org/10.1155/2022/9825551.