



**UTILIZATION OF SACHA INCHI PRESS CAKE IN THE
PRODUCTION OF PLANT-BASED MEAT ALTERNATIVES**

JANET WAMUNI NJOROGÉ

**MASTER OF SCIENCE
IN
INNOVATIVE FOOD SCIENCE AND TECHNOLOGY**

**SCHOOL OF AGRO-INDUSTRY
MAE FAH LUANG UNIVERSITY**

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**THIS THESIS IS A PARTIAL FULFILLMENT OF
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**THESIS APPROVAL
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Thesis Title: Utilization of Sacha Inchi Press Cake in the Production of Plant-based Meat Alternatives

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ABSTRACT

This study evaluated the valorization of Sacha inchi press cake (SP), an oilseed by-product, to produce texturized vegetable protein (TVP) using single-screw extrusion. Steam pretreatment effectively reduced tannin content by 23.6% and saponin contents by 25% ,enhancing palatability of the Pretreated SP, referred to as Sacha inchi press cake meal (SPM), was blended with pea protein isolate (PPI) at SPM:PPI (w/w) ratios to produce five formulations: Control (0:100), TA (10:90), TB (35:65), TC (70:30), and TD (100:0). Increasing SPM incorporation in TVP formulations significantly altered color parameters, as evidenced by decreased lightness and increased redness and yellowness, thereby imparting a more meat-like appearance; however, elevated SPM levels were associated with a progressive decline in textural integrity. Among formulations, TA displayed a more compact and continuous microstructure with reduced pore formation and favorable textural properties comparable to commercial TVP (COM). Based on these characteristics, TA was selected for further analysis, showing high protein content (69.42%, d.b.), a balanced essential amino acid profile, and a predominance of oleic and linoleic acids without detectable trans fats. When incorporated into a burger patty, TA showed higher protein content (45.43%, d.b.) and fat retention while maintaining comparable cooking performance to commercial TVP based burger patty. Despite instrumental differences in color and texture, sensory evaluation (n=30) using a 9 -point hedonic scale showed no significant differences ($p > 0.05$) in appearance, aroma, taste, texture, or overall acceptance between TA (7.14), COM (6.77), and minced chicken burgers (7.27). Consumer perception data further indicated that the SPM-based burger was associated with health, modernity,

and environmental sustainability, with acceptance independent of food neophilia. These findings demonstrate the technological feasibility, nutritional value, and sensory competitiveness of upcycled Sacha inchi press meal as a sustainable ingredient for plant-based meat analogues, although further refinement of structural anisotropy and texture through advanced extrusion strategies may enhance meat-like fidelity.

Keywords: Sacha Inchi Press Cake, Texturized Vegetable Protein, Plant-Based Meat Alternatives, Food Waste Valorization, Consumer Acceptance, Sustainable Food Innovation



TABLE OF CONTENTS

CHAPTER	Page
1 INTRODUCTION	1
1.1 Background	1
1.2 Objectives	4
1.3 Problem Statement	5
1.4 Research Hypotheses	6
1.5 Significance of the Research	7
1.6 Scope of Research	7
1.7 Possible Limitations	8
1.8 Expected Output/Outcome/Impact	8
2 LITERATURE REVIEW	11
2.1 Sacha Inchi: A Nutritional Powerhouse	11
2.2 Valorization of Agro-Food By-products	12
2.3 Sacha Inchi Press Cake (SP)	14
2.4 Nutritional Profile of Plant-based Meat Alternatives	16
2.5 Extrusion Technology for Plant-Based Meat Alternatives	18
2.6 Texturized Vegetable Proteins (TVP)	19
2.7 Acceptance and Perception of PBMA	25
3 RESEARCH METHODOLOGY	30
3.1 Experimental Design	30
3.2 Materials	31
3.3 Pretreatment and Production of Textured Vegetable Protein (TVP)	32
3.4 TVP Physicochemical Analyses	34
3.5 TVP Functional Properties	35
3.6 Visual Surface Appearance and Microstructure by Scanning Electron Microscopy (SEM)	36
3.7 Textural Properties Measurement	37
3.8 Nutritional Composition of SP-TVP	37
3.9 Production of SP-TVP Burger Patties	38

TABLE OF CONTENTS

CHAPTER	Page
3.10 SP-TVP Burger Patty Analysis	39
3.11 Consumer Acceptability and Perception Of SP-TVP Burger Patty	41
3.12 Statistical Analysis	43
4 RESULTS AND DISCUSSION	45
4.1 Analysis of Anti- nutritional Properties in Pretreated Sacha Inchi Press Cake	45
4.2 Color and Visual Appearance	47
4.3 Functional Properties of Sacha Inchi Press Meal–incorporated Texturized Vegetable Protein (SP-TVP) Powder	50
4.4 Structure and Texture	51
4.5 Selection of the Optimal Sample	55
4.6 Nutritional Composition of Selected TVP	55
4.7 Development of Sacha Inchi Press Cake Burger Patty	61
4.8 Nutritional Composition of TA Burger Patty	61
4.9 NOVA Classification of TA Burger Patty	67
4.10 Color TA Burger Patty	67
4.11 Cooking Properties	69
4.12 Texture	70
4.13 Sensory and Consumer Acceptance	71
4.14 Consumer Perceptions, Expectations, and Acceptance of an Upcycled Sacha Inchi Press Cake Burger	75
5 CONCLUSION	79
REFERENCES	81
APPENDIX	100
CURRICULUM VITAE	103

LIST OF TABLES

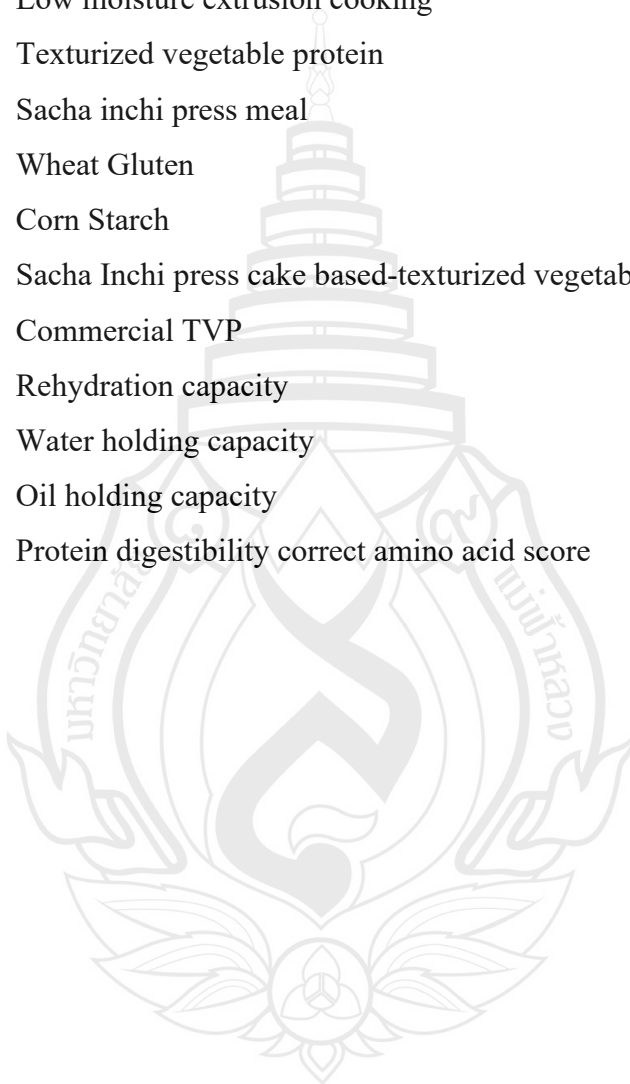
Table	Page
2.1 Structural, nutritional, and functional properties of plant proteins	23
3.1 Blend compositions (wt, %) used for the preparation of Sacha inchi press meal–incorporated texturized vegetable protein (TVP) samples	34
3.2 TVP based burger patty processing	39
4.1 Physicochemical and techno-functional properties of commercial (COM), control (C), and Sacha inchi press cake– incorporated texturized vegetable protein (TVP) samples (TA–TD)	49
4.2 Texture profile analysis (TPA) of commercial, control, and Sacha inchi press meal (SPM)–incorporated texturized vegetable protein (TVP) samples (TA–TD)	52
4.3 Proximate composition of the optimum Sacha inchi press meal– incorporated texturized vegetable protein (SP-TVP)	57
4.4 Amino acid profile of the optimum Sacha inchi press meal–incorporated texturized vegetable protein (SP-TVP)	58
4.5 Fatty acid composition of the optimum Sacha inchi press meal– incorporated texturized vegetable protein (SP-TVP)	60
4.6 Proximate composition of TA burger patty (Sacha inchi press meal– incorporated texturized vegetable protein) on a dry matter basis	62
4.7 Amino acid profile of TA burger patty (Sacha inchi press meal– incorporated texturized vegetable protein) on a dry matter basis	64
4.8 Fatty acid composition of TA burger patty on a dry matter basis	65
4.9 Color and cooking properties of TA and COM burger patty	68
4.10 Texture profile analysis (TPA) parameters of TA and COM TVP burger patties	71
4.11 Sensory evaluation of SP burger patties compared with commercial TVP and chicken burger patties	72
4.12 Acceptability of SP-burger patties compared with meat burger patties and association with food neophilia	74
4.13 Consumer sensory and economic expectations toward the product (%)	77

LIST OF FIGURES

Figure	Page
2.1 Sacha Inchi fruit, Sacha Inchi kernel, Sacha Inchi oil, Sacha Inchi press cake	16
2.2 Scheme of a twin-screw extruder for high-moisture extrusion of proteinaceous materials into fibrous meat analogue	20
2.3 Scheme of a twin-screw extruder for low-moisture extrusion of proteinaceous materials into spongy or fibrous network	20
2.4 Key reasons for the limited diversity of plant proteins in Australian plant-based meat analogues, with arrow size indicating relative importance	27
2.5 The global market size and growth of first- and second-generation meat alternatives	29
3.1 Overall methodology	30
4.1 Tannin and saponin content of SP and SPM on a dry matter basis	47
4.2 Visual appearance, macrostructure, and microstructure of commercial (COM), control (C), and Sacha inchi press meal–incorporated texturized vegetable protein (SP-TVP) samples (TA–TD)	54
4.3 Sensory profile of COM, TA and chicken (n = 30)	73
4.4 Acceptability scores (5-point Likert scale) for SP and meat burger patties in eating and offering contexts	75
4.5 Distribution of consumer selections for semantic differential attributes describing SP-based and meat burger patties	78

ABBREVIATIONS AND SYMBOLS

SP	Sacha Inchi press cake powder
PBMAs	Plant based meat alternatives
HMEC	High moisture extrusion cooking
LMEC	Low moisture extrusion cooking
TVP	Texturized vegetable protein
SPM	Sacha inchi press meal
WG	Wheat Gluten
CS	Corn Starch
SP-TVP	Sacha Inchi press cake based-texturized vegetable protein
COM	Commercial TVP
RHC	Rehydration capacity
WHC	Water holding capacity
OHC	Oil holding capacity
PDCAAS	Protein digestibility correct amino acid score



CHAPTER 1

INTRODUCTION

1.1 Background

The global population is projected to reach 8.5 billion by 2030 and nearly 9.7 billion by 2050, intensifying the demand for nutritious and sustainable food sources (United Nations, 2024). This demographic expansion, particularly in developing regions, has been accompanied by shifts in dietary habits toward more resource-intensive, animal-based proteins; a phenomenon referred to as the “livestock revolution” (Delgado, 2003). While livestock products are nutrient dense, their production contributes significantly to greenhouse gas emissions, excessive water use, and environmental degradation. Consequently, the global food industry is increasingly focused on identifying sustainable and alternative protein sources capable of meeting nutritional needs while minimizing ecological impact (Zhao et al., 2022b).

Plant-based proteins have emerged as promising alternatives due to their lower environmental footprint, potential health benefits, and alignment with ethical and sustainability goals. The development of plant-based meat analogues, in particular, reflects growing consumer interest in nutritious, climate-friendly, and animal-free food options (Meng et al., 2025). These innovations also contribute to the achievement of several United Nations Sustainable Development Goals, notably SDGs 2 (Zero Hunger), 3 (Good Health and Well-being), 12 (Responsible Consumption and Production), and 13 (Climate Action) (Ali & Bharali, 2025). However, despite technological advances, the plant protein market remains heavily dependent on soy. This reliance not only limits dietary diversification but also raises sustainability concerns due to the environmental impact and allergenicity associated with soy cultivation (Anyiam et al., 2025).

To address these challenges, recent research has focused on the valorization of agricultural by-products as alternative protein sources, particularly oilseed press cakes, nutrient-rich residues obtained after oil extraction. These by-products, often used as

animal feed or compost, are high in protein, fiber, and minerals and offer considerable potential for human nutrition (Singh et al., 2022). Their utilization in food applications aligns with the principles of a circular bio economy, reducing waste while creating value added products that support both environmental and economic sustainability (Sarangi et al., 2024) .

Among potential oilseeds, Sacha Inchi (*Plukenetia volubilis* L.), commonly known as the “Inca peanut,” represents a particularly promising candidate. Native to the Amazon basin, Sacha Inchi has gained global attention for its oil, which is exceptionally rich in omega-3 and omega-6 fatty acids, and for its high-quality protein content (Torres Sánchez et al., 2021). Following oil extraction, the Sacha Inchi press cake (SP) constituting approximately 55–67% of the seed mass remains underutilized despite its favorable nutritional composition, which includes 32–62% protein, 5–25% residual oil, and around 25% dietary fiber (Kong et al., 2023a; Ruiz et al., 2013; Wang et al., 2018). However, the direct incorporation of SP into food formulations is constrained by its inherent bitterness, astringency, and the presence of antinutritional factors such as tannins, phytic acid, and saponins (Cirkovic Velickovic & Stanic-Vucinic, 2017; Sharma et al., 2023).

To enhance the sensory and functional quality of SP, pre-treatment strategies such as hydro-thermal treatments modification among them, steam can be employed to reduce antinutritional compounds and improve protein solubility and flavor (Vera et al., 2024). Once optimized, the pre-treated Sacha Inchi press cake (SP) can serve as a promising raw material for developing plant-based meat alternatives. Low-moisture extrusion is the most established technique for structuring plant proteins into meat analogues. During this process, the protein-rich blend is subjected to controlled shear and heat in a single- or twin-screw extruder, promoting protein denaturation and network formation. Upon exiting the die, a rapid pressure drop generates steam expansion, yielding a porous, fibrous structure that solidifies into textured vegetable protein (TVP) with meat-like texture and appearance (Luise et al., 2025). The TVP production from underutilized plant sources offers a sustainable approach to developing high-protein ingredients that can mimic the texture and functionality of meat while addressing both environmental and nutritional objectives.

The development of Sacha inchi press cake based TVP (SP-TVP) represents an opportunity to both diversify plant-based protein sources and advance circular bioeconomy goals by upcycling an underutilized by-product into a high-protein ingredient. In this context, a detailed understanding of how steam pretreatment and extrusion conditions affect the textural, techno-functional, and structural properties of SP-TVP is essential for designing products that can realistically compete with conventional meat and established TVPs in real food applications. Recent research has shown that oilseed press cakes from sunflower, flaxseed, pumpkin seed, and rapeseed can be incorporated into textured vegetable proteins, most often via twin-screw extrusion, thereby broadening the raw material base for meat analogues (Lallinger & Rauh, 2024; Luise et al., 2025; Singh et al., 2024). In parallel, Sacha inchi by-products have mainly been evaluated as flours, protein extracts, or beverage ingredients in model food systems, where they enhance protein content, techno-functional properties, or bioactive profiles, rather than being used directly as structural components in TVP matrices (Alejandro Ruiz et al., 2025; Kong et al., 2023b; Njoroge et al., 2025; Torres Sánchez et al., 2021). Consequently, the application of SPM as a primary structural ingredient in TVP systems remains largely unexplored.

Burgers represent one of the most widely consumed meat products globally and are therefore a relevant carrier for alternative proteins (Tabarestani et al., 2024). However, consumer acceptance of Plant based meat alternatives (PBMA) is strongly influenced by expectations formed prior to consumption. When the perceived sensory experience fails to meet these expectations, a disconfirmation occurs, often resulting in product rejection (Delwiche, 2004). This mismatch is particularly relevant for meat analogues, where visual appearance, texture, and cooking behavior are expected to closely resemble those of conventional meat. Previous studies have shown that low acceptance of PBMA is frequently associated with unsatisfactory texture and sensory properties, as well as consumers' lack of confidence in nutritional value and product safety (Kołodziejczak et al., 2022). Among omnivores and flexitarians, inferior sensory appeal and limited similarity to meat remain major barriers to adoption, highlighting the technical challenge of producing fibrous, meat-like textures from plant proteins (Kołodziejczak et al., 2022).

Beyond sensory quality, consumer acceptance of novel protein foods is shaped by psychological, cultural, and symbolic factors. There is growing evidence that acceptance of meat alternatives varies widely across populations, yet research on consumer attitudes toward PBMA remains heavily concentrated in Western contexts (Bryant et al., 2019). Outside the West, including in many Asian and developing countries where meat consumption is projected to increase, quantitative research on consumer acceptance, preferences, and perception remains limited (Bryant et al., 2019). Since the success of novel food technologies depends largely on sustained consumer adoption, understanding acceptance drivers is critical (Szejda et al., 2021). Dietary choices are further influenced by social, cultural, traditional, and environmental factors, as well as by income growth and consumption context, emphasizing the complexity of consumer decision-making processes (Forsberg et al., 2025).

The present study evaluates the feasibility of valorizing steam-pretreated Sacha Inchi press cake, blended with pea protein isolate, for the production of textured vegetable protein via low-moisture single-screw extrusion. The effects of formulation and processing conditions on the textural, techno-functional, and structural properties of SPM-based TVP are systematically investigated. The most promising TVP formulation is subsequently incorporated into plant-based burger patties and characterized in terms of physicochemical properties, nutritional composition, sensory quality, and cooking behavior. Furthermore, consumer acceptance, perception, and the role of food neophilia are examined in comparison with commercial plant-based and chicken burger patties. By integrating by-product valorization, process engineering, product development, and consumer research, this study advances the utilization of Sacha Inchi press cake from an underutilized by-product into a functional, consumer-relevant ingredient for next-generation plant-based meat alternatives

1.2 Objectives

1.2.1 Main Objective

To evaluate Sacha Inchi press cake (SP) as a functional ingredient for Textured Vegetable Protein (TVP) production and its application in plant-based burger pattie

1.2.2 Specific Objectives

1. Effect of steam pretreatment on press cake: To evaluate the effect of steam pretreatment on tannin and saponin contents of Sacha inchi press cake and its implications for reducing bitterness and astringency.
2. Physicochemical and functional characterization: To characterize the physicochemical properties of Sacha inchi press cake–based textured vegetable protein (SP-TVP), including nutritional composition, techno-functional properties, and textural attributes.
3. TVP development and characterization: To produce textured vegetable protein from steam-pretreated Sacha inchi press cake blended with pea protein isolate using low-moisture single-screw extrusion, and to evaluate its textural, techno-functional, nutritional and structural properties.
4. Burger formulation and quality assessment: To formulate plant-based burger patties using SP-TVP as the primary structural protein and to assess their physicochemical properties, nutritional composition, and cooking behavior.
5. Sensory quality and consumer acceptance: To assess the sensory attributes, consumer acceptance, and perception of SP-TVP-based burger patties in comparison with commercial plant-based and chicken burger patties, including the role of food neophilia.

1.3 Problem Statement

The rapid expansion of the plant-based meat alternative market has increased the demand for sustainable and diversified protein sources. However, this demand is met with a persistent overreliance on soy as the dominant protein ingredient in plant-based meat alternatives (PBMA). This reliance not only limits dietary diversification but also raises allergenicity and sustainability concerns due to the environmental impact associated with soy cultivation.

One potential solution lies in the utilization of agro-industrial by-products such as sacha inchi press cake (SP). Despite being a nutrient-dense material which includes 32-62% protein, 5-25% residual oil and around 25% dietary fiber, SP remains largely

underutilized. This underutilization is primarily due to its common disposal or use as low-value animal feed, resulting in the loss of a potentially valuable food resource.

The limited application of SP in human food systems is further caused by sensory challenges. Specifically, bitterness, astringency due to the presence of antinutritional factors (saponins and tannins) which negatively affect its palatability in food formulations. As a result, its incorporation into PBMA and other food products remains constrained.

In addition, the successful development and adoption of novel plant-based ingredients such as Sacha inchi press meal (SPM) which is steam pretreated sacha inchi press cake are hindered by insufficient understanding of consumer acceptability, particularly in non-Western markets. In emerging economies such as Thailand, the lack of comprehensive data on consumer preferences, taste expectations, and acceptance drivers limits the ability to design products that align with local market demands.

Consequently, the combination of underutilized protein resources and sensory limitations, overdependence on soy, and inadequate consumer insights creates a critical barrier to advancing sustainable and diversified plant-based meat alternatives. Addressing these interconnected challenges is essential to unlocking the full potential of SPM and supporting the development of innovative, acceptable, and sustainable food products.

1.4 Research Hypotheses

1.4.1 Steam pretreatment significantly improves the suitability of Sacha inchi press cake for extrusion by reducing tannin and saponin contents, thereby improving its palatability.

1.4.2 Texturized vegetable protein (TVP) produced from Sacha inchi press cake exhibits physicochemical, nutritional, structural, and textural properties comparable to those of commercial TVP.

1.4.3 Burger patties formulated using Sacha inchi press cake-based texturized vegetable protein demonstrate physicochemical, nutritional, cooking, and textural properties comparable to burger patties prepared with commercial TVP.

1.4.4 Burger patties formulated with Sacha inchi press cake–based textured vegetable protein achieve consumer acceptance levels comparable to commercial TVP-based plant-based burgers.

1.4.5 Higher levels of food neophilia are associated with significantly greater consumer acceptance and more positive perception of Sacha inchi press cake–based burger patties.

1.5 Significance of the Research

This research contributes to sustainable food innovation by valorizing Sacha Inchi press cake, an underutilized agro-industrial by-product, in the development of nutritionally enhanced plant-based meat alternatives. The findings are expected to benefit both the food industry and health-conscious consumers by offering a novel, nutrient-dense, and environmentally sustainable alternative to conventional PBMA, potentially shaping future product development and dietary trends in the global plant-based sector.

1.6 Scope of Research

This research investigates the feasibility of valorizing Sacha inchi press cake (SP), a nutrient-rich by-product of cold-press oil extraction, for application in textured vegetable protein (TVP) and SP-TVP-based plant-based burger patties. Textured vegetable protein is produced from steam-pretreated Sacha inchi press cake (also referred to as Sacha inchi press meal, SPM) blended with pea protein isolate (PI) to replace soy in the formulation using low-moisture single-screw extrusion at 10:90, 35:65, 70:30, and 100:0 (w/w) at a fixed 43.8% inclusion level, with a control consisting of pea protein isolate–wheat gluten–corn starch formulation (10:4:1, w/w/w) and a commercial TVP serving as benchmarks. The extruded TVPs are characterized for physicochemical, textural, and microstructural properties using scanning electron microscopy (SEM). The SP-TVP formulation exhibiting the most favorable functional

and structural attributes is selected for nutritional evaluation and subsequent incorporation into burger patty formulations.

The extruded TVPs are incorporated into plant-based burger patties and evaluated for nutritional composition, physicochemical properties, textural characteristics, and sensory acceptability. Consumer acceptance and perception are assessed at Mae Fah Luang University, Chiang Rai, Thailand, involving university staff and students aged 18–65 years ($n = 30$) for sensory evaluation, ($n = 60$) for consumer acceptance and perception survey.

1.7 Possible Limitations

1.7.1 Sensory Challenges

Potential difficulties in achieving optimal texture and taste with incorporation of Sacha Inchi press cake, which may affect acceptability.

1.7.2 Consumer Bias

Existing consumer bias or unfamiliarity with Sacha Inchi may influence survey responses and perception.

1.8 Expected Output/Outcome/Impact

1.8.1 Expected Outputs

1. Development of SP-based textured vegetable protein: Production of textured vegetable protein (TVP) formulated from steam-pretreated Sacha inchi press cake, referred to as Sacha inchi press meal (SPM), blended with pea protein isolate (PI) using low-moisture single-screw extrusion.

2. Formulation of plant-based burger patties: Development of prototype plant-based burger patties incorporating Sacha inchi press meal-based textured vegetable protein (SP-TVP) as the primary structural protein ingredient.

3. Physicochemical, functional, and structural dataset: Generation of data on the physicochemical and techno-functional properties of SP-TVP, including water

and oil holding capacities, textural attributes, and microstructural characteristics assessed by scanning electron microscopy (SEM).

4. Nutritional composition dataset: Determination of the nutritional composition of SP-TVP and SP-TVP-based burger patties, including proximate composition, fiber, amino acid and fatty acid profile, and selected quality attributes relevant to plant-based meat analogues.

5. Sensory and consumer perception data: Generation of sensory evaluation and consumer acceptability data for SP-TVP-based burger patties, including eating acceptability and willingness to offer the product to others, together with consumer perception and expectation data and analysis of their association with food neophilia, perceived healthfulness, sustainability, and purchase intent.

1.8.2 Anticipated Outcomes

1. Nutritional Enhancement: Burger patties containing SP-TVP are expected to have significantly higher protein and dietary fiber compared to soy-based commercial TVP burger patties.

2. Improved Functional Performance: SP-TVP is anticipated to show improved texturization and water/oil holding, suitable for burger patty manufacturing.

3. High Sensory Acceptability: Formulated patties are expected to meet or exceed consumer liking scores relative to commercial soy-based alternatives.

4. Positive Consumer Perception: Consumers are anticipated to view SP-based patties as healthier, more sustainable, positively influencing purchase intent.

5. Agro-Industrial By-product Valorization: Demonstration that Sacha Inchi press cake, an oilseed by-product, can be transformed into a functional, value-added ingredient for next-generation plant-based foods.

1.8.3 Projected Impact

This project directly supports several United Nations Sustainable Development Goals (SDGs) through its focus on sustainable plant-based meat alternatives derived from Sacha Inchi press cake (SP-TVP). The anticipated impacts include:

1. SDG 2 – Zero Hunger

The development of nutrient-rich, plant-based protein products contributes to food and nutrition security by offering accessible and affordable protein sources, especially in regions vulnerable to protein-energy malnutrition.

2. SDG 3 – Good Health and Well-Being

The project promotes healthier dietary patterns by enhancing intake of fiber and omega-3 fatty acids, while reducing dependence on red and processed meats, thereby potentially lowering the risk of non-communicable diseases.

3. SDG 8 – Decent Work and Economic Growth

By valorizing underutilized agro-industrial by-products like Sacha Inchi press cake, the project creates new economic opportunities along the value chain from raw material producers to food processors and retailers.

4. SDG 9 – Industry, Innovation and Infrastructure

The research supports technological innovation through the application of single-screw extrusion for SP-TVP development, contributing to sustainable food processing infrastructure and capacity building.

5. SDG 12 – Responsible Consumption and Production

This project embodies circular economy principles by upcycling Sacha Inchi press cake into value-added food ingredients, thereby reducing agro-industrial waste and encouraging sustainable production practices.

6. SDG 13 – Climate Action

Transitioning from animal-based proteins to plant-based alternatives significantly reduces greenhouse gas emissions, land use, and water consumption, contributing to climate mitigation efforts

CHAPTER 2

LITERATURE REVIEW

2.1 Sacha Inchi: A Nutritional Powerhouse

Sacha Inchi (*Plukenetia volubilis*), commonly known as the “Inca peanut” or “mountain peanut,” is a plant native to the Amazon basin. Originally cultivated by the Incas, this ancient crop has recently gained global attention as a superfood due to its rich nutritional profile and health benefits. Known for its high omega fatty acid content and quality protein, Sacha Inchi has become a popular ingredient in functional foods and wellness products. Its unique composition makes it valuable across several industries, with applications in food, cosmetics, and biodiesel (Kodahl, 2020).

Sacha Inchi has deep historical roots in the Amazon region, especially in Peru, where it has been traditionally cultivated for centuries. Peru continues to lead in Sacha Inchi production, with an annual seed yield of approximately 1,200 tons (Kittibunchakul et al., 2022). As global demand for its health benefits has risen, Sacha Inchi cultivation has expanded to countries such as China, Vietnam, Thailand, and Taiwan. This expansion is driven by the plant’s adaptability and its high commercial value, making it an attractive crop in global agricultural markets (Norhazlindah et al., 2022).

The nutritional composition of Sacha Inchi seeds is a major reason for its popularity. The seeds are rich in oil, containing 45–60% oil content, predominantly made up of essential fatty acids. The oil profile includes omega-3 (47–51%) and omega-6 (33–36%) fatty acids, which together account for over 90% of the total lipid fraction (Kodahl, 2020; Norhazlindah et al., 2022). These fatty acids are important for cardiovascular health and are associated with anti-inflammatory and anti-cancer properties. Additionally, Sacha Inchi seeds contain high-quality protein, typically ranging from 21–30% (Cordero-Clavijo et al., 2024), as well as phytosterols, vitamins, carotenoids, and other beneficial bioactive compounds (Torres-Sanchez et al., 2023).

The omega-3 and omega-6 fatty acids in Sacha Inchi are linked to various health benefits, including cardiovascular protection, skin health improvement, and reduced risk of

chronic inflammatory conditions. With an optimal ω -6/ ω -3 ratio of 0.83–1.09, Sacha Inchi supports cardiovascular health and may reduce risks of hypertension, depression, and autoimmune diseases (Sierra et al., 2021).

Sacha Inchi seeds oil's health-promoting properties and unique sensory characteristics, including its distinct taste and aroma, contribute to its market demand. Sixteen volatile compounds responsible for its unique flavor have been identified (Ramos-Escudero et al., 2021). Commercially, Sacha Inchi oil is used in a variety of edible products, such as cooking oils, salad dressings, and yogurt. Beyond foods, Sacha Inchi oil finds applications in cosmetics, nanoparticle formulations, and biodiesel, reflecting its versatile industrial value (Sierra et al., 2021; Wang et al., 2018).

2.2 Valorization of Agro-Food By-products

The growing global demand for food resources has led to significant shortages, creating challenges for sustainable food production (Zhao et al., 2022b). Simultaneously, agro-industrial activities generate an estimated 1.3 billion tons of waste globally each year, exacerbating environmental concerns and complicating waste management strategies critical for sustainability (Bhardwaj et al., 2025). In response, researchers and industries are increasingly exploring renewable and cost-effective resources to support integrated biorefineries, which align with the principles of a circular economy (Daimary et al., 2025). These biorefineries aim to efficiently utilize food by-products, reducing waste while creating value-added products that contribute to environmental and economic sustainability.

One promising approach to meeting the rising demand for essential nutrients, particularly proteins, involves repurposing agro-industrial by-products such as residual cakes from edible oil production. These protein-rich by-products can be processed into vegetable protein concentrates by eliminating non-protein components while preserving their nutritional integrity (Mondor & Hernandez Alvarez, 2022). Additionally, the food industry is shifting towards zero-waste production, where by-products such as shells, skins, pulp, stems, and seeds often discarded in landfills are repurposed for novel food applications (Ahmad et al., 2024). This not only mitigates environmental damage but also

provides an affordable, sustainable source of nutrients, contributing to the development of functional and nutritious food products.

Recent studies have demonstrated various strategies for utilizing agro-food by-products in innovative food applications. For instance, González-Díaz et al. (2024) explored the valorization of brewer's spent grain (BSG), the primary by-product of beer production, by incorporating it into the cultivation medium for *Ganoderma lucidum*, leading to the development of functional food ingredients enriched with dietary fiber and protein. The study also tested partial substitution of wheat flour with BSG-derived biomass in bread prototypes, demonstrating favorable sensory attributes. Similarly, Pomasa et al. (2025) investigated the potential of banana peel powder as an innovative ingredient for gluten-free cookies. The inclusion of banana peel powder enhanced the antioxidant properties of the cookies, contributing to improved nutritional value while maintaining consumer acceptability.

Furthermore, Náthia-Neves and Alonso (2021) examined the valorization of sunflower cake, a by-product of sunflower oil refining, through microwave-assisted extraction (MAE) to remove chlorogenic acid (CGA) and obtain a protein-rich flour suitable for human consumption. The study optimized the extraction process in two stages, first identifying ethanol 70% as the most effective solvent and then evaluating the effects of power (100–300 W) and extraction time (30–120 seconds) on CGA recovery. The optimized MAE process efficiently extracted 8.4 ± 0.1 mg CGA/g of raw material within just 30 seconds, while the ORAC assay confirmed the antioxidant capacity of the extracts. Additionally, FTIR and SEM analyses demonstrated the structural impact of irradiation power on the sunflower by-product. The process yielded a residual solid with 26% protein and essential amino acids, highlighting its potential application in food products for human nutrition.

Beyond the food industry, the valorization of agricultural waste has broader applications, including in cosmetics, bioplastics, and biomedical fields (Pandey et al., 2025). Bioactive compounds extracted from food waste, such as anthocyanins, carotenoids, and polyphenols, can serve as natural pigments, dietary supplements, and functional additives, offering sustainable alternatives to synthetic ingredients. By harnessing the potential of agro-industrial by-products, industries can reduce waste disposal costs, enhance economic sustainability, and advance the objectives of a circular economy.

(Ahmad et al., 2024). This transition from waste to resource utilization underscores the importance of integrating food science innovations into a sustainable global food system.

2.3 Sacha Inchi Press Cake (SP)

Sacha inchi press cake (SP) as seen Figure 2.1, is a protein-rich by-product from the seed oil extraction industry. Sacha Inchi oil extraction typically yields 28.90% to 42.10% oil by weight, leaving behind a substantial amount of press cake, which constitutes about 54.75% to 67.35% of the original seed mass (Kong et al., 2023b). Given the growing market for Sacha Inchi oil valued at approximately USD 101 million in 2022 and projected to reach USD 143.65 million by 2030 (Verified, 2024).

The global generation of press cake as a by-product is significant. This by-product, which is often discarded despite its high protein content, offers an untapped resource for nutrition and food industry applications. Studies have shown that defatted Sacha Inchi seed residues contain up to 59.10% protein by dry weight, creating an opportunity to advance the protein-based Sacha Inchi industry by finding new uses for these residues (Sharma et al., 2023; Wang et al., 2018). The protein in Sacha Inchi seeds is highly regarded for its health benefits, particularly due to its substantial tryptophan (44 mg/g) and phenylalanine (3 mg/g) content. It has been recognized by the World Health Organization (WHO) and the Food and Agriculture Organization (FAO) as a high-quality protein suitable for human consumption (Hanssen & Schmitz-Hübsch, 2011).

Protein content in Sacha Inchi oil press cake (SP) varies, typically falling between 32% and 62%, which aligns it with other common protein sources like soybean meal, widely used in feed formulations and functional foods (Ibáñez et al., 2020). However, protein levels can differ based on seed variety, with *Plukenetia volubilis* yielding higher concentrations (59%) than *Plukenetia huayllabambana* (46%) (Ruiz et al., 2013). In addition to protein, SP retains around 5–25% lipids post-extraction, primarily composed of essential fatty acids, notably α -linolenic (~50%) and linoleic (~35%) acids. This lipid profile, richer in polyunsaturated fatty acids than soybean meal, is beneficial for food enrichment purposes (Rawdkuen et al., 2016; Ruiz et al., 2013).

Carbohydrate content in SP ranges from approximately 4.97% to 26.8%, and its fiber composition includes total dietary fiber (around 25%), with values reported for crude, neutral, and acid detergent fibers. These levels, which include hemicellulose and lignin, resemble those in soybean meal, marking SP as a similar dietary fiber source (Jagersberger, 2013; Martinez et al., 2020). Additionally, SP is mineral-rich, containing potassium, phosphorus, calcium, and magnesium. For instance, calcium, phosphorus, and iron concentrations in SP are comparable to those in soybean meal, making it a feasible substitute (Rawdkuen et al., 2016; Ruiz et al., 2013).

Despite these benefits, SP contains minor amounts of antinutritional factors like tannins, phytic acid, hemagglutinins, alkaloids, oxalates, nitrates, thiocyanates and saponins and trypsin inhibitors. Tannins, for instance, may impart an astringent flavor and reduce protein digestibility due to their ability to form complexes with proteins, though the trypsin inhibitor levels are lower in SP compared to soybean meals (Cirkovic Velickovic & Stanic-Vucinic, 2017). SP's antioxidant properties, though underexplored, have shown promising activity, possibly due to its phenolic compounds (ranging between 51 and 312 mg gallic acid equivalents per 100 g). Its antioxidant potential suggests it may be a natural alternative to synthetic antioxidants (Jagersberger, 2013; Rawdkuen et al., 2016).

In terms of amino acids, SP is rich in essential amino acids like lysine, histidine, and leucine, as well as notable amounts of isoleucine, valine, tryptophan, and phenylalanine. While its amino acid profile largely aligns with FAO/WHO standards, lysine and leucine content may be slightly lower. Among non-essential amino acids, SP has high levels of tyrosine, glutamic acid, and cysteine. Besides, *in vitro* digestibility ranges from 88.50% to 93.60%, which improves with cooking (Vanegas-Azuero & Gutiérrez, 2018). This composition highlights SP as a valuable, well-balanced protein source comparable to soy, with broad applications in food, dietary supplements, and functional foods.



Source Torres Sánchez et al. (2021)

Figure 2.1 Sacha Inchi fruit, Sacha Inchi kernel, Sacha Inchi oil, Sacha Inchi press cake

2.4 Nutritional Profile of Plant-based Meat Alternatives

Plant-based meats are structured products derived from plants that are engineered to replace conventional animal meats including poultry and seafood and are marketed as meat substitutes, analogues, or alternatives (Rees Clayton et al., 2019). Despite their rapid rise in popularity, there are still no clearer nutritional guidance and this could help to further support the emergence of healthier plant-based options (Brodersen et al., 2025). An array of studies has been conducted in many countries to try and figure out the nutritional quality of PBMA. This section will highlight some of the most recent studies examining the nutritional profile of PBMA versus their meat counterparts. Alessandrini et al. (2021) conducted a study comparing the nutrient profiles of plant-based meat alternatives (PBMA) and traditional meat products, finding that PBMA generally had a healthier profile due to their lower energy density, total fat, and saturated fat, as well as their higher dietary fiber content. However, PBMA had lower protein levels and, in many cases, higher salt content than traditional meat products. Studies analyzing PBMA and meat products from UK retailers reported that PBMA generally had lower energy density, total fat, saturated fat, and protein while being richer in fiber (Szenderák et al., 2022)

Similarly, Bryngelsson et al. (2022) assessed PBMA through supermarket searches and packaging information, confirming that these products tend to be lower in saturated fat and higher in dietary fiber. Additionally, micronutrient content varied among PBMA, with some products offering higher levels of iron and folate compared to their meat-based counterparts. Harnack et al. (2021) further supported these findings,

highlighting that plant-based ground beef alternatives provided a good source of dietary fiber and comparable iron levels to ground beef.

Despite these nutritional benefits, PBMAAs also present certain limitations. One of the most commonly reported concerns is their high sodium content. Several studies have noted that PBMAAs often contain elevated sodium levels, which may pose health risks if consumed in excess. Szenderák et al. (2022) reported that sodium levels were high across all PBMA categories except for sausages, with many products exceeding recommended limits. Similarly, Harnack et al. (2021) found that plant-based ground beef alternatives contained significantly higher sodium levels compared to conventional meat products. Moreover, PBMAAs tend to have lower protein content, as observed in four out of six PBMA categories analyzed by Szenderák et al. (2022). Micronutrient availability also varied among PBMAAs, with discrepancies in vitamin B12 levels; for instance, plant-based sausages contained higher amounts, whereas PBMA bacon had lower levels compared to meat equivalents (Bryngelsson et al., 2022).

Another limitation in these studies is the potential influence of data collection constraints. Many of the studies were conducted during the COVID-19 pandemic, which limited access to a diverse range of PBMA products. For example, the study by Szenderák et al. (2022) was restricted to a single retailer out of the 14 initially targeted. Similarly, Tonheim et al. (2022) encountered challenges in their survey of PBMAAs in Norway due to pandemic-related restrictions on supplier availability and data collection. Furthermore, Bryngelsson et al. (2022) identified inconsistencies in micronutrient labeling across PBMAAs, underscoring the need for more comprehensive data. Harnack et al. (2021) also highlighted inaccuracies in product labeling and database limitations, which could affect the reliability of nutritional assessments.

Overall results from most research indicated that PBMAAs contained significantly more fiber and lower energy density, total and saturated fat, cholesterol, and protein content. Regarding micronutrients, iron levels in PBMAAs were found to be comparable to or higher than those in meat, but vitamin B12 and zinc levels were lower. Additionally, studies noted that sodium levels in PBMAAs were higher. The study results clearly indicate that the nutritional composition of PBMAAs varies not only between different products and brands but also emphasize the difficulty of replicating the sensory qualities of meat while maintaining comparable levels of macronutrients and essential micronutrients.

2.5 Extrusion Technology for Plant-based Meat Alternatives

Extrusion is a thermomechanical process that applies controlled shear, heat, and pressure to plant proteins to form fibrous structures resembling meat analogues. It involves preconditioning, mixing and cooking in the barrel, and shaping through a die (Baig et al., 2025). The main techniques for texturized vegetable protein (TVP) production are low-moisture extrusion cooking (LMEC) and high-moisture extrusion cooking (HMEC) (Schmid et al., 2022)

LMEC operates at 10–40% moisture and produces dry, expanded products requiring rehydration (Schmid et al., 2022). Under high shear and temperature, proteins denature and reorganize into cross-linked structures that expand upon exiting the die. Soy flour and soy protein concentrate are commonly used due to cost-effectiveness (Schmid et al., 2022). LMEC enables continuous, energy-efficient production, but also promotes reactions such as Maillard browning, deamidation, and lipid oxidation, which influence flavor and nutritional quality depending on process conditions (Li & Li, 2023). Incorporation of 0.5–0.9% Sacha Inchi oil at 21.7–22.4% moisture and 135°C has been shown to enhance the nutritional profile of soy-based TVP (Prasert et al., 2022).

HMEC operates at 40–70% moisture and produces fibrous, meat-like textures through phase separation and protein alignment during cooling in a cooling die (Osen & Schweiggert-Weisz, 2016). It has been applied to proteins such as soy, pea, wheat gluten, and faba bean. Compared with LMEC, HMEC yields denser, anisotropic structures with greater cutting strength and elasticity due to moisture-facilitated fiber formation.

Moisture content strongly affects flavor retention. Low-moisture systems may lose volatile compounds through evaporation, whereas high-moisture systems enhance volatile retention but may dilute certain aromas. For example, soy protein extruded at 30% moisture showed lower aroma intensity yet higher consumer preference than at 40% moisture (Milani et al., 2014). HMEC can also reduce undesirable beany notes (Saldanha do Carmo et al., 2021).

Extrusion alters protein functionality and digestibility through heat-induced denaturation and bond formation. High-moisture systems are primarily stabilized by hydrogen bonds, whereas low-moisture systems favor disulfide linkages (Zhao et al.,

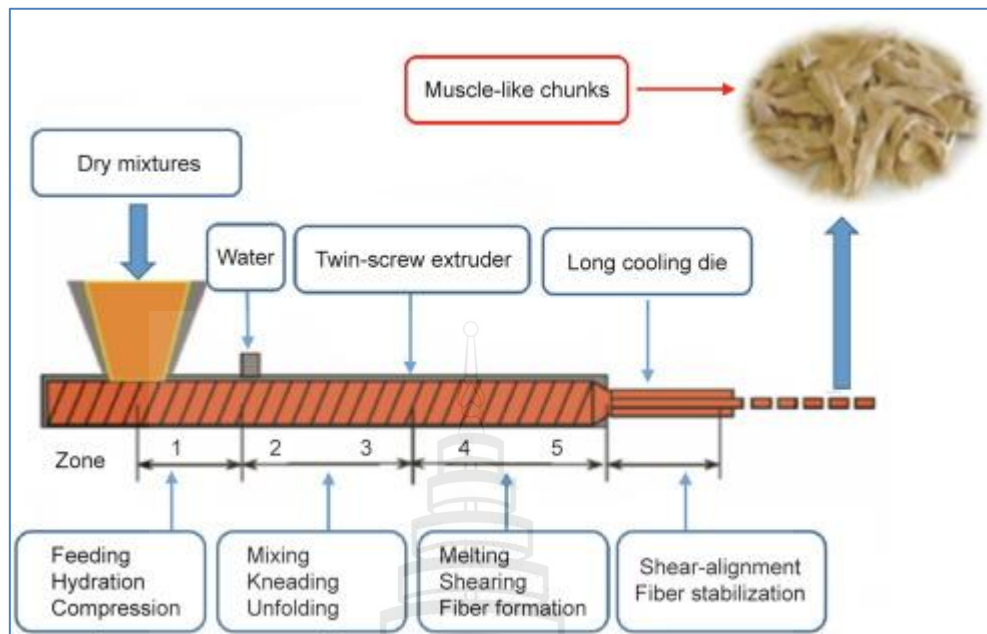
2022a). Processing parameters collectively determine final structure and functionality. Starch gelatinization contributes to structural integrity and improved enzymatic digestibility (Ye et al., 2017), while lipids affect texture, stability, and flavor through protein interactions and oxidation-derived volatiles (Kyriakopoulou et al., 2019). Overall, LMEC and HMEC are essential technologies for plant-based meat production, offering distinct structural, sensory, and nutritional outcomes.

2.6 Texturized Vegetable Proteins (TVP)

Texturized vegetable protein (TVP) is extensively used as a meat analogue due to its fibrous texture and high protein content (Esbroeck et al., 2023; Kyriakopoulou et al., 2019). Extrusion is the primary method for structuring TVP, as it enhances its functional and sensory properties through controlled shear, heat, and pressure (Dekkers et al., 2018). Product characteristics are strongly influenced by processing variables such as screw speed, die temperature, and moisture content. Higher die temperatures increase expansion and reduce density, whereas excessive conditions can impair water absorption and texture (Lyu et al., 2023).

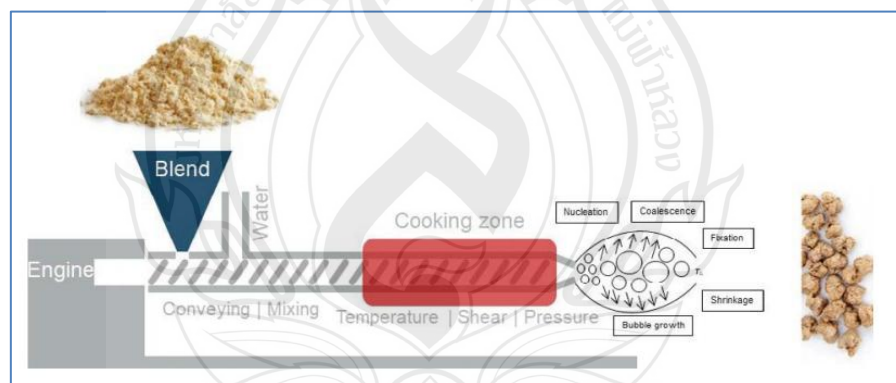
TVP structuring has been described by the “suspension model,” in which the protein melt separates into continuous and dispersed phases whose alignment determines fibrous formation (Dekkers et al., 2018). Proper preconditioning is essential to this process; uniform hydration through steam and water addition promotes plasticization, improves lamination, and stabilizes extrusion, while inadequate preconditioning leads to excessive expansion and poor texture (Ramos-Diaz et al., 2022).

As illustrated in Figures 2.2 and 2.3, both low- and high-moisture extrusion systems comprise four main components: a feeder for controlled raw material input, a preconditioner for moisture adjustment, an extrusion cooker for protein plasticization under shear and heat, and a die assembly that shapes and sets the final structure (Ramos-Diaz et al., 2022). Precise control of these components is critical for achieving consistent texture and product quality.



Source Sun et al. (2021)

Figure 2.2 Scheme of a twin-screw extruder for high-moisture extrusion of proteinaceous materials into fibrous meat analogue



Source Verheyen et al. (2022)

Figure 2.3 Scheme of a twin-screw extruder for low-moisture extrusion of proteinaceous materials into spongy or fibrous network

The role of textured vegetable proteins in developing meat analogues: influence of structural properties and extrusion conditions

Texturized vegetable proteins (TVPs) are central to plant-based meat analogues due to their fibrous structure, which mimics animal muscle tissue (van Esbroeck et al., 2024).

Typically containing ~60% protein, TVPs are rehydrated and blended with fats and binders to reproduce meat-like sensory and structural attributes. Structural characteristics such as porosity, pore size, and wall thickness strongly influence rehydration behavior and final texture; for example, thicker cell walls increase batter stiffness, whereas smaller pores enhance patty firmness (van Esbroeck et al., 2024). These features are largely determined during low-moisture extrusion (LME), where protein concentrates or isolates undergo shear-induced alignment and crosslinking.

Rehydration capacity (RHC) is a key functional parameter, closely associated with hardness, shear force, juiciness, and cooking loss. Extrusion conditions including moisture content, barrel temperature, and screw speed significantly influence these properties. Higher moisture promotes stronger protein networks and improved texture, while excessive die temperatures may weaken crosslinking and reduce cohesiveness (Brishti et al., 2021; Samard et al., 2021). Raw material selection further modulates structure; wheat gluten enhances soy protein texturization, and blends of soy isolates or concentrates with gluten are widely used for patties and muscle-like products (Kyriakopoulou et al., 2019). Alternative proteins from oilseeds, cereals, and legumes including sunflower, rapeseed, and peanut are increasingly explored for their functionality and availability (Mazumder et al., 2023). High-moisture extrusion (HME) has further advanced fibrous structuring, expanding applications in whole-cut analogues.

Comparative analyses of commercial TVPs reveal substantial variability in composition and functional performance, emphasizing the need for precise process control. Extrusion has also been applied to valorize by-products such as soy and flaxseed press cakes, improving water and oil holding capacity and mechanical strength while minimizing off-flavors (Bali et al., 2024; Lallinger & Rauh, 2024),

Protein quality remains critical in formulation. Soy protein as seen in Table 2.1, with a PDCAAS of ~0.9–1.0, exhibits enhanced water and oil holding capacity and fiber formation when extruded at ~120°C and 60% moisture. Wheat protein (PDCAAS ~0.45) requires higher temperatures (~170°C) to achieve optimal elasticity, particularly when blended with legumes. Pea and mung bean proteins demonstrate improved oil holding and gelation upon extrusion, while Sacha Inchi protein (120–140°C) shows enhanced digestibility and emulsion stability (Brishti et al., 2021; Imran & Liyan, 2023; Rawdkuen et al., 2022). Texturized vegetable proteins (TVPs) are central to plant-based meat

analogues due to their fibrous structure, which mimics animal muscle tissue (van Esbroeck et al., 2024). Typically containing ~60% protein, TVPs are rehydrated and blended with fats and binders to reproduce meat-like sensory and structural attributes. Structural characteristics such as porosity, pore size, and wall thickness strongly influence rehydration behavior and final texture; for example, thicker cell walls increase batter stiffness, whereas smaller pores enhance patty firmness (van Esbroeck et al., 2024). These features are largely determined during low-moisture extrusion (LME), where protein concentrates or isolates undergo shear-induced alignment and crosslinking.



Table 2.1 Structural, nutritional, and functional properties of plant proteins

Plant Protein	Structural Properties	PDCAAS Levels	Condition of Extrusion	Effect of Extrusion on Product	Functional Properties	References
Soy Protein	Contains globulins (glycinin, β -conglycinin); globular structure	High (~0.9–1.0)	120°C with 60% moisture	Improved water and oil holding capacity	Fiber formation, gelation and aggregation by extrusion	Bali et al. (2024), Imran and Liyan (2023)
Wheat protein	(gliadins) and glutelins gliadins	Low (~0.45)	170°C with 57% moisture	High texturization, hardness, chewiness and fibrous texture	Used together with legume proteins to provide fibrous texture (Singh et al., 2024) e; elasticity and extensibility	Imran and Liyan (2023)
Pea protein	Four major components: Globulin, albumin, glutelin and prolamin Globulin which contains legumin (11S protein	Relatively high 0.8–0.9	115°C with 30% moisture	enhanced oil holding capacity and reduced water holding capacity	Similar functions like soy-bean proteins	Imran and Liyan (2023), Singh et al. (2024)

Table 2.1 (continued)

Plant Protein	Structural Properties	PDCAAS Levels	Condition of Extrusion	Effect of Extrusion on Product	Functional Properties	References
Mung Bean Protein	Globulin, Albumins, Gliadin Glutelin	0.5–0.7	144.57°C with 49.33% moisture	Under these conditions, all expansion ratio, bulk density, rehydration ratio, water absorption capacity and degree of texturization) were desirably altered. protein fibril formation during texturization.	Good gelation, water-holding	Brishti et al. (2021), Imran and Liyan (2023)
Sacha Inchi Protein	Albumins (43.7%), globulins (27.3%), prolamins (3.0%), glutelins (31.9%)	Relatively high	120-140°C	Enhances digestibility, reduces anti-nutritional factors	Low water holding, moderate oil holding capacity, high emulsion stability and relatively high emulsion capabilities, high forming properties	Jagersberger (2013), Rawdkuen et al. (2016, 2018), Torres-Sanchez et al. (2023)

2.7 Acceptance and Perception of PBMA

2.7.1 Consumption and Perception of Meat Alternatives

A crucial determinant in the acceptability of plant-based meat alternatives (PBMA) is their similarity to conventional meat regarding sensory perception and nutritional composition (Cheon et al., 2024). In an online questionnaire study, Ketelings et al. (2023) investigated if consumers regarded meat alternatives as healthier, the extent to which consumers accurately assessed the nutritional content of meat (alternatives), and whether a nutrition claim could mislead consumers. A study of 120 Dutch consumers revealed that meat replacements were predominantly seen as healthier than meat products. Consumers tend to overrate the protein content of meat alternatives compared to meat products, particularly when the alternatives are labeled as 'rich' in protein.

The search query conducted by Sendhil et al. (2024) yielded 1,964 papers indicating a rising trend in research into consumers' preferences for PBMA. Consumer endorsement primarily stemmed from individual choices regarding health advantages, a transition to vegetarianism, ethical considerations, and sustainability. The choice correlated with the articulation of the potential advantages of the PBMA, price reductions, and media-influenced consumption.

Consumers exhibit variability in food essentialism, which refers to the assumption that food categories include inherent and unchangeable 'essences' that account for their common characteristics. Cheon et al. (2024) investigated the correlation between food essentialism and the belief that plant-based meat alternatives possess analogous characteristics to the animal-derived goods they imitate. Participants (N=298) evaluated two animal-derived food items (beef burger and canned tuna) alongside two matching plant-based meat alternatives (plant-based burger and tuna) based on perceived processing, naturalness, nutritional value, flavor (similar to beef or fish), common health advantages, and overall preference. Participants with elevated food essentialism views assessed PBMA as less processed, more natural, more akin to beef (plant-based burger exclusively), offering superior health advantages compared to animal-based goods, and as more favorable (plant-based tuna exclusively). The

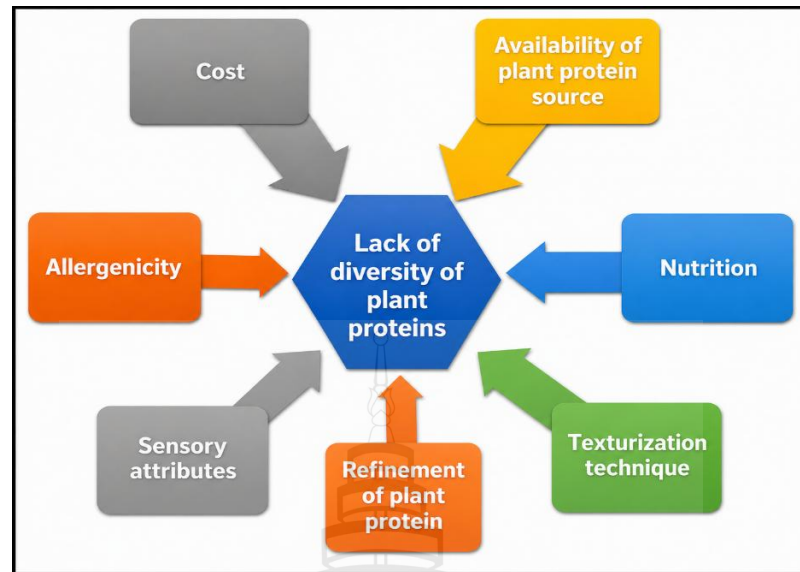
correlations between food essentialism and perceived food properties were more consistently observed for plant-based meat alternatives (PBMA) than for their animal-based counterparts. Furthermore, the belief that food items within a common category, such as beef, possess similar essences and properties may also apply to PBMA, despite their non-animal origins. The anticipated parallels between alternative protein products and the meat-based items they emulate have been recognized as a significant factor influencing the acceptance of alternative proteins (Giacalone et al., 2022). Taste is seen as a significant factor influencing consumers' propensity to embrace different proteins (Onwezen et al., 2021).

Despite the growing research output on PBMA food, consumer acceptance, and preferences, a significant number of papers originate from institutions in affluent countries, such as the United States Department of Agriculture and Wageningen University. The research initiative has yet to be augmented to generate and advocate for PBMA in developing nations (Sendhil et al., 2024).

2.7.2 Factors Influencing Consumption, Acceptability and Perception of Plant Based Meat Alternatives (Pbma)

1. Resource availability

Limited regional suitability of certain crops, particularly soy, has constrained plant protein diversity (Figure 2.4). As soy cultivation is less suitable in parts of the Northern Hemisphere, alternative proteins such as yellow peas and fava beans have been explored for plant-based meat alternatives (PBMA) (Ferawati et al., 2021). Sustainability considerations increasingly guide raw material selection. For example, life cycle assessment showed that pumpkin seed flour, despite being locally sourced, exhibited a higher environmental impact than soy due to less efficient processing (Saerens et al., 2021). Globally abundant crops such as wheat (~800 million metric tons) and potatoes (~400 million metric tons) remain underutilized for high-protein concentrates in PBMA. Chickpea, given its availability and functionality, is considered a promising alternative protein source (Boukid, 2021).



Source Miller et al. (2024)

Figure 2.4 Key reasons for the limited diversity of plant proteins in Australian plant-based meat analogues, with arrow size indicating relative importance

2. Sensory attributes

Flavor remains a primary determinant of consumer acceptance. Soy proteins may impart undesirable beany notes originating from lipid oxidation during processing, though optimized drying and storage can mitigate these effects (Li & Li, 2020). Additives such as yeast extracts and spices, as well as soy leghemoglobin, have been used commercially to enhance meat-like flavor. Pea protein may exhibit earthy notes, although dry texturization reduces off flavors (Ebert et al., 2022). Fava bean proteins can present bitterness due to phenolic compounds, and high-moisture extrusion may further modify flavor profiles (Tuccillo et al., 2022). Chickpea protein is generally considered neutral in flavor and color, though sensory outcomes vary (Boukid, 2021). Continued advances in flavor chemistry are expected to support further diversification of PBMA formulations.

3. Allergenicity

Soy and wheat remain dominant in commercial PBMA formulations despite known allergenic risks, particularly gluten-related intolerance (Osen et al., 2014). Pea and fava bean proteins are increasingly investigated as alternatives due to lower perceived allergenicity, although cross-reactivity among legumes warrants consideration (Marsh et al., 2021). Chickpea is regarded as relatively hypoallergenic but remains underutilized

(Boukid, 2021). While allergenicity currently plays a secondary role in ingredient selection, it may become a stronger market differentiator as consumer awareness increases.

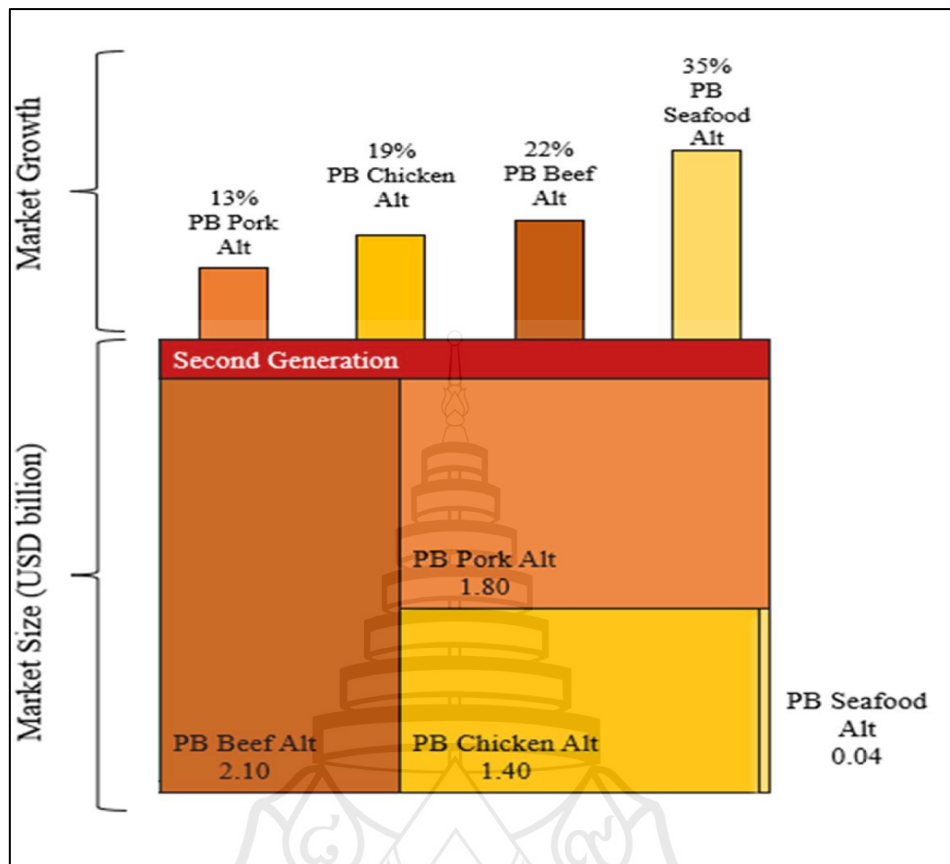
4. Nutritional quality

Protein quantity and quality are critical in PBMA. Although the Protein Digestibility-Corrected Amino Acid Score (PDCAAS) has historically been used, the Digestible Indispensable Amino Acid Score (DIAAS) provides a more accurate assessment of indispensable amino acid digestibility (Mathai et al., 2017). Soy, pea, and wheat exhibit DIAAS (values of 91, 70, and 48, respectively, while blends such as soy–wheat (90:10) and pea–wheat (60:40) achieve values of 90 and 85 (Herreman et al., 2020). Other proteins, including potato (100), canola (72), lupin (68), and rapeseed (67), also demonstrate competitive scores. Strategic protein blending therefore enables improvement of amino acid balance and overall PBMA nutritional quality.

2.7.3 Market Trends and Growth

Plant-based meat alternatives continue to attract significant investment and consumer interest. The global PBMA market is projected to grow as seen in Figure 2.5 at a compound annual growth rate (CAGR) of approximately 13–19%, substantially exceeding that of conventional meat (Boukid, 2021; van Vliet et al., 2021). North America currently holds the largest market share, followed by Europe and South America. Despite rapid growth, PBMA sales (~\$5–6 billion in 2021) remain small relative to the global beef market (> \$800 billion).

Product segmentation shows strong growth in plant-based beef, pork, and chicken analogues. Plant-based beef is projected to reach over \$16 billion by 2032, with burgers representing the dominant category. Pork and chicken alternatives are also expanding, particularly in Europe and North America (Future Market, 2022). However, market expansion depends on continued improvements in sensory performance, cost competitiveness, and nutritional quality (Kołodziejczak et al., 2021; Maningat et al., 2021). Given current projections, PBMA are expected to complement rather than replace conventional meat markets (Caputo et al., 2024).



Notes The market growth and size data are calculated from various reports from 2019 to 2022. (Time periods vary for all of the data portrayed in the figure)

Source Caputo et al. (2024)

Figure 2.5 The global market size and growth of first- and second-generation meat alternatives

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Experimental Design

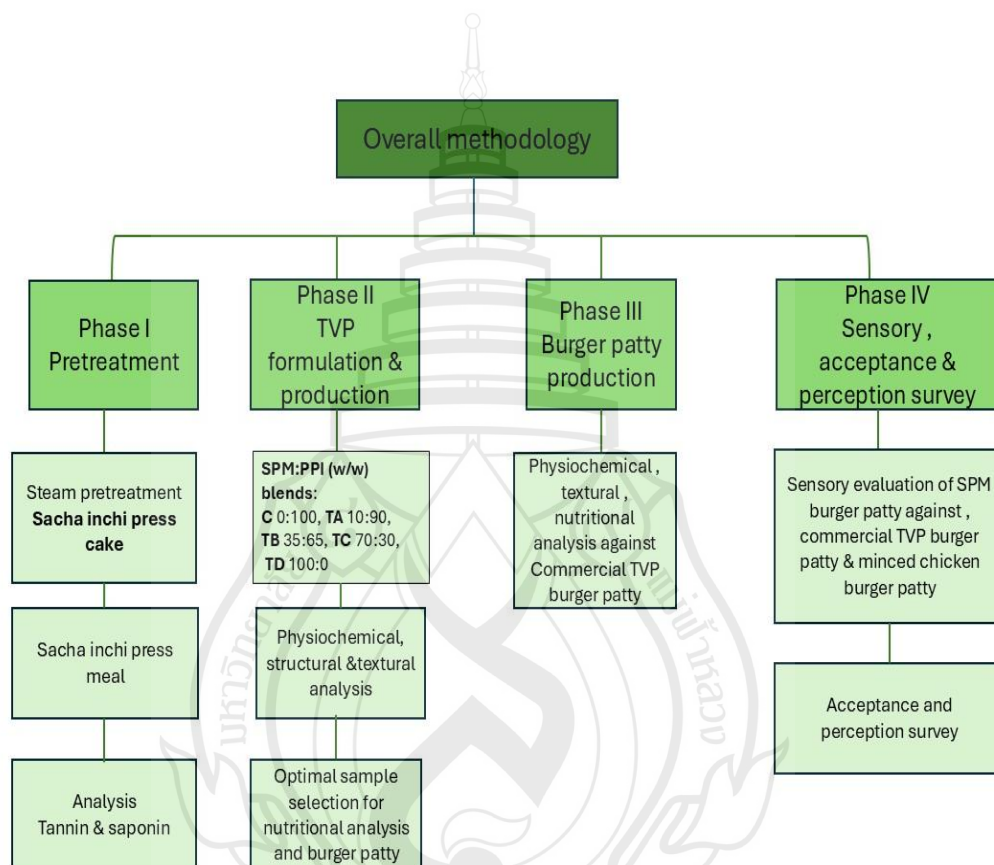


Figure 3.1 Overall methodology

A multi-phase experimental design was employed integrating formulation optimization, comparative product evaluation, and consumer research as seen in Figure 3.1. In Phase I, sacha inchi press cake (SP) was steam-pretreated to obtain sacha inchi press meal (SPM), which served as the experimental ingredient. Phase II, a completely randomized design (CRD) was used to evaluate SPM substitution level in textured vegetable protein (TVP) formulations under fixed extrusion conditions, with substitution

ratio as the independent variable and physicochemical and structural attributes as response variables. Each treatment was produced in triplicate independent runs.

In Phase III, the selected SPM-based TVP (TA, 10% SPM) was incorporated into burger patties formulated identically to the commercial TVP (COM), differing only in protein matrix composition. A single-factor comparative design was applied, with product type (TA vs. COM; and chicken as reference for sensory evaluation) treated as the fixed effect. Dependent variables included instrumental color and cooking properties ($n = 3$), texture profile parameters ($n = 3$), proximate composition and amino acid profile (laboratory reference analysis), fatty acid composition (GC-FID), and sensory attributes ($n = 30$)

Phase IV employed a within-subject consumer evaluation design to assess sensory acceptance, product perception, comparative acceptability, and the influence of food neophilia. For hedonic evaluation ($n = 30$), TA, COM, and chicken burgers were presented in randomized order and rated using a 9-point hedonic scale; differences among samples were analyzed using the Friedman test for related samples, followed by Wilcoxon signed-rank tests with Bonferroni adjustment ($\alpha = 0.05$). In the broader consumer study ($N = 60$), perception of SP-based and meat burgers was assessed using semantic differential scales (e.g., healthy–unhealthy, natural–artificial), while acceptability in eating and offering contexts was measured using a 5-point Likert scale. The association between food neophilia and acceptability of the SP-based burger was examined.

3.2 Materials

Sacha inchi press cake (*Plukenetia volubilis* L.) was supplied by Tai C.M.S Standard Industrial Co., Ltd., Khun Tan, Chiang Rai and was received on 7th June 2025. Upon receipt, the sample was sorted to remove impurities, dried to a moisture content below 10%, vacuum-packaged, and stored at -20°C until further use. Pea protein isolate (PI) and wheat gluten (WG) were purchased from Krungthep Chemipan Co., Ltd., Bangkok, Thailand. Additives such as iodized salt (PRUNG THIP®, Thai Refined Salt Co., Ltd., Samut Sakhon, Thailand) and corn flour (KNORR®, Unilever Thai Trading Limited, Bangkok, Thailand), were purchased from a local supermarket and used without

further modification. Commercial TVP (COM) (long granule shape, size 5 mm length and 2 mm width) was purchased from Food Tech Products, Co., Ltd., Prathumthani, Thailand. Palm kernel oil was obtained from The Natural Palm Oil Co., Ltd. (Bangkok, Thailand). Kappa carrageenan was supplied by Lana Grow Co., Ltd. (Nonthaburi, Thailand). Sodium alginate and sodium phosphate were purchased from Krungthep Chemipan Co., Ltd. (Bangkok, Thailand). Monosodium glutamate (MSG) was obtained from Ajinomoto (Thailand) Co., Ltd. (Bangkok, Thailand). Black pepper was supplied by Raithanya Company Limited (Bang Yai, Thailand). Transglutaminase was obtained from PTK Solutions and Supplies Co., Ltd. (Bangkok, Thailand). Vegetable seasoning was purchased from F-Plus Company Limited (Nakhon Pathom, Thailand).

3.3 Pretreatment and Production of Textured Vegetable Protein (TVP)

3.3.1 Pretreatment of Sacha Inchi Press Cake

SP was subjected to a proprietary steam-based pretreatment under controlled temperature and time conditions designed to achieve thermal stabilization and structural modification to produce Sacha inchi press meal (SPM). Specific steps and ratios are not disclosed due to intellectual property protection. However, the following operating ranges can be provided to support reproducibility. The press cake was exposed to low-pressure saturated steam (approximately 100–110°C) for a moderate treatment duration (40–60 min). The material was treated at a solid-to-moisture context equivalent to 1:1–1:2 (w/v) slurry or its steam-contact equivalent, ensuring thorough wet heat penetration. After steaming, the material was drained, dried in a hot-air oven at 50–60°C to a moisture content below 10%, and milled and sieved (mesh size 60) to obtain a homogeneous meal (SPM) (Nguyen et al., 2022). The SPM was then vacuum packed and stored at 25°C until further utilization.

3.3.2 Extrusion Processing

In accordance with Table 3.1, a mixture of materials was produced and weighed into the bowl. A mixer bowl (Model 5KPM5EWH, KITCHENAID®, St. Joseph, MI, USA) was filled with water and half of the dry ingredients. The remaining half of the dried ingredients were added gradually while the mixture was whisked together. After

homogenizing the mixture for 15 minutes, it was refrigerated at 4°C for the 12 hours (Lee et al., 2024) (model MR-FS45ES, Mitsubishi Electric Corp., Tokyo, Japan). Following the allotted time, the mixture was loaded into a traditional single-screw extruder (model SE-D28L280X Charreon TUT Co., Ltd., Bangkok, Thailand) with the following parameters: feed moisture content of 30%, die temperature of 150°C, feed rate of 100 g/min, screw speed of 280 rpm, feeding zone temperature of 100°C, and compression zone temperature of 150°C. Following extrusion, the SP-TVP were gathered and dried at 50°C for 12 hours at 10% moisture content in a tabletop electric oven (OTTO, CO-707, Supor Co., Ltd., Hangzhou, China) until they reached a consistent weight. They were then placed in plastic ziplock bags (Ziploc®, San Diego, CA, USA) and kept at 25°C until further examination. To guarantee the correctness of the trial replication, this step was carried out in triplicate.

Table 3.1 lists the blend compositions used to make the textured vegetable protein (TVP) samples. The primary ingredients, Sacha inchi press meal (SPM) and pea protein isolate (PI), were mixed in roughly 10:90, 35:65, 70:30, and 100:0 (w/w) ratios; however, their combined weight remained constant at 43.8% (w/w) of the total weight of all ingredients. In the meantime, minor substances such as corn starch (CS), wheat gluten (WG), and salt were added to each sample at a rate of 17.52%, 4.38%, and 1% (w/w) of the total weight of the PI and SPM, respectively. The ratio of SP based on the total weight of the primary constituents, SPM and PI, was used to identify the samples' names. In particular, TVP samples containing SPM and PI at roughly 0:100, 10:90, 35:65, 70:30, and 100:0 (w/w) were designated as C, TA, TB, TC, and TD, respectively. To separate the impact of different SPM-to-pea protein ratios on TVP characteristics, CS, WG, and salt levels were kept constant across all formulations. By keeping levels constant, it is possible to credit observed changes in texture, color, and functional qualities to the replacement of pea protein with SPM rather than to variations in the amount of starch, gluten, or salt.

Table 3.1 Blend compositions (wt, %) used for the preparation of Sacha inchi press meal–incorporated texturized vegetable protein (TVP) samples

Sample	SPM:PI	Base mixture (wt, %)	Other ingredients (wt, %)			
			Wheat gluten	Corn starch	Salt	Water
C	0:100	43.80	17.52	4.38	1.00	33.30
TA	10:90					
TB	35:65					
TC	70:30					
TD	100:0					

Note The base mixture was prepared from Sacha inchi press cake meal (SPM) and pea protein isolate (PI) as the main protein block attributing to 43.8% of the total weight. The additional ingredients (wheat gluten, corn starch, salt, and water) were added at constant levels across all formulations to add up to a total of 100% to facilitate extrusion and texture formation.

3.4 TVP Physicochemical Analyses

The textured vegetable proteins (TVPs) were milled into powder using a blender (PHILIPS ProBlend, model HR2041/30/AC, Taizhou, China) and subsequently passed through a 60-mesh sieve to obtain a homogeneous fine powder. The resulting powder was used for physicochemical, functional, and nutritional analyses.

Color Analysis

Color characteristics of the powdered dry TVP samples were determined using a portable spectrophotometric colorimeter (CM-600d, Konica Minolta Inc., Tokyo, Japan) configured with a D65 illuminant and a 10° standard observer angle. Prior to sample measurement, the instrument was standardized against a certified white calibration tile according to the CIE 1976 L*, a*, and b* color system (ISO/CIE, 2019). For each sample, color measurements were collected from ten randomly selected positions on the sample surface to account for possible variation in particle distribution. The obtained color coordinates were expressed as CIE L*, a*, and b* values, where L* represents the degree of brightness on a scale ranging from 0 (black) to 100 (white). The a* coordinate describes the red–green chromatic axis, with positive and negative

values corresponding to redness and greenness, respectively, whereas the b^* coordinate reflects the yellow–blue axis, in which positive values indicate yellowness and negative values indicate blueness.

3.5 TVP Functional Properties

3.5.1 Water-holding Capacity (WHC) and Oil Holding Capacity (OHC)

The water- and oil-holding capacities (WHC and OHC) were evaluated following the procedure described by Ketnawa and Rawdkuen (2023). For WHC, a 15 mL centrifuge tube that had been previously weighed was filled with 5 mL of deionized (DI) water and 0.5 g (W_0) of powdered dried TVP analog sample (W_1). After giving the combination a thorough vortex, it was let to rest at room temperature for five minutes. After centrifugation at 8000x g for 10 minutes, the supernatant was discarded, and the tube holding the residue was turned upside down and let to rest for five minutes before being weighed again (W_2).

For OHC, a 15 mL centrifuge tube that had been previously weighed was filled with 0.5 g (O_0) of each sample and 5 mL canola oil (O_1). After 30 minutes at ambient temperature, the mixture was centrifuged for 10 minutes at 8000 x g. The tube holding the protein sediment was reweighed (O_2) after the oil was removed and the excess oil was drained by inverting it for ten minutes. Every sample was run three times. Equations (1) and (2) were used to compute the WHC and OHC, which were then expressed as grams of water and oil absorbed per gram of material, respectively.

$$\text{Water Holding Capacity (WHC)} \quad (1)$$

$$WHC (g/g) = \frac{W_2 - W_1 - W_0}{W_0}$$

$$\text{Oil Holding Capacity (OHC)} \quad (2)$$

$$OHC (g/g) = \frac{O_2 - O_1 - O_0}{O_0}$$

3.5.2 Rehydration Capacity and Rehydration Yield

Rehydration capacity and rehydration yield were determined with minor modifications to the method previously described by Ketnawa and Rawdkuen (2023) to conduct the analysis of rehydration capacity and yield. Analyses were conducted using intact textured vegetable protein (TVP) pieces, without systematic grinding or particle size reduction; minor trimming of individual pieces was performed only when necessary to achieve the target sample mass. Ten grams of TVPs were rehydrated in 150 milliliters of distilled water (1:15 solid-to-liquid ratio, w/v) for one hour at room temperature (RT), and then they were drained on a mesh screen for another hour. The rehydration capacity (RHC) and rehydration yield (RHY), which may be computed using Equations (3) and (4), were determined by recording the final weight.

$$\text{Rehydration Capacity (RHC)} \quad (3)$$

$$RHC (g/g) = \frac{\text{Weight after rehydration (g)} - \text{Weight before rehydration (g)}}{\text{Weight before rehydration (g)}}$$

$$\text{Rehydration Yield (RHY)} \quad (4)$$

$$RHY(\%) = \left(\frac{\text{Weight after rehydration (g)} - \text{Weight before rehydration (g)}}{\text{Weight before rehydration (g)}} \right) \times 100$$

3.6 Visual Surface Appearance and Microstructure by Scanning Electron Microscopy (SEM)

Visual surface appearance: TVPs were captured using a portable picture studio box with high-brightness LED modules and a mobile phone (iPhone 16, Apple®, Cupertino, CA, USA) (Ketnawa & Rawdkuen, 2023). Microstructure: Fibrous structures and air cell formations in TVPs were seen using scanning electron microscopy (SEM) analysis. A scanning electron microscope (TESCAN, MIRA, TESCAN ORSAY HOLDING, Brno, Czech Republic) was used to examine the microstructure of TVP. After preparing the sample pieces and mounting them on aluminum stubs using double-sided carbon tape, gold particles were applied. With a maximum resolution of 200 μm and an accelerating voltage of 10 keV, the photos were

taken at magnification levels of 500 $\times$, 2000 $\times$, and 5000 $\times$, respectively (Ketnawa & Rawdkuen, 2023).

3.7 Textural Properties Measurement

The mechanical properties of rehydrated texturized vegetable protein (TVP) samples were characterized by texture profile analysis (TPA). Before measurement, each sample was hydrated in distilled water at a sample-to-water ratio of 1:1 (w/v) for 60 min to achieve uniform moisture distribution. Evaluation was done using a texture analyzer (XT Plus, Stable Micro Systems, Surrey, UK) equipped with a cylindrical compression probe (SMSP/36R, 36 mm diameter). Samples were subjected to two consecutive compression cycles under strain-controlled conditions. Instrument settings were established at a pre-test speed of 1 mm/s, compression speed of 5 mm/s, and return speed of 5 mm/s, with a deformation of 50%. A trigger force of 10 g was applied to initiate sample contact, and a 5 s recovery period was allowed between the first and second compression cycles. Force–time data generated during compression were processed using EXPONENT CONNECT® software (Stable Micro Systems, Surrey, UK) to determine hardness (g), adhesiveness, cohesiveness, springiness (%), gumminess, chewiness (g·s), and resilience (%). Each formulation was analyzed using twelve independent replicates, and the obtained values were expressed as mean values.

3.8 Nutritional Composition of SP-TVP

The SP-TVP (Sacha inchi press meal texturized vegetable protein) formulation with the most favorable physicochemical and functional characteristics was selected for proximate, fiber, amino acid and fatty acid analysis. The TVP was ground into powder using a blender (PHILIPS, ProBlend, HR2041/30/AC, Taizhou, China) and sifted through a 60-mesh sieve to obtain a homogeneous fine powder.

3.8.1 Proximate Analysis

Moisture, protein, fat, and ash were measured using The Association of Official Analytical Chemists (AOAC) (Official Methods of Analysis of AOAC International, 2023). The TVP's moisture content was ascertained by oven-drying it at 105°C. About 3 g of sample powder was burned overnight at 575°C in a furnace (Fisher Scientific, Waltham, MA, USA) to estimate the ash content. Using the Kjeldahl method and a conversion factor of 6.25, the protein content of sample powders was calculated for total nitrogen content. Petroleum ether was used as an extraction solvent in a Soxhlet system to determine the fat content.

Each proximate composition was examined three times and expressed as a percentage of dry weight (wt%, d.b.). Equation (5) illustrates how the total protein, fat, and ash levels were subtracted from 100% to determine the total carbohydrate value.

$$\text{Total carbohydrate (wt\%, d.b.)} = 100 - (\text{protein} + \text{ash} + \text{fat}) \text{ (wt\%, d.b.)} \quad (5)$$

3.8.2 Amino Acids, Fatty Acids Compositions and Dietary Fiber

For additional compositional analyses, the Sacha inchi press meal-based textured vegetable protein (SP-TVP) formulation with the best physicochemical and functional characteristics was chosen. Central Laboratory Co., Ltd. (Chiang Mai, Thailand) used approved internal procedures to determine the dietary fiber level, fatty acid profile, and amino acid composition. In accordance with the Official Journal of the European Commission Directive 98/64/EC, L257 (L257/16), amino acids were examined using technique TE-CH-372. While dietary fiber content was assessed using AOAC (2019) technique 985.29 (Horwitz, 2019), fatty acid composition was ascertained using technique TE-CH-208, which is based on AOAC (2019) Method 996.06 (Horwitz, 2019). The results were presented as either a percentage on a wet weight basis (% w.b.) or as mg/100 g sample.

3.9 Production of SP-TVP Burger Patties

As indicated in Table 3.2 below, the TVP burger patties were made using the method described by Samard et al. (2021). For one hour, the dried SP-TVP and COM

TVP samples were hydrated with water at a 1:12 ratio. The hydrated TVP samples were pulverized using a meat grinder (TC12/INOX F.A.C.EM.spA via fabbriche., Torino, Italy) fitted with a 0.5-cm die plate after being drained over a typical 8-mesh sieve for ten minutes. The proportions of the ground TVP sample and other materials were weighed as shown in Table 3.2 First, the ground TVP was combined with palm kernel oil for two minutes. Next, it was manually mixed with other powdered additives for ten more minutes. Finally, the enzyme transglutaminase was introduced and kneaded for three minutes. Each 100 g of paste was made into a ball and then hand-pressed into a patty. After being placed in a plastic bag, each TVP burger was incubated for one hour at room temperature. To finish the enzyme activity, patties were then kept at 4°C for a whole day (Samard et al., 2021). The sample was promptly thawed till the internal temperature reached 25°C (raw patty) after 24 hours of patty formation. Samples will be fried using pan with glass cover at 160°C for 7 min (3.5 min per side). The internal endpoint temperature of cooked patties ranged between 75 and 80°C (Samard et al., 2021). The cooked patties were then equilibrated to room temperature for 1 h.

Table 3.2 TVP based burger patty processing

Ingredients	Weight (g/100g)
TVP	81.5
Palm kernel oil	12.5
Kappa carrageenan	1.0
Sodium alginate	1.0
Sodium phosphate	0.5
Salt	0.1
Mono sodium glutamate	0.5
Black pepper	0.4
Transglutaminase	1.0
Vegetable seasoning	1.5

Note Formulation expressed as g/100 g (w/w). All components sum to 100 g.

Source Samard et al. (2021)

3.10 SP-TVP Burger Patty Analysis

3.10.1 Proximate Composition of SP-TVP Burger Patty

Moisture, protein, fat, fiber, and ash were measured using the Association of Official Analytical Chemists (AOAC) (Official Methods of Analysis of AOAC International, 2023). The method of oven-drying the burger at 105°C was used to measure its moisture content. The Enzymatic-Gravimetric approach was used to measure crude fiber. Petroleum ether was used as an extracting solvent in a Soxhlet apparatus to determine the fat content. About 3 g of sample powder was burned at 575°C for an entire night in a furnace (Fisher Scientific, Waltham, MA, USA) to estimate the ash content. Using a conversion ratio of 6.25, the Kjeldahl technique was used to calculate the protein content of sample powders for total nitrogen content. Petroleum ether was used as an extraction solvent in a Soxhlet system to determine the fat content. Each proximate composition was examined three times and expressed as a percentage of dry weight (wt%, d.b.). Equation 6 illustrates how the total protein, fat, and ash levels were subtracted from 100% to determine the total carbohydrate value.

$$\text{Total carbohydrate (wt\%, d.b.)} = 100 - (\text{protein} + \text{ash} + \text{fat}) \text{ (wt\%, d.b.)} \quad (6)$$

3.10.2 Fatty Acid Profile and Amino Acid Composition

A compositional analysis was performed on the Sacha inchi press meal-based textured vegetable protein (SP-TVP) burger. Central Laboratory Co., Ltd. (Chiang Mai, Thailand) used approved internal procedures to determine the fatty acid profile, and amino acid composition. In accordance with the Official Journal of the European Commission Directive 98/64/EC, L257 (L257/16), amino acids were examined using technique TE-CH-372. While fatty acid composition was ascertained using technique TE-CH-208, which is based on AOAC (2019) Method 996.06 (Horwitz, 2019). The results were presented as either a percentage on a wet weight basis (% w.b.) or as mg/100 g sample.

3.10.3 Physical Properties of the SP-TVP Burgers

Cooking loss was calculated as the percentage weight difference between raw and cooked patties using the following equation:

$$\text{Cooking loss (\%)} = \frac{\text{Raw patty weight (g)} - \text{Cooked patty weight (g)}}{\text{Raw patty weight (g)}} \times 100$$

Moisture content of raw and cooked patties was determined by drying 2 g samples at 103°C for 16 h. Moisture retention was calculated as:

$$\text{Moisture retention (\%)} = \frac{\text{Cooked patty weight (g)} \times \text{Moisture in cooked patty (\%)}}{\text{Raw patty weight (g)} \times \text{Moisture in raw patty (\%)}} \times 100$$

Fat retention was calculated as:

$$\text{Fat retention (\%)} = \frac{\text{Cooked patty weight (g)} \times \text{Fat in cooked patty (\%)}}{\text{Raw patty weight (g)} \times \text{Fat in raw patty (\%)}} \times 100$$

All cooking-related measurements were conducted in triplicate for each TVP treatment, except for cooking loss, which was determined using eight independent patties to enhance statistical reliability (Hong et al., 2022). Whole burger patties standardized to 100 g were used for all analyses. Cooking was performed at 160°C for 7 min (3.5 min per side) under controlled conditions (Samard et al., 2021).

3.10.4 Texture Measurements

Texture profile analysis (TPA) was carried out using a TA.XTplus Texture Analyzer (Stable Micro Systems, Surrey, UK) equipped with a P/75 cylindrical probe (75 mm diameter). Burger patties were cooked at 160°C for 7 min until an internal temperature of approximately 75°C was reached. Samples were analyzed immediately after cooking while warm. Each patty was divided into four equal portions prior to testing. A two-cycle compression test was performed at 50% strain with a trigger force of 5 g. The pre-test speed was 1.0 mm/s, the test speed 1.0 mm/s, and the post-test speed 5.0 mm/s. Hardness (peak force of the first compression), resilience (ratio of the withdrawal area to the compression area of the first cycle), cohesiveness (area of the second compression divided by that of the first compression), springiness (ratio of time to peak force in the second cycle to that in the first cycle), and chewiness (hardness × cohesiveness × springiness) were calculated using EXPONENT CONNECT® software (Stable Micro Systems, Surrey, UK). Four replicates were performed for each

formulation, and results were expressed as mean values (Hong et al., 2022).

3.11 Consumer Acceptability and Perception Of SP-TVP Burger Patty

3.11.1 Sensory Acceptability

Using a 9-point hedonic scale, sensory attributes such appearance, taste, texture, scent, and general acceptability were assessed to make sure customer preferences are taken into account when developing new products (Wichchukit & O'Mahony, 2014). Thirty untrained adult panelists $n=30$; (15 females and 15 men, ages 18 to 65) participated in a single session of sensory evaluation at Mae Fah Luang University's Food Sensory Laboratory. To minimize the impact of sample order presentation, each panelist assessed the three burger patty variations (SP-TVP, commercial TVP, and chicken) in a sequential monadic fashion. Prior to evaluation, samples were placed in a temperature-controlled chamber set at 37°C for 10 min to equilibrate to a uniform internal temperature before sensory analysis. A 50 ml disposable cup was filled with about 20 g of each sample, each of which was coded with a distinct three-digit number. In between samples, panelists were instructed to rinse their palates with some drinking water. A controlled environment with white light (300 lx) and a relative humidity of $54\pm1\%$ was used to conduct a sensory session in isolated rooms (individual cabins) at $22\pm1^\circ\text{C}$. Additionally, all panelists were informed ahead of time that the samples are innovative goods intended to replace traditional animal products in order to lessen the impact of shocks. Before the session, the University was asked for ethical approval to use human volunteers for the sensory examination. (Mazumder et al., 2024).

3.11.2 Consumer Perception

Understanding consumer attitudes toward health benefits and sustainability is vital for the market success of SP-based burger patties. The research incorporates surveys to assess perceptions and purchase intentions, considering factors such as price, and nutritional information (Michel et al., 2021).

3.11.3 Survey Participants

60 employees and students from Mae Fah Luang University participated in the poll, with age and sex quotas set (50% female and equal distribution across ages 18–65). Participants who complete the survey for less than half of the median will also be disqualified (Hartmann & Siegrist, 2017).

3.11.4 Survey Procedure

The questionnaire was distributed through Google Forms and required approximately 12 minutes for completion, consistent with the methodology described by Michel et al. (2021). After providing demographic details such as age and gender, respondents were randomly assigned to one of two experimental groups. The first group evaluated perceptions related to SP-based plant-derived burger patties, with participants receiving a concise description of SP beforehand, whereas the second group focused on perceptions associated with conventional meat products. Subsequently, participants assessed either meat burgers or SP-based meat alternatives, depending on their assigned group, using an eleven-point semantic differential scale. Product perceptions were evaluated using contrasting descriptors such as “healthy versus unhealthy” and “modern versus traditional.” These questions were intended to determine participants’ attitudes toward conventional meat burgers and SP-based plant-derived patties. Dietary intake patterns were also examined. Participants reported how frequently they consumed various animal-derived products, including processed meats, pork, beef, poultry, and lamb, together with plant-based protein foods such as tofu, lentils, and meat substitute products. A six-category frequency scale was applied for this assessment. In line with the conversion system proposed by Hagmann et al. (2019), the responses were standardized into weekly intake values. “Several times daily” corresponded to 14 occasions per week, “once daily” to 7 occasions weekly, “4–6 times weekly” to 5 occasions weekly, “1–3 times weekly” to 2 occasions weekly, “1–3 times monthly” to 0.5 occasions weekly, and “rarely or never” to zero consumption. These converted values were then summed to generate an overall weekly consumption score for both meat-based and plant-derived protein foods, following Michel et al. (2021). Participants were additionally requested to indicate the dietary pattern that best represented their lifestyle, with available options including omnivore, flexitarian, pescatarian, vegetarian, and vegan. Brief explanatory notes for each dietary category

were provided directly below the question to improve participant understanding.

In the next phase of the survey, respondents were again randomly divided into two groups. One set of participants evaluated the social acceptability of consuming SP-based plant-derived burger patties, whereas the other assessed the appropriateness of offering these products to guests. Responses were recorded using a five-point scale ranging from 1 (“highly inappropriate”) to 5 (“highly appropriate”). The final section of the questionnaire focused on product perception attributes. Participants compared SP-based plant-derived burger patties with traditional meat burgers in relation to sensory and economic characteristics, specifically flavor, texture, and perceived price, according to the approach adopted by Michel et al. (2021).

3.12 Statistical Analysis

Statistical evaluation of the experimental data was carried out using IBM SPSS Statistics version 26.0 (IBM Corp., Armonk, NY, USA). Differences in physicochemical properties, cooking characteristics, texture parameters, and compositional measurements among samples were determined through one-way analysis of variance (ANOVA). Where significant differences were identified, Duncan’s multiple range test was employed as a post hoc procedure for mean separation. Sensory evaluation results obtained from dependent samples were analyzed using the Friedman non-parametric test. Pairwise comparisons between samples were subsequently performed using the Wilcoxon signed-rank test with Bonferroni correction applied. In addition, consumer acceptability data were compared using Wilcoxon signed-rank analysis, while relationships between food neophilia and product acceptability scores were examined using Pearson’s correlation coefficient. Statistical significance was established at $p \leq 0.05$. All experimental results are reported as mean values accompanied by standard deviation (mean $\pm$ SD). The corresponding number of replicates used for each analysis is provided within the relevant tables and figures.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Analysis of Anti- nutritional Properties in Pretreated Sacha Inchi Press Cake

Tannins and saponins are primary contributors to the astringent and bitter sensory attributes of sacha inchi press cake. Therefore, their reduction, as illustrated in Figure 4.1, is essential to enhance its suitability for incorporation into food products.

Saponins are heat-resistant, water-soluble secondary metabolites in high concentrations in Sacha Inchi (Landines Vera et al., 2024). While they possess bioactive properties beneficial to human health, their presence in food products is often minimized due to the astringency and a bitter flavor they impart to food (Salim et al., 2023). In this study, the saponin content of the raw Sacha inchi press-cake extract was quantified at 0.280 mg/g extract, aligning closely with the findings of Rawdkuen et al. (2016), who reported a value of 0.277 mg/g using a similar extraction methodology.

Upon subjecting the press-cake to a steaming treatment, a significant reduction in saponin content was observed, with the extract yielding 0.210 mg/g as observed in Figure 4.1. This represents a decrease of approximately 25%, underscoring the efficacy of thermal processing in mitigating saponin levels. The reduction can be attributed to the hydrolytic degradation of saponins under heat, as well as their potential leaching into the aqueous phase during steaming.

Supporting this observation, Landines Vera et al. (2024) investigated the effects of hydrothermal treatments on Sacha inchi cake and found that autoclaving at 121°C for thirty minutes significantly reduced antinutrient levels, including saponins, compared to untreated controls. Their study reported a significant reduction of 43% following hydrothermal treatment indicating that autoclaving would be a better pretreatment method compared to steaming in terms of saponin reduction. These

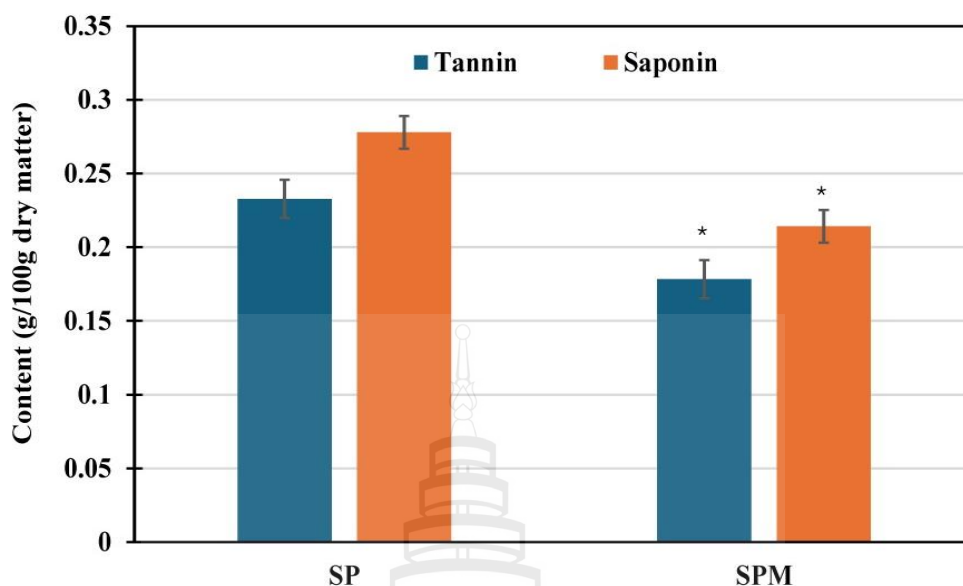
findings corroborate the notion that thermal processing is effective in reducing saponin concentrations in Sacha inchi products.

Tannins can impair nutrient utilization by binding to proteins and minerals, thereby reducing the digestibility of proteins and carbohydrates and ultimately depressing growth performance (Landines Vera et al., 2024). Tannins contribute directly to major organoleptic properties, in particular to taste attributes such as astringency and bitter taste (Soares et al., 2020), therefore the importance of its reduction in food production. In this study, the reduction in tannin content from 0.233 g/100 g in the untreated Sacha inchi press cake to 0.178 g/100 g, indicating a 23.6% decrease. High temperatures break down the tannin-protein complex, inducing the leaching of tannins in the cooking liquid, thus increasing the digestibility and palatability of the pressing cake (Landines Vera et al., 2024). This decline is consistent with previous studies showing that hydrothermal or moist-heat treatments can effectively reduce antinutritional polyphenols such as tannins in oilseed by-products.

According to Landines Vera et al. (2024), hydrothermal processing of SP significantly reduced total tannins by 52.78% from 0.216 g/100 g to 0.102 g/100g after autoclaving for 30 minutes. Similarly, Cadena et al. (2025) reported lower tannin levels (6.08–2.55 mg tannic acid eq./100 g) in Sacha inchi flours subjected to thermo-mechanical and chemical treatments, emphasizing that heat can disrupt polyphenolic structures or promote oxidation of reactive hydroxyl groups, thereby reducing measurable tannins.

The implications of these findings are twofold. First, the reduction in saponin and tannin content enhances the palatability of SP, making it more suitable for incorporation into food products. Second, it aligns with the objectives of food processing techniques aimed at improving the nutritional profile and consumer acceptance of plant-based ingredients.

The steaming treatment applied in this study effectively reduced the saponin and tannin content of SP, aligning with existing literature on the impact of hydro-thermal processing on antinutrient levels.



Note SP represents the raw Sacha inchi press cake, while SPM represents the treated sample. Values are presented as mean $\pm$ standard deviation ($n = 3$). Asterisks indicate significant differences between raw and treated samples for each compound ($p < 0.05$).

Figure 4.1 Tannin and saponin content of SP and SPM on a dry matter basis

4.2 Color and Visual Appearance

Color plays a critical role in determining SP suitability for food applications and consumer acceptance (Alejandro Ruiz et al., 2025). The color parameters (L^* , a^* , and b^*) varied significantly ($p < 0.05$) with increasing levels of Sacha inchi press meal (SPM) in the textured vegetable protein (TVP) as seen in Table 4.1. The L^* values decreased progressively from the control (C, 76.94) to TD (69.95), indicating a gradual darkening of the samples as SPM incorporation increased as seen in the visual pictures in Figure 4.2. This reduction in lightness can be attributed to the presence of residual pigments and higher concentrations of proteins, polyphenols, and dietary fiber, which are retained in the defatted flour after oil extraction. These compounds can reduce reflectance and contribute to an opaquer and less luminous appearance (Alejandro Ruiz et al., 2025).

Similar darkening trends have been reported when SP (Sacha inchi press cake) was incorporated into bakery systems, where increasing SP content significantly decreased L^*

and b^* values while increasing a^* values (Rungrot et al., 2021). Likewise, Alejandro Ruiz et al. (2025) observed that Sacha inchi oilcake flour exhibited markedly lower lightness ($L^* \approx 68.6$) and higher a^* and b^* values than wheat flour ($L^* \approx 91.8$), confirming the natural brownish hue of the by-product. In the present study, a^* values increased steadily from 3.34 (C) to 6.60 (TD), reflecting enhanced redness with higher SPM inclusion, while b^* values increased from 19.43 to 21.87, indicating greater yellowness. Comparable results were reported by Rawdkuen et al. (2022), who found darker and more reddish Thai Sacha inchi protein isolates compared to the Peru Sacha inchi protein isolate, highlighting the influence of pigment and phenolic content. These consistent findings suggest that the progressive addition of SPM to TVP enhances red-brown coloration due to both the inherent pigments of the press cake and intensified non-enzymatic browning reactions during extrusion. Overall, SPM incorporation produced darker, redder, and more yellow TVP samples, potentially improving the visual appeal by imparting a roasted appearance desirable in meat-like analogues.

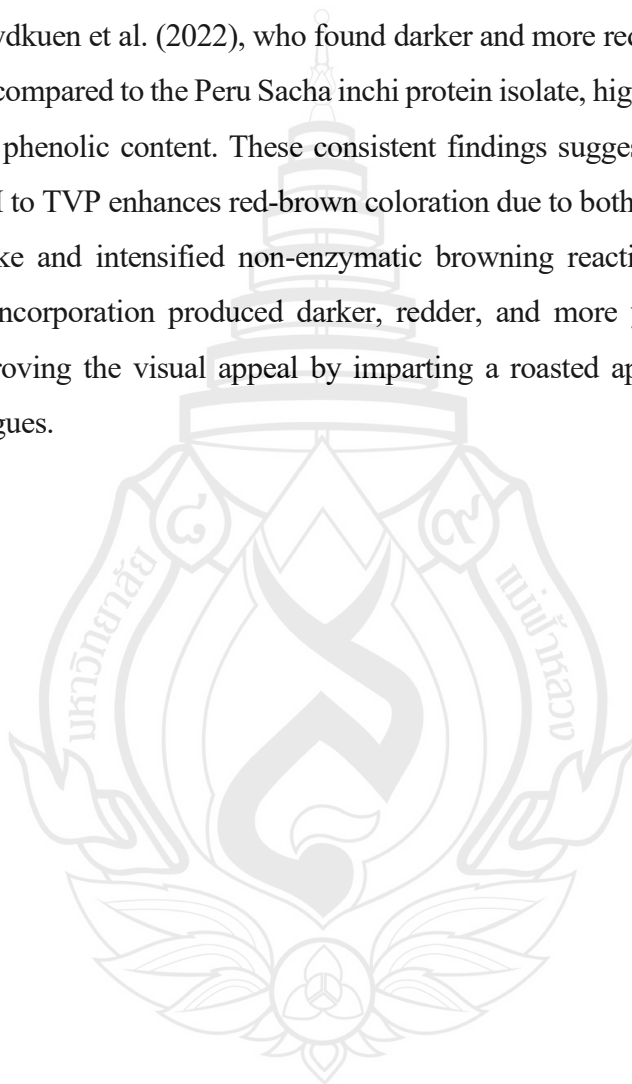


Table 4.1 Physicochemical and techno-functional properties of commercial (COM), control (C), and Sacha inchi press cake– incorporated texturized vegetable protein (TVP) samples (TA–TD)

TVP	Color properties			Techno-functional properties			
	L* (Lightness)	a* (Red green chroma)	b* (Yellow blue chroma)	WHC (Water holding capacity, g H ₂ O/g sample)	OHC (Oil holding capacity, g oil/g sample)	RHC (Rehydration holding capacity, g/g)	RHY (Rehydration holding capacity, %)
COM	81.01± 0.43 ^a	2.79 ± 0.14 ^c	16.66 ±0.88 ^d	4.00±0.29 ^a	1.84±0.01 ^b	2.66±0.1 ^a	265.87±0.1 ^a
C	76.94 ± 0.25 ^b	3.34 ± 0.23 ^{de}	19.43 ± 0.19 ^c	3.92±0.06 ^a	1.79±0.00 ^c	1.85±0.02 ^b	184.64±0.02 ^b
TA	75.14 ±0.44 ^{bc}	3.54 ± 0.17 ^d	19.96 ± 0.32 ^{bc}	3.71±0.15 ^b	1.80±0.02 ^{bc}	1.81±0.06 ^b	181.23±0.06 ^b
TB	73.55 ±0.46 ^c	4.56 ± 0.49 ^c	20.23 ±0.63 ^{bc}	3.41±0.08 ^{bc}	1.82±0.03 ^{bc}	1.72±0.13 ^b	171.65±0.13 ^b
TC	71.43 ± 1.34 ^d	5.97± 0.04 ^b	21.16 ± 0.74 ^{ab}	3.02±0.14 ^c	1.83±0.02 ^b	1.68±0.22 ^b	167.77±0.22 ^b
TD	69.95 ±1.20 ^d	6.60± 0.24 ^a	21.87 ± 0.45 ^a	2.88±0.09 ^c	1.92±0.01 ^a	1.63±0.06 ^b	163.04±0.06 ^b

Note Mean ± SD (n = 3); different superscripts indicate significant differences (p < 0.05, Tukey's test)

TVP: SPM: PI—C (0:100), TA (10:90), TB (35:65), TC (70:30), TD (100:0); COM = commercial TVP

4.3 Functional Properties of Sacha Inchi Press Meal–incorporated Texturized Vegetable Protein (SP-TVP) Powder

Water and oil holding capacity

The water- and oil-holding capacities are critical functional attributes that influence the texture, juiciness, and overall sensory perception of textured vegetable proteins (TVP) and other plant-based meat analogues. In the present study, incorporation of SPM significantly affected both oil and water holding capacity parameters ($p < 0.05$) as seen in Table 4.1. The water-holding capacity (WHC) decreased markedly from 3.92 g/g to 2.88 g/g as seen on Table 4.1, whereas the oil holding capacity (OHC) of the extrudates increased from 1.79 g/g in control to 1.92 g/g at the highest press cake inclusion level. These trends highlight compositional and structural modifications within the protein matrix induced by SPM addition.

Water-holding capacity reflects the ability of the protein matrix to retain water through capillary and hydrophilic interactions, and it is closely related to the number of polar amino acid residues and the integrity of the gel network. Proteins with higher WHC typically yield meat analogues with improved juiciness, mouthfeel, and structural stability during rehydration (Bali et al., 2024). The reduction in WHC observed with increased press meal supplementation may be attributed to the inherent physicochemical characteristics of Sacha inchi proteins and their lower content of hydrophilic residues. Rawdkuen et al. (2022) reported that Sacha inchi protein isolates exhibit lower WHC than soy protein isolates, likely due to fewer polar amino acid groups available for water binding. Consequently, the lower WHC in SP fortified extrudates could stem from its smaller proportion of polar groups, reduced solubility, and higher fiber content, which limits water penetration and matrix swelling during rehydration.

In contrast, the OHC increased with higher SPM inclusion, suggesting enhanced lipid- protein interactions within the extrudate matrix. Oil holding capacity reflects the protein's ability to physically entrap and associate with lipids through hydrophobic interactions between non-polar amino acid side chains and hydrocarbon chains of lipids. Rawdkuen et al. (2022) reported that Sacha inchi protein isolates from Thai and

Peruvian press cakes exhibited OHC values of 2.8 and 2.9 g/g, respectively which are higher than those of pea (1.7–1.9 g/g), lentil (1.9–2.1 g/g), navy bean (2.0 g/g), and chickpea (1.4–2.1 g/g) proteins. The relatively higher OHC in SPM enriched extrudates can therefore be attributed to the increased exposure of hydrophobic domains during extrusion, facilitating stronger lipid entrapment. Enhanced OHC not only improves flavor and juiciness but also supports pigment retention, particularly of carotenoids and other oil-soluble compounds, which contribute to the desirable appearance of meat analogues (Kumar et al., 2022).

Despite the decrease in WHC, the rehydration capacity and yield did not differ significantly ($p > 0.05$) among treatments (C-TD). This indicates that the structural integrity and water absorption ability of the extrudates were not severely compromised by the inclusion of SPM. The nonsignificant differences in rehydration suggest that the compact matrix formed during extrusion was still capable of retaining sufficient porosity for water uptake.

The observed reduction in WHC and improvement in OHC suggest that SPM incorporation modifies the hydrophilic–hydrophobic balance of the protein matrix. While this may slightly reduce the hydration capacity, it enhances oil retention, which could benefit the texture, color, and sensory acceptability of the final TVP product. Optimization of press cake inclusion levels is therefore essential to balance water and oil interactions for desirable rehydration and mouthfeel characteristics in plant-based meat formulations.

4.4 Structure and Texture

Texture is one of the most critical attributes determining the quality and consumer acceptance of textured vegetable proteins (TVPs), as it defines how closely plant-based analogues replicate the fibrous, cohesive structure of meat (Ketnawa & Rawdkuen, 2023). Incorporation of Sacha inchi press meal (SPM) into pea-based formulations significantly influenced the textural characteristics of the extrudates, resulting in distinct variations in hardness, chewiness, gumminess, cohesiveness, and springiness (Table 4.2).

Table 4.2 Texture profile analysis (TPA) of commercial, control, and Sacha inchi press meal (SPM)–incorporated texturized vegetable protein (TVP) samples (TA–TD)

Textural profile	Unit	COM	C	TA	TB	TC	TD
Hardness	G	1196.18 ± 31.63 ^c	1684.53 ± 20.05 ^a	1522.26 ± 20.41 ^b	964.28 ± 32.79 ^d	827.29 ± 29.16 ^d	633.77 ± 51.24 ^e
Adhesiveness	g.s	−5.59 ± 4.01 ^{ab}	−0.85 ± 0.24 ^a	−14.52 ± 0.30 ^b	−5.58 ± 2.79 ^{ab}	−2.27 ± 1.83 ^{ab}	−6.14 ± 5.98 ^{ab}
Springiness	%	0.941 ± 0.007 ^{ab}	0.964 ± 0.063 ^a	0.898 ± 0.054 ^{ab}	0.795 ± 0.044 ^b	0.794 ± 0.025 ^b	0.614 ± 0.033 ^c
Cohesiveness	-	0.684 ± 0.026 ^a	0.652 ± 0.036 ^a	0.540 ± 0.063 ^b	0.505 ± 0.049 ^{bc}	0.465 ± 0.046 ^{bc}	0.402 ± 0.019 ^c
Gumminess	G	818.29 ± 51.38 ^b	1098.55 ± 67.73 ^a	769.01 ± 83.50 ^b	387.62 ± 56.15 ^c	383.50 ± 42.40 ^c	343.52 ± 59.38 ^c
Chewiness	G	770.41 ± 47.06 ^b	1059.26 ± 17.80 ^a	613.80 ± 5.21 ^c	310.51 ± 68.85 ^d	302.10 ± 20.64 ^d	237.54 ± 31.76 ^d
Resilience	%	0.380 ± 0.011 ^a	0.391 ± 0.026 ^a	0.279 ± 0.005 ^{bc}	0.181 ± 0.004 ^d	0.245 ± 0.017 ^c	0.305 ± 0.036 ^b

Note Values are presented as mean ± standard deviation (n = 3). Means within the same row followed by different superscript letters are significantly different (p < 0.05), according to Tukey's multiple comparison test.

TVP: SPM: PI—C (0:100), TA (10:90), TB (35:65), TC (70:30), TD (100:0); COM = commercial TVP.

The Control (C-100% PI) exhibited the highest hardness (1684.53 g) and chewiness (1059.26 g), consistent with the formation of a strong and continuous protein network typical of legume-based extrudates. Scanning electron microscopy (SEM) micrographs (Figure 4.2) suggested a compact, fibrillar matrix with minimal visible porosity, which is consistent with well-developed protein alignment and intermolecular interactions during extrusion. Similar trends have been reported in pea protein extrusions by Plattner et al. (2024) who observed increasing pea protein isolate inclusion from 30–60% led to significantly higher product hardness (14,160–16,885 g) and toughness (36,690–46,195 g. s).

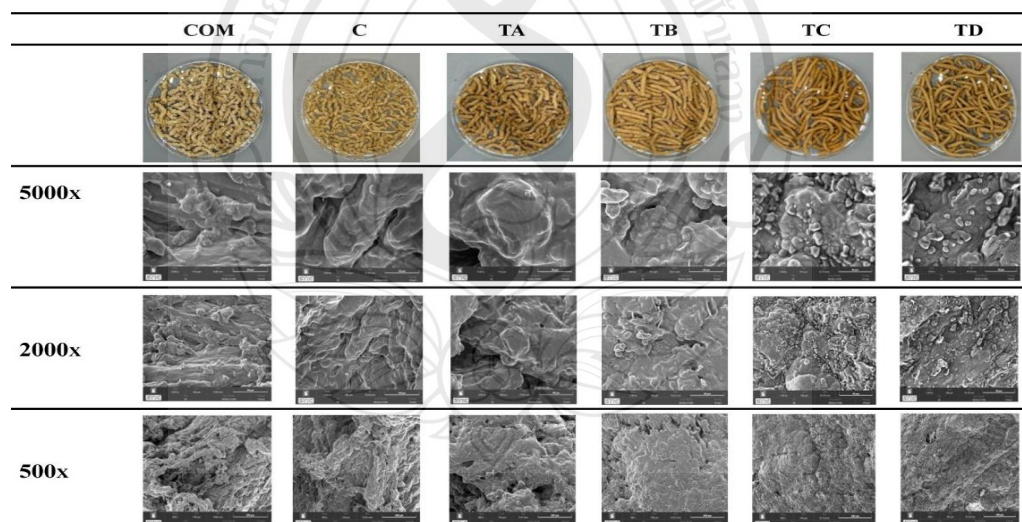
As the proportion of Sacha inchi press meal (SPM) increased (TA–TD), hardness and gumminess decreased markedly from 1522.26 g to 633.77g and from 769.01 g to 343.52 g, respectively, suggesting progressive softening of the structure (Table 4.3). This trend was accompanied by microstructural changes observed under SEM (Figure 4.2), where SPM-containing samples displayed increasingly porous, irregular matrices with coarse particulate inclusions and fragmented surfaces. This reduction can be attributed to the higher lipid and fiber content of SPM, which interferes with protein–protein interactions and weakens the formation of a cohesive matrix (Luise et al., 2025). Similar weakening of the protein structure has been observed when soy bean meal was integrated into pea-based extrudates, resulting in reduction in fibrous structure leading to decrease in chewiness and hardness (Wang et al., 2024).

Cohesiveness and springiness also declined with increasing SPM levels, reflecting weaker internal bonding within the extrudate matrix (Table 4.2). This behavior aligns with previous reports showing that oilseed press cake incorporation disrupts protein alignment, leading to a fragmented, less elastic texture (Lallinger & Rauh, 2024; Luise et al., 2025). In the present study, SEM images of higher-SPM treatments (TC, TD) revealed fragmented matrices and voids, features consistent with disrupted protein alignment and insufficient chain entanglement. Such discontinuous morphologies have been linked to decreased elasticity and water retention in pea and soy extrudates (Wang et al., 2024).

Interestingly, resilience exhibited a non-linear pattern, declining at moderate SPM levels but showing partial recovery in TD (100 % SP) (Table 4.2). SEM micrographs of TD showed smoother surfaces compared to TC, which may indicate that residual lipids within the press cake acted as plasticizers. The lubricating effect of oil can reduce intermolecular

friction and enhance chain mobility, thereby allowing limited elastic recovery even as overall matrix integrity is reduced: similar effects of lipid-mediated plasticization have been described in high-moisture extrusion systems containing residual or added oils (Kendler et al., 2021). The commercial TVP (COM) exhibited a highly aligned fibrous morphology and intermediate hardness (1196.18 g), characteristic of industrially optimized extrudates produced under controlled shear and moisture conditions. The anisotropic fiber alignment observed in COM, compared to the more isotropic structures of laboratory samples, highlights the influence of extrusion parameters on structural anisotropy and mechanical strength.

Overall, the SEM observations and TPA data collectively indicate that progressive inclusion of SPM transforms the microstructure from a compact, cohesive protein network to a more porous, particulate-dominated matrix, accompanied by decreased hardness, gumminess, cohesiveness, chewiness and springiness. However, moderate substitution levels (e.g., TA) appear to provide a desirable balance between SPM incorporation and retention of acceptable textural integrity, with structural and mechanical properties closer to those of commercial reference. These results suggest that controlled incorporation of SPM can be used to modulate the texture and microstructure of plant-based meat analogues.



Note Images show the physical characteristics (visual and structural) of TVP samples, including both macro- and micro-structural.

Figure 4.2 Visual appearance, macrostructure, and microstructure of commercial (COM), control (C), and Sacha inchi press meal-incorporated texturized vegetable protein (SP-TVP) samples (TA–TD)

4.5 Selection of the Optimal Sample

Among the SPM-incorporated formulations, TA (10:90) demonstrated significantly superior ($p < 0.05$) textural properties including hardness, springiness, cohesiveness, gumminess, and chewiness relative to higher substitution levels (TB–TD), indicating a more cohesive and well-developed protein network. Notably, TA exceeded the commercial TVP (COM) in hardness and was comparable in chewiness and gumminess, reflecting enhanced structural integrity and overall textural quality.

Water and oil holding capacities were significantly affected by SPM inclusion ($p < 0.05$). TA exhibited relatively high WHC, significantly greater than TB–TD, suggesting improved matrix integrity and retention of hydrophilic interactions. Although slightly lower than the control (C), TA maintained WHC within a functionally acceptable range. In contrast, WHC decreased progressively with increasing SPM levels, likely due to disruption of the protein network and reduced availability of polar binding sites. Conversely, OHC increased with higher SPM inclusion, with TD showing the highest value; however, this did not offset the concurrent deterioration in structural and hydration properties. Compared to COM, TA displayed comparable WHC and OHC while maintaining a more balanced functional profile.

These findings were corroborated by SEM analysis, where TA exhibited a compact and continuous microstructure with reduced pore formation, whereas TB–TD showed increasingly porous and fragmented matrices, indicative of weakened protein–protein interactions. Collectively, the integrated textural, functional, and microstructural results identify TA as the optimal formulation, achieving a balanced incorporation of SPM while preserving desirable TVP-like characteristics, and was therefore selected for subsequent compositional and sensory analyses.

4.6 Nutritional Composition of Selected TVP

4.6.1 Proximate Analysis

The proximate composition of the TA TVP is shown in Table 4.3. The moisture content $5.17 \pm 0.84\%$ was lower than that of commercial soy-based TVP $7.99 \pm 0.06\%$ which

reported by Ketnawa and Rawdkuen (2023) and within the range for Sacha inchi press cake 5.1–12.4% (Torres Sánchez et al., 2021) . The low moisture content suggests improved shelf stability and reduced microbial susceptibility. The protein content $69.42 \pm 0.13\%$ was higher than commercial soy based TVP $47.29\% \pm 0.59$ (Ketnawa & Rawdkuen, 2023) and pea based high moisture meat analog 51.33–59.36% (Plattner et al., 2024), but slightly lower than pea protein isolate 81.5% (Chan et al., 2023). This indicates that combining Sacha inchi press meal with pea protein isolate enhances the overall protein content compared to conventional soy-based TVP while balancing the nutritional composition of the blend. The ash content $4.00 \pm 0.05\%$ was comparable to Sacha inchi press cake 4.6–8.7% (Torres Sánchez et al., 2021) and lower than the commercial soy TVP $8.02\% \pm 0.04$ (Ketnawa & Rawdkuen, 2023), reflecting inherent mineral differences among the raw materials. The lipid content $2.91 \pm 0.01\%$ exceeded those reported for soy- and pea-based meat analogs 0.84–2.05% but remained below that of Sacha inchi press cake 4.8–25.5%, (Torres Sánchez et al., 2021). The carbohydrate content $23.61 \pm 0.19\%$ was lower than in Commercial soy based TVP $39.73\% \pm 0.5$ (Ketnawa & Rawdkuen, 2023) but higher than in pea protein isolate 13.2% (Chan et al., 2023) indicating the contribution of non-protein components from Sacha inchi press meal. The fiber content $1.44 \pm 0.02\%$ was below the ranges reported for pea based high moisture meat analogs 5.62–10.12% (Plattner et al., 2024) and Sacha inchi press cake 3.0–17.3% (Torres Sánchez et al., 2021), which may be attributed to the use of refined protein ingredients and fiber reduction during extrusion. Overall, TA produced a high-protein, low-fat, and shelf-stable TVP with a balanced nutrient composition, demonstrating potential as a plant-based alternative comparable to conventional soy-based TVP.

Table 4.3 Proximate composition of the optimum Sacha inchi press meal–incorporated texturized vegetable protein (SP-TVP)

Proximate composition (g/100 g dry basis)	
Moisture	5.17±0.84
protein	69.42±0.13
Ash	4.00±0.05
Lipid	2.91±0.01
Carbohydrate	23.61±0.19
Fiber	1.44±0.02

Note Values are expressed as mean ± standard deviation (n = 3) on a dry basis (g/100 g).

Carbohydrate content was calculated by difference. Differences were considered statistically significant at $p < 0.05$.

4.6.2 Amino Acid Profile

The amino acid profile of TA TVP as shown in Table 4.4 indicates that it is a nutritionally balanced plant-based protein source, supplying substantial levels of both essential (EAAs) and non-essential amino acids (NEAAs). Key EAAs such as leucine (5713 mg/100 g), valine (5026 mg/100 g), and lysine (3495 mg/100 g) exceed adult requirements for a 70 kg individual, supporting muscle maintenance and overall nitrogen balance (Food & Agriculture Organization of the United, 2013). Tryptophan (736 mg/100 g) and histidine (1741 mg/100 g) are also present in sufficient amounts, further enhancing its nutritional profile. Methionine (795 mg/100 g) remains the limiting amino acid (~49% of adult requirement), consistent with SP (6-17mg/100g), suggesting that dietary complementation with methionine-rich cereals could optimize protein quality.

The NEAAs are abundant, particularly glutamic acid (14,023 mg/100 g) and aspartic acid (7,259 mg/100 g), which are important for metabolic functions, and as precursors for neurotransmitters (Dalangin et al., 2020). High levels of alanine, glycine, proline, serine, and arginine may contribute to functional properties such as protein solubility, gelation, and bioactive peptide potential, while cystine (1,209 mg/100 g) complements the sulfur amino acid profile (Trevino et al., 2007). Tyrosine (2,863 mg/100 g) is also notable for supporting catecholamine synthesis, which has been linked to cognitive performance under stress (Yeghiayan et al., 2001). As these values do not incorporate protein digestibility, indices such as PDCAAS or DIAAS cannot be calculated, and the present discussion of protein quality is

therefore restricted to amino acid composition. Collectively, TA TVP exhibits a favorable amino acid profile for incorporation into plant-based foods, particularly when combined with methionine-rich cereal ingredients.

Table 4.4 Amino acid profile of the optimum Sacha inchi press meal–incorporated texturized vegetable protein (SP-TVP)

Amino acids (mg/100 g dry basis)	
Essential amino acids	
Histidine	1740.73
Isoleucine	2604.32
Leucine	5712.80
Lysine	3494.68
Methionine	795.40
Phenylalanine	4190.52
Threonine	2229.09
Tryptophan	735.94
Valine	5025.69
Non-essential amino acids	
Glutamic acid	14022.99
Aspartic acid	7259.22
Alanine	2401.74
Glycine	2757.48
Proline	4054.70
Serine	4105.57
Tyrosine	2863.14
Arginine	4551.73
Cystine	1209.25
Hydroxylysine	ND
Hydroxyproline	ND

Note Analysis performed by Central Laboratory (Thailand) Co., Ltd. using in-house methods TE-CH-372 (based on Official Journal of the European Communities, Commission Directive 98/64/EC, L257 (1998), Annex Part A, pp. 14–23) and TE-CH-373 (based on Journal of Food Chemistry, Vol. 193 (2016), pp. 26–29). Only a single test was performed using the standard method. All amino acids are reported on a dry matter basis.

4.6.3 Fatty Acid

The fatty acid composition of TA-TVP (Table 4.5) reveals a profile characterized by a predominance of unsaturated fatty acids and relatively low level of saturated fat. The total saturated fatty acids (SFA) in TA were 1.11 g/100 g DM, comprising mainly palmitic acid (C16:0; 0.76 g/100 g), followed by stearic acid (C18:0; 0.23 g/100 g) and minor amounts of myristic and longer-chain acids. The absence of trans fatty acids (ND) is nutritionally favorable and is consistent with recommendations to keep trans-fat below 1% of total energy intake. Likewise, the low SFA proportion aligns with the < 10% of the total energy intake limit advised by the United Nations to minimize cardiovascular risk (FAO, 2010). These results indicate that, on a compositional basis, TA has a lipid profile characterized by low saturated fat, absence of detectable trans-fat, and predominance of oleic and linoleic acids.

Monounsaturated fatty acids (MUFA) totaled 0.87 g/100 g DM, almost entirely represented by oleic acid (C18:1 n9c). Such dominance of oleic acid is characteristic of oilseeds and has been associated in the literature with improved plasma lipid profiles when it replaces saturated fat in the diet (Plötz et al., 2017).

The total polyunsaturated fatty acids (PUFA) amounted to 0.53 g/100 g DM, mainly linoleic acid (C18:2 n6; 484.46 mg/100 g) and a small quantity of α -linolenic acid (C18:3 n3; 53.35 mg/100 g), yielding an n-6/n-3 ratio of approximately 9:6. Although this ratio falls within the acceptable limit (<10:1) established by FAO (2010), the absolute levels of n-6 and n-3 polyunsaturated fatty acids remain substantially below the recommended ranges of 2.5–9% total energy intake for linoleic acid and 0.5–2% total energy intake for α -linolenic acid. Considering the low overall lipid content 2.91%, TA contributes only modestly to daily essential fatty acid intake and should not be regarded as a primary dietary source of n-3 or n-6 PUFAs.

From a dietary perspective, the lipid fraction of TA is qualitatively favorable but quantitatively limited. The low total fat (2.91%) is compatible FAO/WHO recommendations for fat intake 5–35% (FAO, 2010), while predominance of unsaturated fatty acids and the absence of detectable trans-fat are consistent with current guidance for cardiovascular health. Nonetheless, the low content of essential n-3 fatty acids suggests that consumers would require complementary n-3 sources, such as Sacha inchi oil or other n-3-rich ingredients, to meet FAO/WHO minimum intakes. From a technological standpoint, future formulations could explore the controlled re-incorporation of small amounts of ALA-rich oil.

Table 4.5 Fatty acid composition of the optimum Sacha inchi press meal–incorporated texturized vegetable protein (SP-TVP)

Component	Notation	Value
Saturated fatty acids (SFA)		g/100 g lipids
Myristic acid	C14:0	0.02
Palmitic acid	C16:0	0.76
Heptadecanoic acid	C17:0	0.01
Stearic acid	C18:0	0.23
Arachidic acid	C20:0	0.02
Behenic acid	C22:0	0.02
Lignoceric acid	C24:0	0.02
ΣSFA		1.11
Monounsaturated fatty acids (MUFA)		
Palmitoleic acid	C16:1n7	ND
Oleic acid (cis-9)	C18:1n9c	0.84
Eicosenoic acid (cis-11)	C20:1n11	0.02
Elaidic acid (trans-9)	C18:1n9t	ND
ΣMUFA		0.87
Polyunsaturated fatty acids (PUFA)		
Linoleic acid (cis-9,12)	C18:2n6	0.48
γ-Linolenic acid	C18:3n6	ND
α-Linolenic acid	C18:3n3	0.05
Eicosadienoic acid	C20:2	ND
Eicosatrienoic acid	C20:3n6	ND
Arachidonic acid	C20:4n6	ND
Eicosapentaenoic acid	C20:5n3	ND
ΣPUFA		0.53

Table 4.5 (continued)

Component	Notation	Value
Lipid quality indices		
Total unsaturated fatty acids (MUFA + PUFA)		1.40
Trans fatty acids		ND
Omega fatty acids		mg/100 g sample
Omega-3 fatty acids		50.35
Omega-6 fatty acids		484.46
Omega-9 fatty acids		841.87

Note Fatty acid analysis was performed by Central Laboratory (Thailand) Co., Ltd. using gas chromatography–flame ionization detection (GC–FID) following standard methods. Results are expressed on a dry matter basis. Fatty acids are classified into saturated, monounsaturated, and polyunsaturated groups, with selected individual fatty acids reported.

4.7 Development of Sacha Inchi Press Cake Burger Patty

Within this framework, burger patties formulated using a Sacha inchi press meal-pea based textured vegetable protein system (TA) were systematically compared with a commercial TVP (COM)-based burger. The objective of this comparison was to evaluate the effects of partially substitution with sacha inchi press meal (SPM) on the compositional profile, techno-functional performance, sensory attributes, and consumer acceptance of the final burger product.

4.8 Nutritional Composition of TA Burger Patty

4.8.1 Proximate Analysis for Burgers

As shown in Table 4.6, TA patties showed significantly higher protein (45.43 g/100 g dry basis) and lipid contents (12.40 g/100 g dry basis), with lower carbohydrate and fiber contents, compared with COM patties. This profile is consistent with the composition of Sacha inchi press meal, a protein-rich oilseed by-product containing moderate residual

lipids and relatively lower carbohydrate levels (Rawdkuen et al., 2016). The elevated protein content observed in TA also aligns with previous reports on research designed meat analogues, typically exhibit higher protein contents than commercial products. For example, Auppasuk et al. (2025) reported protein contents of approximately 75% in experimental TVP compared with 50% in commercial TVP, while Ketnawa and Rawdkuen (2023) observed higher protein and lower carbohydrate contents in experimental Phoenix mushroom-based TVP than in commercial counterparts. This observation is consistent with the findings of Hong et al. (2022), who reported substantial variability in protein content among TVP products depending on protein source, with textured pea protein generally exhibiting higher protein levels than wheat gluten or mixed-protein TVPs. The dietary fiber content of TA (3.93 g/100 g dry basis) was lower than that of COM (4.76 g/100 g dry basis), which may influence textural properties, given the role of fiber in water retention and matrix structure in plant-based meat analogues. TA also exhibited lower ash content (4.68 g/100 g dry basis), indicating differences in mineral composition relative to COM. Additionally, the higher moisture content of COM patties may affect both textural attributes and shelf-life stability. Overall, these results demonstrate that partial replacement of conventional TVP with Sacha inchi press meal yields burger patties with enhanced protein and lipid contents and reduced carbohydrate and fiber levels, supporting the potential of SPM as a sustainable ingredient for protein-dense plant-based burger formulations.

Table 4.6 Proximate composition of TA burger patty (Sacha inchi press meal–incorporated texturized vegetable protein) on a dry matter basis

Proximate composition (g/100 g dry basis)		
	TA	COM
Moisture	55.08±0.56 ^b	63.32±0.03 ^a
protein	45.43±0.24 ^a	39.99±0.55 ^b
Ash	4.68±0.00 ^b	6.20±0.00 ^a
Lipid	12.40±0.02 ^a	9.45±0.00 ^b
Carbohydrate	37.63±0.04 ^b	44.28±0.05 ^a
Fiber	3.93±0.15 ^b	4.76±0.12 ^a

Note Values are expressed as mean ± standard deviation (n = 3) on a dry basis (g/100 g).

Carbohydrate content was calculated by difference. Differences were considered statistically significant at $p < 0.05$.

4.8.2 Amino Acid Composition of Burger Patty

The amino acid composition of the sachal press meal-based burger patty (TA) as seen in Table 4.7 provides partial insight into the nutritional quality of the protein fraction introduced through partial substitution of conventional TVP protein. TA was rich in branched-chain amino acids, including leucine (1705.29 mg/100 g), isoleucine (941.75 mg/100 g), and valine (1071.77 mg/100g), as well as lysine (1174.77 mg/100 g), phenylalanine (1166.42 mg/100 g), and threonine (757.36 mg/100 g), in line with Rawdkuen et al. (2016) findings that Sachal press cake is a protein-dense plant ingredient. When expressed as estimated intakes (mg/kg bw/day) and compared with WHO (2007) adult requirements, most indispensable amino acids in TA burger patty were slightly below the recommended levels, typically supplying approximately 70–90% of requirements. Leucine, isoleucine, valine, lysine, threonine, phenylalanine, and histidine all approached, but did not fully meet, WHO reference values, indicating a generally balanced but moderately limiting essential amino acid profile. Despite falling marginally short of requirements, the relatively high lysine content remains nutritionally relevant, as lysine is frequently limiting in cereal-based protein systems, particularly wheat, which is widely used in plant-based meat analogues (Leinonen et al., 2019; WHO, 2007). Tryptophan represented an exception, as its estimated intake exceeded the WHO requirement. In contrast, sulfur amino acids constituted the principal nutritional limitation. Methionine was markedly below the WHO requirement, and even when considered together with cystine, total sulfur amino acid intake provided less than 50% of the recommended level. Such limitations are characteristic of plant proteins, in which one or two indispensable amino acids are often deficient (e.g., low lysine in wheat and low methionine in soy) (Chen et al., 2026).

The NEAAs were abundant, particularly glutamic acid and aspartic acid, which are important for metabolic functions, and as precursors for neurotransmitters (Dalangin et al., 2020). The abundance of glycine, proline, serine, and arginine may contribute to functional properties such as protein solubility, gelation, and bioactive peptide potential (Trevino et al., 2007). Overall, the TA burger patty protein fraction demonstrates a generally favorable but slightly limiting indispensable amino acid profile relative to WHO/FAO/UNU adult requirements, with sulfur amino acids identified as the primary constraint. These findings highlight both the nutritional value

of sachu inchi press meal and the importance of complementary formulation strategies or dietary pairing to achieve amino acid adequacy in plant-based burger systems.

Table 4.7 Amino acid profile of TA burger patty (Sachu inchi press meal–incorporated texturized vegetable protein) on a dry matter basis

Amino acids (mg/100 g dry basis) TA burger patty	
Essential amino acids	
Histidine	535.60
Isoleucine	941.75
Leucine	1705.29
Lysine	1174.77
Methionine	< 200.00
Phenylalanine	1166.42
Threonine	757.36
Tryptophan	161.26
Valine	1071.77
Non-essential amino acids	
Glutamic acid	4676.52
Aspartic acid	2155.92
Alanine	823.51
Glycine	897.67
Proline	1457.54
Serine	1114.15
Tyrosine	776.34
Arginine	1436.80
Cystine	< 200.00
Hydroxylysine	ND
Hydroxyproline	ND

Note Analysis performed by Central Laboratory (Thailand) Co., Ltd. using in-house methods TE-CH-372 (based on Official Journal of the European Communities, Commission Directive 98/64/EC, L257 (1998), Annex Part A, pp. 14–23) and TE-CH-373 (based on Journal of Food Chemistry, Vol. 193 (2016), pp. 26–29). Only a single test was performed using the standard method. All amino acids are reported on a dry matter basis.

4.8.3 Fatty Acid Composition

The fatty acid composition of the TA burger patties reflects the combined effects of formulation strategy and ingredient functionality as seen in Table 4.8. The total lipid content was 12.41 g/100 g (dry basis), with saturated fatty acids predominating (10.69 g/100 g), mainly Lauric acid (6.10 g/100 g) myristic acid (2.03 g/100 g) and palmitic acids (1.19 g/100 g). This profile is consistent with the inclusion of 12.5 g palm kernel oil per 100 g formulation, a fat source commonly used in plant-based meat analogues (PBMA) due to its ability to remain solid at refrigeration and ambient temperatures while melting during cooking, thereby mimicking the thermal and sensory behavior of animal fat (National Consumers League, 2022). Unsaturated fatty acids were present at lower levels (0.86 g/100 g), largely as monounsaturated fatty acids dominated by oleic acid (0.76g/100g), with only minor contributions from polyunsaturated fatty acids. The limited omega-3 and omega-6 contents likely reflect the low inclusion level of Sacha inchi press meal the TVP formulation, wherein Sacha inchi press meal and pea protein isolate were blended at an approximate 10:90 ratio within a constant total protein block of 43.8% (w/w) and its use as a defatted press cake rather than an oil, despite the inherently favorable fatty acid profile of Sacha inchi oil (Samrit et al., 2024). From a nutritional perspective, the high proportion of saturated fat represents a trade-off commonly observed in PBMA (National Consumers League, 2022), balancing health considerations with the need for meat-like texture and juiciness. Notably there was no trans fats detected, aligning with FAO/WHO recommendations (FAO, 2010). Overall, the lipid profile highlights the technological suitability of the formulation while indicating opportunities for future optimization through partial replacement of saturated fats with structured unsaturated lipid systems.

Table 4.8 Fatty acid composition of TA burger patty on a dry matter basis

Component	Notation	Value
Saturated fatty acids (SFA)		g/100 g lipids
Lauric acid	C12:0	6.10
Myristic acid	C14:0	2.03
Palmitic acid	C16:0	1.19
Heptadecanoic acid	C17:0	0.06
Stearic acid	C18:0	0.30

Table 4.8 (continued)

Component	Notation	Value
Behenic acid	C22:0	ND
Lignoceric acid	C24:0	ND
ΣSFA		10.69
Monounsaturated fatty acids (MUFA)		
Palmitoleic acid	C16:1n7	ND
Oleic acid (cis-9)	C18:1n9c	0.73
Eicosenoic acid (cis-11)	C20:1n11	ND
Elaidic acid (trans-9)	C18:1n9t	ND
ΣMUFA		0.76
Polyunsaturated fatty acids (PUFA)		
Linoleic acid (cis-9,12)	C18:2n6	0.02
γ-Linolenic acid	C18:3n6	0.03
α-Linolenic acid	C18:3n3	0.01
Eicosadienoic acid	C20:2	0.02
Eicosatrienoic acid	C20:3n6	ND
Arachidonic acid	C20:4n6	ND
Eicosapentaenoic acid	C20:5n3	ND
ΣPUFA		0.10
Lipid quality indices		
Total unsaturated fatty acids (UFA)		0.86
Trans fatty acids		ND
Omega fatty acids		mg/100 g sample
Total omega-3		17.83
Total omega-6		61.52

Note Analysis performed by Central Laboratory (Thailand) Co., Ltd. using Gas Chromatography with Flame Ionization Detector (GC-FID). Only a single test was performed using the standard method. All fatty acids are reported on a dry matter basis. Fatty acids are categorized as saturated, monounsaturated, and polyunsaturated, with selected individual fatty acids also reported.

4.9 NOVA Classification of TA Burger Patty

Under the NOVA framework, TA burger patty is classified as Group 4 (Ultra-processed) (Del Carmen Fernández-Fígares Jiménez & López-Moreno, 2025) because it is an industrial formulation of fractionated substances such as Sacha Inchi press cake, protein isolates, and wheat gluten which were reconstituted through low-moisture extrusion to create a fibrous, shelf-stable protein matrix (Tompá et al., 2025; Vila-Clarà et al., 2024). The inclusion of “markers of ultra-processing,” such as transglutaminase for cross-linking and kappa carrageenan for textural stability, signifies a level of chemical and mechanical modification absent in culinary preparations (Messina & Messina, 2025). While this upcycled byproduct approach offers significant sustainability advantages, the reliance on industrial additives like sodium phosphate and MSG to achieve hyper-palatability fulfills the core NOVA criteria for a technological food product (Del Carmen Fernández-Fígares Jiménez & López-Moreno, 2025). Consequently, the patty exemplifies the modern food science paradox where a nutritionally optimized, plant-based alternative remains structurally categorized as ultra-processed due to its complete deconstruction and subsequent synthesis (Bąkowska et al., 2026).

4.10 Color TA Burger Patty

Color is a critical quality attribute influencing consumer perception and acceptance of plant-based meat analogues, as it directly affects expectations related to freshness, doneness, and resemblance to conventional meat products (Rathnayake et al., 2025). In the present study, significant differences in instrumental color parameters (L^* , a^* , and b^*) were observed as seen in Table 4.9 between burger patties formulated with sacha inchi press meal–pea TVP (TA) and the commercial soy-based TVP burger (COM) as seen in Table 12. TA patties exhibited lower lightness ($L^* = 54.25$) compared with COM ($L^* = 60.12$), indicating a darker appearance associated with the inclusion of Sacha inchi press cake, which retains residual pigments, polyphenols, and higher concentrations of proteins and dietary fiber following oil extraction. These components reduce surface

reflectance and produce a more opaque and less luminous matrix, as previously reported for defatted oilseed by-products (Alejandro Ruiz et al., 2025). Similar darkening effects have been documented in bakery and composite food systems incorporating sacha inchi press cake, where increasing inclusion levels led to significant decreases in L^* and b^* values and increases in a^* values (Rungrot et al., 2021). In contrast, COM patties displayed higher lightness and lower chromatic intensity, reflecting the color characteristics of soy-based TVP formulations. Commercial TVPs are typically produced from soy flour or soy protein concentrate, which appear as white to pale yellow powders and impart a lighter visual appearance to the final product (Ketnawa & Rawdkuen, 2023).

Despite measurable differences in instrumental color parameters, no significant variation was observed in sensory color and appearance scores among formulations, with TA patties exhibiting only marginal, non-significant reductions relative to COM and minced chicken controls. These findings indicate that incorporation of Sacha inchi press meal alters objective color attributes without compromising visual acceptability, maintaining sensory quality comparable to conventional burger products.

Table 4.9 Color and cooking properties of TA and COM burger patty

	TA burger patty	COM burger patty
Color properties		
L^* (Lightness)	54.25 ± 0.70^b	60.12 ± 0.09^a
a^* (Red-green chroma)	8.26 ± 0.19^a	7.74 ± 0.05^b
b^* (Yellow-blue chroma)	19.22 ± 0.26^a	16.14 ± 0.60^b
Cooking properties		
Cooking loss (%)	13.05 ± 2.64^a	16.99 ± 0.66^a
Moisture retention (%)	72.24 ± 2.41^a	73.79 ± 0.94^a
Fat retention (%)	86.17 ± 0.31^a	34.64 ± 0.93^b
Compressed juiciness (%)	5.40 ± 0.79^a	6.83 ± 0.45^a

Note Values are expressed as mean $\pm$ standard deviation ($n = 3$). Means in the same row with different superscript letters differ significantly at different ($p < 0.05$), (independent-samples t-test, SPSS).

4.11 Cooking Properties

Cooking performance was evaluated using cooking loss, moisture retention, fat retention, and compressed juiciness, parameters that are closely associated with product yield, juiciness, tenderness, and overall sensory quality in burger-type products (Hong et al., 2022). Cooking loss, which primarily reflects the release of moisture and fat during heating, is influenced by formulation variables, protein structure, and cooking conditions (Yi et al., 2012). Moisture and fat retentions describe the ability of the matrix to retain water and lipids after cooking and are critical determinants of consumer acceptability (Hong et al., 2022).

In the present study, cooking loss did not differ significantly ($p > 0.05$) between TA burger patties ($13.05 \pm 2.64\%$) and COM burger patties ($16.99 \pm 0.66\%$), indicating comparable cooking yield as observed in Table 4.10. Similarly, moisture retention remained high and statistically similar in TA ($72.24 \pm 2.41\%$) and COM ($73.79 \pm 0.94\%$), suggesting equivalent water-holding capacity despite differences in TVP composition. Compressed juiciness also showed no significant difference between TA (5.40 ± 0.79) and COM (6.83 ± 0.45), indicating that perceived juiciness was maintained across formulations.

In contrast, fat retention differed markedly, with TA burger patty exhibiting significantly higher fat retention ($86.17 \pm 0.31\%$) than COM ($34.64 \pm 0.93\%$). This pronounced difference may be partly attributed to the oil-holding capacity of Sacha inchi press cake proteins, which has been reported to be higher than other plant protein sources (Rawdkuen et al., 2022). In addition to the influence of Sacha inchi press meal, the TA burger had higher protein, which enhances lipid entrapment predominantly via protein gelation during thermal processing. This mechanism involves heat-induced denaturation of proteins, exposing hydrophobic domains that interact with lipid droplets while hydrophilic regions retain water, thereby forming a robust gel matrix that minimizes free oil release and improves product juiciness (Hong et al., 2022; Sakai et al., 2023). Improved fat retention is particularly relevant for plant-based burger systems, as it supports flavor retention, mouthfeel, and the development of meat-like eating quality (Vila-Clarà et al., 2024). Overall, these results demonstrate that partial

replacement of conventional TVP with Sacha inchi press meal preserves key cooking performance attributes while enhancing lipid retention, supporting its technological suitability for plant-based burger applications.

4.12 Texture

Textural profile analysis showed significant structural differences between TA and COM burger patties as seen in Table 4.10, primarily attributable to the properties of the respective TVPs. TA exhibited significantly higher hardness (9771.78 ± 10.16) and gumminess (3697.50 ± 24.47), indicating the formation of a denser and more rigid protein network. This behavior is consistent with the significantly high fat retention observed in TA ($86.17 \pm 0.31\%$) compared with COM ($34.64 \pm 0.93\%$), as retained lipids can be entrapped within the protein matrix, contributing to increased resistance to deformation. Such lipid–protein interactions are commonly reported in plant-based meat analogues, where immobilized oil phases enhance structural stability and firmness (Sakai et al., 2023; Xue et al., 2025).

COM burger patties exhibited higher springiness (0.76 ± 0.11), cohesiveness (0.51 ± 0.03), and resilience (0.16 ± 0.01) than TA, indicating a more elastic and internally cohesive structure characteristic of soy-based TVP matrices (Fei et al., 2026). In contrast, TA patties showed reduced springiness and cohesiveness, reflecting a more compact but less elastic architecture associated with Sacha inchi press meal incorporation (Luise et al., 2025). This structural shift promotes matrix densification likely driven by residual lipids and protein–lipid interactions, which enhance rigidity at the expense of elastic recovery (Sakai et al., 2023). These instrumental findings are consistent with the significantly higher fat retention of TA patties (86.17% vs. 34.64% in COM) and their firmer textural profile. Despite these instrumental differences, sensory texture acceptability did not differ significantly between formulations as seen in Table 4.12 (TA = 6.63 ± 1.73 ; COM = 6.36 ± 1.86), suggesting that increased firmness and reduced elasticity in TA were not perceived negatively by consumers. Overall, TPA results indicate that partial substitution with Sacha inchi press meal alters the

mechanical behavior of plant-based burgers toward a firmer, less elastic texture without adversely affecting sensory acceptance.

Table 4.10 Texture profile analysis (TPA) parameters of TA and COM TVP burger patties

Textural profile	Unit	TA	COM
Hardness	G	9771.78 ± 10.16 ^a	4308.48 ± 18.67 ^b
Adhesiveness	g·s	-1.08 ± 0.81 ^a	-1.03 ± 0.13 ^a
Springiness	%	0.43 ± 0.01 ^b	0.76 ± 0.11 ^a
Cohesiveness	—	0.39 ± 0.01 ^b	0.51 ± 0.03 ^a
Gumminess	G	3697.50 ± 24.47 ^a	2399.48 ± 74.13 ^b
Chewiness	G	1881.81 ± 61.45 ^b	2019.10 ± 7.37 ^a
Resilience	%	0.13 ± 0.01 ^b	0.16 ± 0.01 ^a

Note Values are expressed as mean ± standard deviation (n = 3). Hardness, gumminess and chewiness are expressed in grams (G); adhesiveness in gram-seconds (g·s); springiness, cohesiveness and resilience are dimensionless ratios, reported as proportions or percentages. Means in the same row with different superscript letters differ significantly at $p < 0.05$ (independent-samples t-test).

4.13 Sensory and Consumer Acceptance

Sensory evaluation demonstrated that sachu inchi press meal-based patties (TA) achieved consumer acceptance comparable to both the commercial plant-based control (COM) and minced chicken burgers across all evaluated attributes as observed in Table 4.11 and Figure 4.3. No statistically significant differences ($p > 0.05$) were observed for appearance, color, aroma, taste, texture, or overall acceptance, indicating that partial substitution of conventional TVP with sachu inchi press meal did not compromise sensory quality. TA patties attained an overall acceptance score of (7.14±1.40), comparable to chicken burgers (7.27±1.89) and slightly higher than COM (6.77±1.83), underscoring their strong sensory competitiveness relative to both animal- and plant-based references.

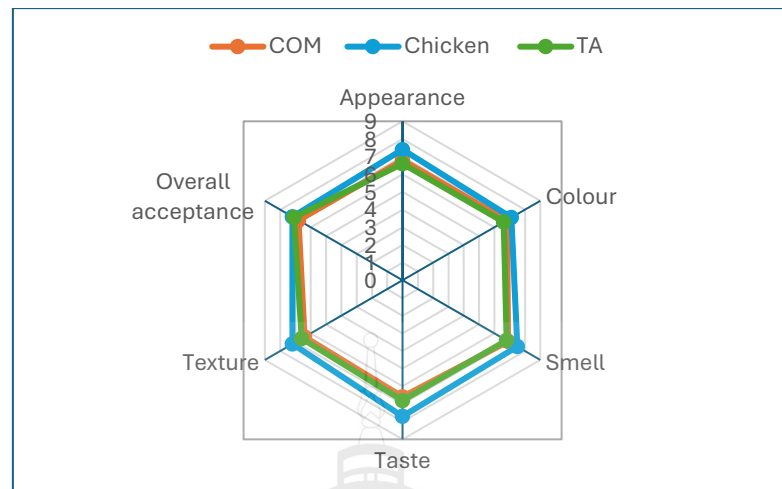
These findings are particularly noteworthy given the demographic profile of the panel. The majority of participants were omnivores (91.9%). This is relevant, as omnivorous consumers especially those with regular meat consumption are often reported to evaluate plant-based meat alternatives less favorably than meat products (Onwezen et al., 2021). The comparable acceptance of TA and chicken burgers therefore suggests that the sensory attributes of the TA formulation were sufficiently meat-like to overcome typical resistance among meat-eating consumers.

Despite instrumental differences in texture and juiciness, sensory texture scores did not differ significantly between TA (6.63 ± 1.73) and COM (6.36 ± 1.86) as seen in Table 4.12. Similarly, although compressed juiciness was lower in TA than COM, this did not translate into reduced sensory acceptance, indicating that enhanced fat retention and matrix compactness in TA may have contributed positively to perceived mouthfeel. Visual attributes followed a similar trend: although instrumental color differences were evident, sensory color and appearance scores for TA were within 3–4% of COM, confirming that the darker appearance imparted by sachá inchi press meal did not adversely affect consumer perception.

Table 4.11 Sensory evaluation of SP burger patties compared with commercial TVP and chicken burger patties

Sensory evaluation of TA, COM and chicken burger patties						
Sample	Appearance	Color	Aroma	Taste	Texture	Overall acceptance
COM	6.77 ± 2.05^a	6.77 ± 1.95^a	6.95 ± 1.80^a	6.59 ± 2.04^a	6.36 ± 1.86^a	6.77 ± 1.83^a
Chicken	7.41 ± 2.10^a	7.14 ± 2.15^a	7.45 ± 1.94^a	7.73 ± 2.05^a	7.23 ± 2.10^a	7.27 ± 1.89^a
TA	6.63 ± 1.88^a	6.59 ± 1.73^a	6.81 ± 1.53^a	6.77 ± 1.53^a	6.63 ± 1.73^a	7.14 ± 1.40^a

Note Sensory evaluation—Values are mean hedonic scores based on a 9-point scale (1 = dislike extremely, 9 = like extremely) obtained from N = 30 consumers. Sensory data for COM, TA, and chicken burger patties were analyzed using the Friedman test for related samples. Where applicable, Wilcoxon signed-rank tests with Bonferroni adjustment were applied for post hoc pairwise comparisons. No significant differences were observed among samples for appearance, color, aroma, texture, taste, or overall acceptance ($p > 0.05$). Offer mean); paired samples t test, $t(50) = -2.72$, $p = 0.009$, $d = 0.38$)



Note Radar plot showing mean sensory scores for appearance, color, smell, taste, texture, and overall acceptance of COM (Commercial TVP), TA (10% SPM TVP) and chicken, as evaluated by 30 untrained panelists using a 9-point hedonic scale (1 = dislike extremely; 9 = like extremely). Higher scores indicate greater consumer acceptability.

Figure 4.3 Sensory profile of COM, TA and chicken (n = 30)

Acceptability assessments corroborated these observations, as seen in Figure 4.4 Sacha inchi press meal-based (SP) burgers exhibited no significant differences in willingness-to-eat and willingness-to-share ratings relative to meat burgers ($p \geq 0.868$; Table 4.13). Critically, no correlation emerged between SP-burger acceptability and food neophilia scores (Pearson's $r = -0.07$, $p = 0.57$), imply that acceptance was not driven by novelty-seeking tendencies. This finding is significant, as food neophobia, diet-related anxiety, social norms, and unfamiliarity are frequently identified as major barriers to the adoption of meat alternatives (Dean et al., 2023; Onwezen et al., 2021). The absence of a neophilia effect suggests that the sensory quality of the TA patties was sufficient to appeal beyond the novelty-oriented consumer segments.

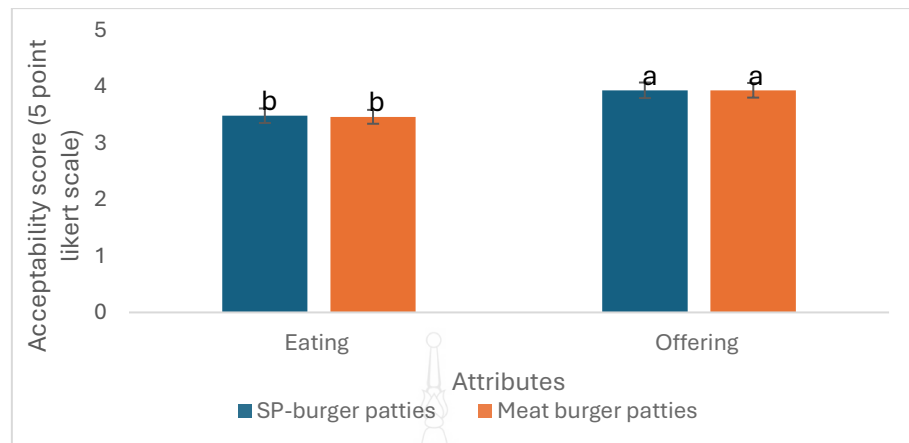
Table 4.12 Acceptability of SP-burger patties compared with meat burger patties and association with food neophilia

Acceptability measure (1–5 Likert)	SP-burger (Mean ± SD)	Meat burger (Mean ± SD)	SP vs. meat (Wilcoxon p)	Food neophilia r (SP burger)	P
Acceptability of eating	3.49 ± 0.93	3.47 ± 0.88	0.868	−0.07	0.57
Acceptability of offering to friends and family	3.94 ± 0.99	3.94 ± 0.93	1.000	−0.07	0.57

Note Acceptability and food neophilia—Acceptability ratings were collected using a 1–5 Likert scale (1 = strongly dislike, 5 = strongly like). Wilcoxon signed-rank tests (two-tailed) were used to compare acceptability between SP-burger and meat burger patties. Pearson correlation coefficients were used to assess the association between food neophilia and acceptability of SP-burger patties only. No statistically significant differences or associations were observed ($p > 0.05$).

These results contrast with numerous reports indicating that alternative proteins are generally evaluated less positively than conventional meat, particularly by high meat consumers (Onwezen et al., 2021). However, prior literature also indicates that younger, highly educated, and urban populations are more receptive to alternative proteins, especially when products closely resemble meat in sensory attributes (Onwezen et al., 2021; Xavier et al., 2025). It is worth noting that majority of participants were omnivores (91.9%), with 69.4% aged 18–25 years and 22.6% aged 26–35 years, reflecting a young adult population recruited in a university setting.

Overall, the data demonstrate that partial replacement of conventional TVP with sachu inchi press meal yields plant-based burgers that achieve sensory equivalence to meat burgers and broad acceptability among predominantly omnivorous, young adult consumers. These outcomes support the potential of sachu inchi press meal as a viable ingredient for scalable plant-based meat alternatives, capable of overcoming common psychological and sensory barriers to meat replacement when appropriately formulated.



Note Mean acceptability scores (5-point Likert scale) for SP and meat burger patties when eaten and when offered to others. Error bars represent standard errors of the mean. No significant differences were observed between products within each context (paired samples tests, $p > 0.05$). Superscript letters indicate a significant difference in overall acceptability between eating and offering contexts (Eating vs Offer mean); paired samples t test, $t(50) = -2.72$, $p = 0.009$, Cohen's $d = 0.38$)

Figure 4.4 Acceptability scores (5-point Likert scale) for SP and meat burger patties in eating and offering contexts

4.14 Consumer Perceptions, Expectations, and Acceptance of an Upcycled Sacha Inchi Press Cake Burger

The consumer perception survey ($N = 60$) elucidated nuanced attitudes toward the sachu inchi press cake-based burger (TA) relative to conventional meat burger, contextualizing sensory acceptance within broader consumer beliefs and expectations as seen in Figure 4.5. TA was more often associated with being healthy and modern, whereas COM was primarily linked to traditionality and naturalness. These patterns echo findings that conventional meat benefits from strong cultural anchoring and a “natural, traditional” image, while plant-based products are positioned as healthier and more innovative alternatives. At the same time, TA was perceived as artificial and expensive (artificial: 71% vs. 37.1% ; expensive: 71% vs. 45.2%), and COM as more affordable (74.2% vs. 41.9%), which is consistent with earlier work showing that plant-based meat alternatives are often penalized on perceived naturalness and price, despite

being seen as healthier and more sustainable (Kershaw et al., 2025). TA is positioned as both health and modern which is important because it can motivate trial, whereas doubts about naturalness and cost can constrain regular use, particularly among consumers with strong meat attachment or high food neophobia (Giacalone et al., 2022; Kershaw et al., 2025). Familiarity with sachu inchi was moderate, and nearly two-thirds of respondents had not previously consumed sachu inchi products, reflecting the nascent exposure typical of upcycled ingredients (Zaman et al., 2026). Expectations of the TA burger relative to a meat burger reflected a strong desire for sensory equivalence as seen in Table 4.13. For taste, a majority of respondents expected TA to taste the same as meat (50%), with fewer anticipating worse (17%) or better (33%) taste; similarly, (50%) expected the same texture, compared with (25%) each expecting worse or better texture. These results align with prior work showing that similarity to meat in taste and texture is a central condition for acceptance of meat alternatives, often more critical than abstract environmental or ethical benefits (Kershaw et al., 2025). Price expectations, however, skewed toward a premium positioning: 43.5% of the respondents expecting the TA burger to be more expensive than meat, compared with 21% anticipating a lower price and 35.5% expecting parity. This is consistent with the broader literature, where plant-based meat alternatives are frequently perceived as higher priced (Giacalone et al., 2022). Together with the higher ratings of “expensive” and “artificial,” these expectations indicate that the TA burger may be perceived as a specialized or premium product rather than a fully mainstream substitute, which may limit uptake among more price-sensitive consumers.

Environmental and sustainability considerations also influenced perceptions. A majority of respondents (58%) rated environmental sustainability as an important purchase criterion, and the “upcycled from sachu inchi press cake” label tended to enhance perceptions of environmental friendliness. This aligns with findings that perceived environmental and ethical benefits can positively influence attitudes toward alternative proteins, although such benefits alone may not fully drive adoption without accompanying sensory and nutritional appeal (Kershaw et al., 2025). Purchase intention data further supported these insights: product claims emphasizing nutritional value (high protein at 72.6%), quality assurance (58.1%), and organic status (43.5%) were identified as influential, indicating that consumers prioritize perceived health and

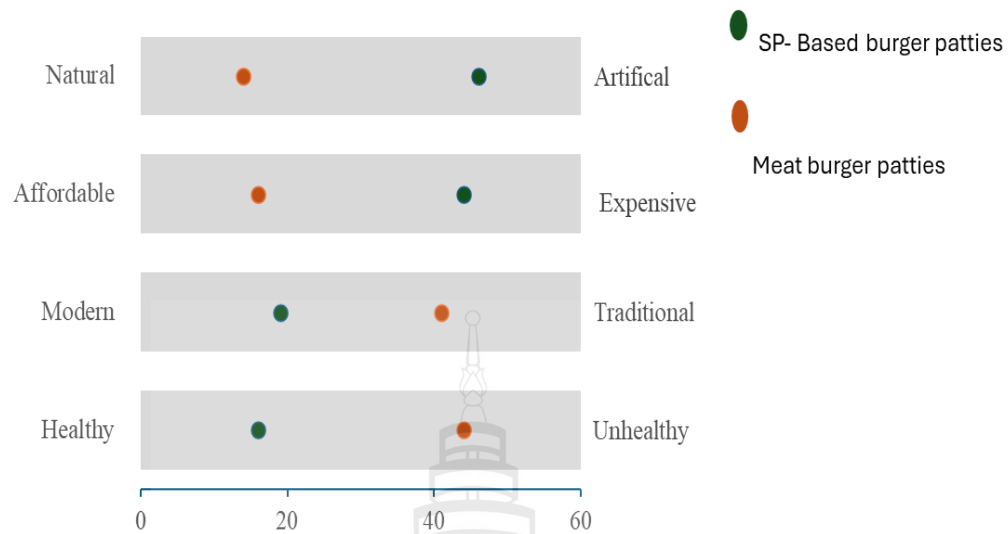
quality credentials when considering novel plant-based products. These priorities reflect broader patterns observed in acceptance research, where health and product credibility shape consumer willingness to incorporate alternative proteins into their diets (Amoneit et al., 2025).

Table 4.13 Consumer sensory and economic expectations toward the product (%)

Category	Parameter	Better (%)	Same (%)	Worse (%)
Sensory expectations	Taste	33.0	50.0	17.0
	Texture	25.0	50.0	25.0
Economic expectation	Price (Higher / Parity / Lower)*	43.5	35.5	21.0

Note For price perception, “Better”, “Same”, and “Worse” correspond to Lower, Parity, and Higher price expectations, respectively.

Overall, these findings suggest that consumer acceptance of SP-based burgers is multifaceted, influenced by nutritional claims, innovation, sustainability consideration, safety perception, and sensory expectations, countered by concerns related to naturalness, price, and familiarity. In line with the broader literature on plant-based meat alternatives, successful positioning of upcycled burgers should prioritize sensory equivalence to meat, transparently communicate safety and processing, and frame environmental benefits as added value. Such an approach may help shift the SP-based burger from a niche, premium product toward broader consumer adoption.



Note Points represent the number of consumers ($N = 60$) choosing each adjective for SP-based or meat burger patties on four semantic differential scales: Healthy vs Unhealthy, Modern vs Traditional, Affordable vs Expensive, and Natural vs Artificial. Higher values indicate that more respondents associated the corresponding adjective with that product.

Figure 4.5 Distribution of consumer selections for semantic differential attributes describing SP-based and meat burger patties

CHAPTER 5

CONCLUSION

This study demonstrates that incorporating 10% steam-pretreated Sacha inchi press meal into pea protein-based formulations yields texturized vegetable protein (TA) with techno-functional properties comparable to commercial soy-based benchmarks. While the inclusion of Sacha inchi and pea isolate elevates the raw material cost to approximately \$3.45/kg (dry basis), this premium is justified by the elimination of common allergens and the integration of “superfood” nutritional profiles. Steam treatment significantly reduced tannin and saponin contents, mitigating bitterness and astringency and thereby enhancing the ingredient’s suitability for meat analogue applications. When applied in burger formulations, the optimized 10% inclusion level (TA) showed higher protein content (45.43 ± 0.24) and fat retention (86.17 ± 0.31) while maintaining comparable cooking performance to the commercial TVP based burger. Notably, although instrumental differences in color and texture were observed, sensory evaluation demonstrated no significant differences ($p > 0.05$) in appearance, aroma, taste, texture, or overall acceptance among the SPM-based burger, commercial TVP burger, and minced chicken burger as seen in Table 16. These findings indicate that partial substitution with Sacha inchi press meal does not compromise sensory quality and can achieve consumer acceptance equivalent to both plant- and animal-based references. Furthermore, consumer perception analysis revealed positive associations with healthfulness, modernity, and environmental sustainability, while acceptance was independent of food neophilia, suggesting appeal beyond novelty-oriented segments. Collectively, the results confirm the technological feasibility, nutritional relevance, and sensory competitiveness of upcycled Sacha inchi press cake in plant-based burger systems. However, from a regulatory and nutritional classification perspective, the final formulation is categorized as NOVA Group 4 (Ultra-Processed). Consequently, the patty exemplifies the modern food science paradox: a nutritionally optimized, allergen-free, and sustainable alternative that remains structurally categorized as ultra-processed due to its complete deconstruction and subsequent synthesis. Nevertheless, further

refinement of structural anisotropy and texture through advanced extrusion strategies may enhance meat-like fidelity. Future research integrating techno-economic and life-cycle assessments will be essential to evaluate the scalability and sustainability trade-offs of SPM–pea protein systems and to support their transition from pilot-scale innovation to industrial application.



REFERENCES

- Ahmad, T., Esposito, F., & Cirillo, T. (2024). Valorization of agro-food by-products: Advancing sustainability and sustainable development goals 2030 through functional compounds recovery. *Food Bioscience*, 62, 105194. <https://doi.org/10.1016/j.fbio.2024.105194>
- Alejandro Ruiz, F. E., Ortega Jácome, J. F., Mora, J. R., Landázuri, A. C., Váscquez Duchicela, P., Váscquez Espinoza, J., . . . Alvarez-Suarez, J. M. (2025). Comprehensive characterization and valorization potential of Amazonian Sacha inchi (*Plukenetia volubilis* L.) seeds, oil, and oilcake by-products for sustainable food applications. *Frontiers in Nutrition*, 12. <https://doi.org/10.3389/fnut.2025.1597300>
- Alessandrini, R., Brown, M. K., Pombo-Rodrigues, S., Bhageerutty, S., He, F. J., & MacGregor, G. A. (2021). Nutritional quality of plant-based meat products available in the UK: A cross-sectional survey. *Nutrients*, 13(12), 4225. <https://doi.org/10.3390/nu13124225>
- Ali, A., & Bharali, P. (2025). The rise of plant-based meat alternatives: Challenges and perspectives. *Food Bioscience*, 68, 106640. <https://doi.org/10.1016/j.fbio.2025.106640>
- Amoneit, M., Gellrich, L., & Weckowska, D. M. (2025). Consumer acceptance of alternative proteins: Exploring determinants of the consumer willingness to buy in Germany. *Foods*, 14(14). <https://doi.org/10.3390/foods14142427>
- Anyiam, P. N., Phongthai, S., Sai-Ut, S., Kingwascharapong, P., Jung, Y. H., Zhang, W., . . . Rawdkuen, S. (2025). Nutritional components and digestibility profiles of some potential plant-based protein sources. *Foods*, 14(10), 1769. <https://doi.org/10.3390/foods14101769>
- Arora, S., Kataria, P., Nautiyal, M., Tuteja, I., Sharma, V., Ahmad, F., . . . Gupta, A. K. (2023). Comprehensive Review On The Role Of Plant Protein As A Possible Meat Analogue: Framing the Future Of Meat. *ACS Omega*, 8(26), 23305-23319. <https://doi.org/10.1021/acsomega.3c01373>

- Auppasuk, P., Chaisuwan, B., Ploypetchara, T., Butseekhot, S., & Sorndech, W. (2025). Influence of elevated protein content in textured vegetable protein on the textural characteristics and sensory attributes of plant-based meat alternatives. *Applied Food Research*, 5(2), 101192. <https://doi.org/10.1016/j.afres.2025.101192>
- Baig, M. A., Ajayi, F. F., Hamdi, M., Baba, W., Brishti, F. H., Khalid, N., . . . Maqsood, S. (2025). Recent research advances in meat analogues: A comprehensive review on production, protein sources, quality attributes, analytical techniques used, and consumer perception. *Food Reviews International*, 41(1), 236-267. <https://doi.org/10.1080/87559129.2024.2396855>
- Bąkowska, M., Pilarczyk, R., Kwita, E., Tomza-Marciniak, A., Udała, J., & Pilarczyk, B. (2026). Meat substitutes, or Plant-Based Meat Alternatives (PBMAs), as an opportunity for sustainable food production. *Sustainability*, 18(5), 2375. <https://doi.org/10.3390/su18052375>
- Bali, A., Zabulionė, A., Kumar, S. P., Liudvinavičiūtė, D., Pečiulytė, L., Rutkaitė, R., . . . Šalaševičienė, A. (2024). Effects of extrusion conditions on the morphological, functional, and sensory properties of soy press cake extrudates. *Heliyon*, 10(12), e32614. <https://doi.org/10.1016/j.heliyon.2024.e32614>
- Bhardwaj, A. K., Thakur, B., Tripathi, S. K., Turabayev, M. E., Aljulaih, A. A., Kharlamova, T. S., . . . Kulinich, S. A. (2025). Recent Advances In Valorizing Agricultural Waste: A sustainable approach. *Waste and Biomass Valorization*. <https://doi.org/10.1007/s12649-025-03419-5>
- Boukid, F. (2021). Plant-based meat analogues: From niche to mainstream. *European Food Research and Technology*, 247, 297-308. <https://doi.org/10.1007/s00217-020-03630-9>
- Brishti, F., Shyan Yea, C., Muhammad, K., Ismail-Fitry, M. R., Zarei, M., & Saari, N. (2021). Texturized mung bean protein as a sustainable food source: Effects of extrusion on its physical, textural and protein quality. *Innovative Food Science & Emerging Technologies*, 67, 102591. <https://doi.org/10.1016/j.ifset.2020.102591>

- Brodersen, L., Rimbach, G., Seidel, U., Rinne, P., Hasler, M., Bosy-Westphal, A., . . . Jans, K. (2025). A nutritional evaluation of plant-based meat and sausage analogues. *Foods*, 14(21), 3674. <https://doi.org/10.3390/foods14213674>
- Bryant, C., Szejda, K., Parekh, N., Desphande, V., & Tse, B. (2019). A survey of consumer perceptions of plant-based and clean meat in the USA, India, and China. *Frontiers in Sustainable Food Systems*, 3, 11. <https://doi.org/10.3389/fsufs.2019.00011>
- Bryngelsson, S., Moshtaghian, H., Bianchi, M., & Hallström, E. (2022). Nutritional assessment of plant-based meat analogues on the Swedish market. *International Journal of Food Sciences and Nutrition*, 73, 1-13. <https://doi.org/10.1080/09637486.2022.2078286>
- Cadena, R., Acosta, D., & Bravo Gómez, J. (2025). Effects of thermo-mechanical and chemical processes on the nutritional and functional quality of Sacha inchi (*Plukenetia volubilis*) flour. *Frontiers in Sustainable Food Systems*, 9. <https://doi.org/10.3389/fsufs.2025.1591362>
- Caputo, V., Sun, J., Staples, A., & Taylor, H. (2024). Market outlook for meat alternatives: Challenges, opportunities, and new developments. *Trends in Food Science & Technology*, 148, 104474. <https://doi.org/10.1016/j.tifs.2024.104474>
- Chan, E., Rodas-Gonzalez, A., Tulbek, M., & Koksel, F. (2023). Effects of protein formula and extrusion cooking conditions on the techno-functional properties of texturised pea proteins. *International Journal of Food Science and Technology*, 59(1), 584-595. <https://doi.org/10.1111/ijfs.16593>
- Chen, L., Lin, X., & Xia, Y. (2026). Plant-based meat alternatives: advancements in ingredients, processing, consumer perception, and future directions. *Journal of Future Foods*, 6(3), 374-388. <https://doi.org/10.1016/j.jfutfo.2025.04.005>
- Cheon, B., Tan, Y., & Forde, C. (2024). Food essentialism is associated with perceptions of plant-based meat alternatives possessing properties of meat-based products. *Food Quality and Preference*, 123. <https://doi.org/10.1016/j.foodqual.2024.105328>

- Cirkovic Velickovic, T., & Stanic-Vucinic, D. (2017). The role of dietary phenolic compounds in protein digestion and processing technologies to improve their antinutritive properties. *Comprehensive Reviews in Food Science and Food Safety*, 17. <https://doi.org/10.1111/1541-4337.12320>
- Cordero-Clavijo, M., Chuck-Hernandez, C., Espinosa-Ramírez, J., Lazo-Vélez, M., & Serna-Saldivar, S. (2024). Effect of multi factor-assisted extraction (pH, ultrasound, and temperature) of protein from Sacha inchi (*Plukenetia volubilis*) and its protein quality and functional characteristics. *Food and Bioproducts Processing*, 144. <https://doi.org/10.1016/j.fbp.2024.01.014>
- Daimary, N., Deb, B., Roy, B., Ranjan, R. K., & Mukherjee, A. (2025). Sustainable biorefinery approach for the transformation of biowaste into biofuels and chemicals for the circular economy: A review. *Sustainable Energy Technologies and Assessments*, 82, 104457. <https://doi.org/10.1016/j.seta.2025.104457>
- Dalangin, R., Kim, A., & Campbell, R. (2020). The role of amino acids in neurotransmission and fluorescent tools for their detection. *International Journal of Molecular Sciences*, 21, 6197. <https://doi.org/10.3390/ijms21176197>
- Dean, D., Rombach, M., Vriesekoop, F., de Koning, W., Aguiar, L., Anderson, M., . . . Alvarez, B. (2023). Should I really pay a premium for this? Consumer perspectives on cultured muscle, plant-based and fungal-based protein as meat alternatives. *Journal of International Food & Agribusiness Marketing*, 36, 1-25. <https://doi.org/10.1080/08974438.2023.2169428>
- Dekkers, B. L., Boom, R. M., & van der Goot, A. J. (2018). Structuring processes for meat analogues. *Trends in Food Science & Technology*, 81, 25-36. <https://doi.org/10.1016/j.tifs.2018.08.011>
- Del Carmen Fernández-Figares Jiménez, M., & López-Moreno, M. (2025). Ultra-processed plant foods: Are they worse than their unprocessed animal-based counterparts?. *Curr Nutr Rep*, 14(1), 115. <https://doi.org/10.1007/s13668-025-00704-6>

- Delgado, C. L. (2003). Rising consumption of meat and milk in developing countries has created a new food revolution. *The Journal of Nutrition*, 133(11), 3907S-3910S. <https://doi.org/10.1093/jn/133.11.3907S>
- Delwiche, J. (2004). The impact of perceptual interactions on perceived flavor. *Food Quality and Preference*, 15(2), 137-146. [https://doi.org/10.1016/S0950-3293\(03\)00041-7](https://doi.org/10.1016/S0950-3293(03)00041-7)
- Ebert, S., Michel, W., Nedele, A. K., Baune, M. C., Terjung, N., Zhang, Y., . . . Weiss, J. (2022). Influence of protein extraction and texturization on odor-active compounds of pea proteins. *J Sci Food Agric*, 102(3), 1021-1029. <https://doi.org/10.1002/jsfa.11437>
- Esbroeck, T., Sala, G., Stieger, M., & Scholten, E. (2023). Effect of structural characteristics on functional properties of textured vegetable proteins. *Food Hydrocolloids*, 149, 109529. <https://doi.org/10.1016/j.foodhyd.2023.109529>
- FAO. (2010). *Fats and fatty acids in human nutrition: Report of an expert consultation* (Vol. 91). Food and Agriculture Organization of the United Nations. https://www.fao.org/fileadmin/user_upload/nutrition/docs/requirements/fatsandfattacidsreport.pdf
- Fei, C., Li, L., Zhao, R., Wang, X., Fan, B., Liu, L., . . . Huang, Y. (2026). Texture and structure of high-moisture extrudates produced from soybean protein isolates with different 7S/11S globulin ratios. *Food Hydrocolloids*, 171, 111771. <https://doi.org/10.1016/j.foodhyd.2025.111771>
- Ferawati, F., Zahari, I., Barman, M., Hefni, M., Ahlström, C., Witthöft, C., . . . Östbring, K. (2021). High-moisture meat analogues produced from yellow pea and faba bean protein isolates/concentrate: Effect of raw material composition and extrusion parameters on texture properties. *Foods*, 10(4), 843. <https://doi.org/10.3390/foods10040843>
- Food & Agriculture Organization of the United. (2013). *Dietary protein quality evaluation in human nutrition: Report of an FAO expert consultation*. Food and Agriculture Organization of the United Nations. <https://www.fao.org/3/i3124e/i3124e.pdf>

- Forsberg, S., Olsson, V., Johansson, M., & Wendin, K. (2025). A question of choice: Trend-sensitive Swedish consumer attitudes toward plant-based meat analogues. *Gastronomy*, 3, 1-19. <https://doi.org/10.3390/gastronomy3030016>
- Future Market, I. (2022). *Meat substitutes market to reach USD 9.7 Bn by 2032 – Comprehensive research report by FMI*. <https://www.globenewswire.com/en/news-release/2022/02/09/2381664/0/en/Meat-Substitutes-Market-to-reach-USD-9-7-Bn-by-2032-Comprehensive-Research-Report-by-FMI.html>
- Giactalone, D., Clausen, M. P., & Jaeger, S. R. (2022). Understanding barriers to consumption of plant-based foods and beverages: Insights from sensory and consumer science. *Current Opinion in Food Science*, 48, 100919. <https://doi.org/10.1016/j.cofs.2022.100919>
- González-Díaz, R. L., Saldarriaga-Hernandez, S., Ramírez-Aguirre, M. D., Guerrero-Higareda, S., García-Cayuela, T., García-Amezquita, L. E., . . . Carrillo-Nieves, D. (2024). Valorization of brewer's spent grains through *Ganoderma lucidum* cultivation: Functional food ingredients and bread prototypes. *LWT*, 214, 117131. <https://doi.org/10.1016/j.lwt.2024.117131>
- Hagmann, D., Siegrist, M., & Hartmann, C. (2019). Meat avoidance: Motives, alternative proteins and diet quality in a sample of Swiss consumers. *Public Health Nutrition*, 22, 1-12. <https://doi.org/10.1017/S1368980019001277>
- Hanssen, H.-P., & Schmitz-Hübsch, M. (2011). Sacha inchi (*Plukenetia volubilis* L.) nut oil and its therapeutic and nutritional uses. In V. R. Preedy, R. R. Watson & V. B. Patel (Eds.), *Nuts and seeds in health and disease prevention* (pp. 991-994). <https://doi.org/10.1016/b978-0-12-375688-6.10117-3>
- Harnack, L., Mork, S., Valluri, S., Weber, C., Schmitz, K., Stevenson, J., . . . Pettit, J. (2021). Nutrient composition of a selection of plant-based ground beef alternative products available in the United States. *Journal of the Academy of Nutrition and Dietetics*, 121(12), 2401-2408. <https://doi.org/10.1016/j.jand.2021.05.002>
- Hartmann, C., & Siegrist, M. (2017). Consumer perception and behaviour regarding sustainable protein consumption: A systematic review. *Trends in Food Science & Technology*, 61, 11-25. <https://doi.org/10.1016/j.tifs.2016.12.006>

- Herreman, L., Nommensen, P., Pennings, B., & Laus, M. (2020). Comprehensive overview of the quality of plant- And animal-sourced proteins based on the digestible indispensable amino acid score. *Food Science & Nutrition*, 8(10), 5379-5391. <https://doi.org/10.1002/fsn3.1809>
- Hong, S., Shen, Y., & Li, Y. (2022). Physicochemical and functional properties of texturized vegetable proteins and cooked patty textures: Comprehensive characterization and correlation analysis. *Foods*, 11(17), 2619. <https://doi.org/10.3390/foods11172619>
- Horwitz, W. (2019). *AOAC guidelines for single laboratory validation of chemical methods for dietary supplements and botanicals*. https://s27415.pcdn.co/wp-content/uploads/2020/01/64ER20-7/Validation_Methods/d-AOAC_Guidelines_For_Single_Laboratory_Validation_Dietary_Supplements_and_Botanicals.pdf
- Ibáñez, M. A., de Blas, C., Cámara, L., & Mateos, G. G. (2020). Chemical composition, protein quality and nutritive value of commercial soybean meals produced from beans from different countries: A meta-analytical study. *Animal Feed Science and Technology*, 267. <https://doi.org/10.1016/j.anifeedsci.2020.114531>
- Imran, M., & Liyan, Z. (2023). Production of plant-based meat: Functionality, limitations and future prospects. *European Food Research and Technology*, 249, 1-25. <https://doi.org/10.1007/s00217-023-04287-w>
- ISO/CIE. (2019). Colorimetry—Part 4: CIE 1976 L*a*b* Colour Space. In *EN ISO/CIE 11664-4:2019*. ISO.
- Jagersberger, J. (2013). *Development of novel products on basis of Sacha Inchi – Use of press cakes and hulls* [Master's thesis]. University of Vienna.
- Kendler, C., Duchardt, A., Karbstein, H. P., & Emin, M. A. (2021). Effect of oil content and oil addition point on the extrusion processing of wheat gluten-based meat analogues. *Foods*, 10(4), 697. <https://doi.org/10.3390/foods10040697>

- Kershaw, J., Nolden, A., Ellinger, L., & Dlamini, N. N. (2025). Consumers' perceptions of plant-based alternatives relative to the foods they directly imitate. *Food Quality and Preference*, 129, 105519.
<https://doi.org/10.1016/j.foodqual.2025.105519>
- Ketelings, L., Benerink, E., Havermans, R., Kremers, S., & de Boer, A. (2023). Fake meat or meat with benefits? How Dutch consumers perceive health and nutritional value of plant-based meat alternatives. *Appetite*, 188, 106616.
<https://doi.org/10.1016/j.appet.2023.106616>
- Ketnawa, S., & Rawdkuen, S. (2023). Properties of texturized vegetable proteins from edible mushrooms by using single-screw extruder. *Foods*, 12(6).
<https://doi.org/10.3390/foods12061269>
- Kittibunchakul, S., Hudthagosol, C., Sanporkha, P., Sapwarobol, S., Temviriyankul, P., & Suttisansanee, U. (2022). Evaluation of sachu inchi (*Plukenetia volubilis* L.) by-products as valuable and sustainable sources of health benefits. *Horticulturae*, 8(4), 344. <https://doi.org/10.3390/horticulturae8040344>
- Kodahl, N. (2020). Sachu 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>
- Kołodziejczak, K., Onopiuk, A., Szpicer, A., & Poltorak, A. (2022). Meat analogues in the perspective of recent scientific research: A review. *Foods*, 11(1), 105.
<https://doi.org/10.3390/foods11010105>
- Kołodziejczak, K., Onopiuk, A., Szpicer, A., & Półtorak, A. (2021). Meat analogues in the perspective of recent scientific research: A review. *Foods*, 11, 105.
<https://doi.org/10.3390/foods11010105>
- Kong, S., Keang, T., Bunthan, M., Say, M., Nat, Y., Tan, C., . . . Tan, R. (2023a). Hydraulic cold-pressed extraction of sachu inchi seeds: Oil yield and its physicochemical properties. *ChemEngineering*, 7, 69.
<https://doi.org/10.3390/chemengineering7040069>
- Kong, S., Keang, T., Bunthan, M., Say, M., Nat, Y., Tan, C. P., . . . Tan, R. (2023b). Hydraulic cold-pressed extraction of sachu inchi seeds: Oil yield and its physicochemical properties. *ChemEngineering*, 7(4).
<https://doi.org/10.3390/chemengineering7040069>

- Kyriakopoulou, K., Dekkers, B., & van der Goot, A. J. (2019). Plant-based meat analogues. In C. M. Galanakis (Ed.), *Sustainable meat production and processing* (pp. 103-126). Academic Press. <https://doi.org/10.1016/B978-0-12-814874-7.00006-7>
- Lallinger, L., & Rauh, C. (2024). Textured vegetable protein from flaxseed press cake and pea – syntonizing chemical and structural properties. *Future Foods*, 10, 100489. <https://doi.org/10.1016/j.fufo.2024.100489>
- Landines Vera, E., Villacres, E., Coello Ojeda, K., Guadalupe Moyano, V., Quezada Tobar, M., Quelal, M. B., . . . Ruales, J. (2024). Evaluation of antinutrients, nutritional, and functional properties in sachu inchi (*Plukenetia volubilis* L) cake treated with hydrothermal processes. *Heliyon*, 10(17), e37291. <https://doi.org/10.1016/j.heliyon.2024.e37291>
- Lee, S., Jung, S. Y., Seo, M. S., & Park, C. S. (2024). Effects of storage temperature on quality characteristics of texturized vegetable protein. *Food Science and Preservation*, 31(1), 46-63. <https://doi.org/10.11002/fsp.2024.31.1.46>
- Leinonen, I., Iannetta, P., Rees, B., Russell, W., Watson, C., & Barnes, A. (2019). Lysine supply is a critical factor in achieving sustainable global protein economy. *Frontiers in Sustainable Food Systems*, 3, 27. <https://doi.org/10.3389/fsufs.2019.00027>
- Li, J., & Li, L. (2023). Effect of extrusion temperature on the structure and emulsifying properties of soy protein isolate-oat β -glucan conjugates formed during high moisture extrusion. *Food Chemistry*, 429, 136787. <https://doi.org/10.1016/j.foodchem.2023.136787>
- Li, X., & Li, J. (2020). The Flavor of Plant-Based Meat Analogues.
- Luisse, L., Gomez, A., Maria, A., Jonas, N., & Rauh, C. (2025). Valorizing press cakes as ingredients in textured vegetable proteins: Processing, structure, and texture. *Journal of Food Science*, 90(8), e70471. <https://doi.org/10.1111/1750-3841.70471>
- Maningat, C., Jeradechachai, T., & Buttshaw, M. (2021). Textured wheat and pea proteins for meat alternative applications. *Cereal Chemistry*, 99, 37-66. <https://doi.org/10.1002/cche.10503>

- Marsh, J., Koppelman, S., Kabourek, J., Johnson, P., & Baumert, J. (2021). A perspective on pea allergy and pea allergens. *Trends in Food Science & Technology*, 116, 186-198. <https://doi.org/10.1016/j.tifs.2021.07.017>
- Martinez, M., Lezcano, P., Lucio, Y., & Luis, A.-C. (2020). Technical note on physical-chemical composition of Sacha inchi (*Plukenetia volubilis*) cake Nota técnica sobre la composición físico-química de la torta de Sacha inchi (*Plukenetia volubilis*). *Cuban Journal of Agricultural Science*, 54. <https://cjasience.com/index.php/CJAS/article/view/934/1053>
- Mathai, J. K., Liu, Y., & Stein, H. H. (2017). Values for digestible indispensable amino acid scores (DIAAS) for some dairy and plant proteins may better describe protein quality than values calculated using the concept for protein digestibility-corrected amino acid scores (PDCAAS). *Br J Nutr*, 117(4), 490-499. <https://doi.org/10.1017/s0007114517000125>
- Mazumder, M. A., Panpipat, W., Chaijan, M., Shetty, K., & Rawdkuen, S. (2023). Role of plant protein on the quality and structure of meat analogs: A new perspective for vegetarian foods. *Future Foods*, 8, 100280. <https://doi.org/10.1016/j.fufo.2023.100280>
- Mazumder, M. A. R., Sangsomboon, M., Ketnawa, S., & Rawdkuen, S. (2024). Mushroom-based Northern Thai style sausages: Physico-chemical, nutritional profile and in vitro digestibility. *Journal of Agriculture and Food Research*, 16, 101103. <https://doi.org/10.1016/j.jafr.2024.101103>
- Meng, Y., Xie, L., You, K., & Chen, W. (2025). Improving the aromatic profile of plant-based meat alternatives: Effects of leghemoglobin and myoglobin addition on volatiles. *Food Chemistry*, 492, 145299. <https://doi.org/10.1016/j.foodchem.2025.145299>
- Messina, M., & Messina, V. (2025). Nova fails to appreciate the value of plant-based meat and dairy alternatives in the diet. *Journal of Food Science*, 90(2), e70039. <https://doi.org/10.1111/1750-3841.70039>
- Michel, F., Hartmann, C., & Siegrist, M. (2021). Consumers' associations, perceptions and acceptance of meat and plant-based meat alternatives. *Food Quality and Preference*, 87, 104063. <https://doi.org/10.1016/j.foodqual.2020.104063>

- Milani, T., Menis-Henrique, M., Jordano, A., Boscolo, M., & Conti-Silva, A. (2014). Pre-extrusion aromatization of a soy protein isolate using volatile compounds and flavor enhancers: Effects on physical characteristics, volatile retention and sensory characteristics of extrudates. *Food Research International*, 62, 375–381. <https://doi.org/10.1016/j.foodres.2014.03.018>
- Miller, O., Scarlett, C., Adhikari, B., & Akanbi, T. (2024). Are plant-based meat analogues fulfilling their potentials? An Australian perspective. *Future Foods*, 9, 100305. <https://doi.org/10.1016/j.fufo.2024.100305>
- Mondor, M., & Hernandez Alvarez, A. J. (2022). Processing technologies to produce plant protein concentrates and isolates. In A. Manickavasagan, L.-T. Lim & A. Ali (Eds.), *Plant protein foods* (pp. 61-108). Springer Nature. https://doi.org/10.1007/978-3-030-91206-2_3
- Náthia-Neves, G., & Alonso, E. (2021). Valorization of sunflower by-product using microwave-assisted extraction to obtain a rich protein flour: Recovery of chlorogenic acid, phenolic content and antioxidant capacity. *Food and Bioproducts Processing*, 125, 57-67. <https://doi.org/10.1016/j.fbp.2020.10.008>
- National Consumers League. (2022). *Plant-based meat alternatives: A consumer-focused agenda to improve understanding and decision-making of plant-based meat products*. N. C. League.
- Nguyen, M., Truong, T., Bui, T., Nguyen, D., Nguyen, T., & Tien, T. (2022). The influence of some technological parameters in the processing of protein-rich powder from Sacha inchi oil pressed-cake. *Ministry of Science and Technology, Vietnam*, 64, 63-67. [https://doi.org/10.31276/VJST.64\(10DB\).63-67](https://doi.org/10.31276/VJST.64(10DB).63-67)
- Njoroge, J. W., Phonphimai, P., Khatmorn, P., Ketnawa, S., Tonkla, P., Vong, V., . . . Donlao, N. (2025). Valorization of Sacha Inchi press cake: Technological advances, market, and regulatory considerations for sustainable food applications. *Food Chemistry Advances*, 9, 101151. <https://doi.org/10.1016/j.focha.2025.101151>

- Norhazlindah, M. F., Jahurul, M. H. A., Norliza, M., Shihabul, A., Islam, S., Nyam, K. L., . . . Zaidul, I. S. M. (2022). Techniques for extraction, characterization, and application of oil from sacha inchi (*Plukenetia volubilis* L.) seed: A review. *Journal of Food Measurement and Characterization*, 17(1), 904-915. <https://doi.org/10.1007/s11694-022-01663-0>
- Official Methods of Analysis of AOAC International*. (2023). Oxford University Press. <https://doi.org/10.1093/9780197610145.001.0001>
- Onwezen, M. C., Bouwman, E. P., Reinders, M. J., & Dagevos, H. (2021). A systematic review on consumer acceptance of alternative proteins: Pulses, algae, insects, plant-based meat alternatives, and cultured meat. *Appetite*, 159, 105058. <https://doi.org/10.1016/j.appet.2020.105058>
- Osen, R., & Schweiggert-Weisz, U. (2016). High-moisture extrusion: Meat analogues. *Reference Module in Food Science*, 1-7. <https://doi.org/10.1016/B978-0-08-100596-5.03099-7>
- Osen, R., Toelstede, S., Wild, F., Eisner, P., & Schweiggert-Weisz, U. (2014). High moisture extrusion cooking of pea protein isolates: Raw material characteristics, extruder responses, and texture properties. *Journal of Food Engineering*, 127, 67-74. <https://doi.org/10.1016/j.jfoodeng.2013.11.023>
- Pandey, A. K., Thakur, S., Mehra, R., Kaler, R. S. S., Paul, M., & Kumar, A. (2025). Transforming Agri-food waste: Innovative pathways toward a zero-waste circular economy. *Food Chemistry: X*, 28, 102604. <https://doi.org/10.1016/j.fochx.2025.102604>
- Plattner, B., Hong, S., Li, Y., Talavera, M., Dogan, H., Plattner, B., . . . Alavi, S. (2024). Use of pea proteins in high-moisture meat analogs: Physicochemical properties of raw formulations and their texturization using extrusion. *Foods*, 13, 1195. <https://doi.org/10.3390/foods13081195>
- Plötz, T., Krümmel, B., Laporte, A., Pingitore, A., Persaud, S. J., Jörns, A., . . . Lenzen, S. (2017). The monounsaturated fatty acid oleate is the major physiological toxic free fatty acid for human beta cells. *Nutr Diabetes*, 7(12), 305. <https://doi.org/10.1038/s41387-017-0005-x>

- Pomasa, P., Sai-Ut, S., Sinthusamran, S., & Techavuthiporn, C. (2025). Valorization of banana peel by-product: An innovative component for gluten-free cookies rendered with corn flour. *Journal of Agriculture and Food Research*, 19, 101744. <https://doi.org/10.1016/j.jafr.2025.101744>
- Prasert, W., Pantoa, T., Chitisankul, W., & Pengpinij, W. (2022). Effects of sacha inchi (*Plukenetia volubilis* L.) oil and extrusion process conditions on physicochemical properties of fortified omega-3 fibrous high moisture meat analogs. *Journal of Food Processing and Preservation*, 46(12), e17227. <https://doi.org/10.1111/jfpp.17227>
- Ramos-Diaz, J. M., Kantanen, K., Edelmann, J. M., Suhonen, H., Sontag-Strohm, T., Jouppila, K., . . . Piironen, V. (2022). Fibrous meat analogues containing oat fiber concentrate and pea protein isolate: Mechanical and physicochemical characterization. *Innovative Food Science & Emerging Technologies*, 77, 102954. <https://doi.org/10.1016/j.ifset.2022.102954>
- Ramos-Escudero, F., Morales, M. T., Ramos Escudero, M., Muñoz, A. M., Cancino Chavez, K., & Asuero, A. G. (2021). Assessment of phenolic and volatile compounds of commercial Sacha inchi oils and sensory evaluation. *Food Research International*, 140, 110022. <https://doi.org/10.1016/j.foodres.2020.110022>
- Rathnayake, D., Nadolny, J. M., Sultanbawa, Y., & Smyth, H. E. (2025). Then, now, and next: A systematic review of colour development in plant-based meat analogues through natural colourants. *Journal of Future Foods*. <https://doi.org/10.1016/j.jfutfo.2025.08.017>
- Rawdkuen, S., D'Amico, S., & Schoenlechner, R. (2022). Physicochemical, functional, and in vitro digestibility of protein isolates from Thai and Peru Sacha Inchi (*Plukenetia volubilis* L.) oil press-cakes. *Foods*, 11(13). <https://doi.org/10.3390/foods11131869>
- Rawdkuen, S., Murdayanti, D., Ketnawa, S., & Phongthai, S. (2016). Chemical properties and nutritional factors of pressed-cake from tea and Sacha inchi seeds. *Food Bioscience*, 15, 64-71. <https://doi.org/10.1016/j.fbio.2016.05.004>

- Rawdkuen, S., Rodzi, N., & Pinijsuwan, S. (2018). Characterization of sacha inchi protein hydrolysates produced by crude papain and Calotropis proteases. *LWT – Food Science and Technology*, 98, 18-24.
<https://doi.org/10.1016/j.lwt.2018.08.008>
- Rees Clayton, E. M., Specht, E. A., Welch, D. R., & Berke, A. P. (2019). Addressing global protein demand through diversification and innovation: An introduction to plant-based and clean meat. In L. Melton, F. Shahidi & P. Varelis (Eds.), *Encyclopedia of food chemistry* (pp. 209-217). Academic Press.
<https://doi.org/10.1016/B978-0-08-100596-5.21704-6>
- Ruiz, C., Díaz, C., Anaya, J., & Rojas, R. (2013). Análisis proximal, antinutrientes, perfil de ácidos grasos y de aminoácidos de semillas y tortas de 2 especies de Sacha inchi (*Plukenetia volubilis* y *Plukenetia huayllabambana*). *Revista de la Sociedad Química del Perú*, 79, 29-36.
- Rungrot, K., Hudthagosol, C., & Sanporkha, P. (2021). Effect of Sacha Inchi pressed-cake (*Plukenetia volubilis* L.) on the physical, chemical and sensory properties of tuiles. *Chiang Mai University Journal of Natural Sciences*, 20(2).
<https://doi.org/10.12982/cmujns.2021.044>
- Saerens, W., Smetana, S., Campenhout, L., Lammers, V., & Heinz, V. (2021). Life cycle assessment of burger patties produced with extruded meat substitutes. *Journal of Cleaner Production*, 306, 127177.
<https://doi.org/10.1016/j.jclepro.2021.127177>
- Sakai, K., Okada, M., & Yamaguchi, S. (2023). Protein-glutaminase improves water-/oil-holding capacity and beany off-flavor profiles of plant-based meat analogs. *PLoS One*, 18(12), e0294637.
<https://doi.org/10.1371/journal.pone.0294637>
- Saldanha do Carmo, C., Costa, L., Serra, A. T., Knutsen, S. H., Sahlstrøm, S., & Bronze, M. R. (2021). Alternative protein sources. In C. M. Galanakis (Ed.), *Food technology disruptions* (pp. 131-174). Academic Press.
<https://doi.org/10.1016/B978-0-12-821470-1.00010-0>
- Salim, R., Nehvi, I., Mir, D., Tyagi, A., Ali, S., & Bhat, O. (2023). A review on anti-nutritional factors: Unraveling the natural gateways to human health. *Frontiers in Nutrition*, 10, 110-119. <https://doi.org/10.3389/fnut.2023.1215873>

- Samard, S., Maung, T.-T., Gu, B.-Y., Kim, M.-H., & Ryu, G.-H. (2021). Influences of extrusion parameters on physicochemical properties of textured vegetable proteins and its meatless burger patty. *Food Science and Biotechnology*, 30, 395-403. <https://doi.org/10.1007/s10068-021-00879-y>
- Samrit, T., Osotprasit, S., Chaiwichien, A., Suksomboon, P., Chansap, S., Athipornchai, A., . . . Kueakhai, P. (2024). Cold-pressed sachu inchi oil: High in omega-3 and prevents fat accumulation in the liver. *Pharmaceuticals (Basel)*, 17(2), 220. <https://doi.org/10.3390/ph17020220>
- Saranghi, P., Pal, P., Singh, A., Sahoo, U., & Prus, P. (2024). Food waste to food security: Transition from bioresources to sustainability. *Resources*, 13(12), 164. <https://doi.org/10.3390/resources13120164>
- Schmid, E.-M., Farahnaky, A., Adhikari, B., & Torley, P. (2022). High moisture extrusion cooking of meat analogs: A review of mechanisms of protein texturization. *Comprehensive Reviews in Food Science and Food Safety*, 21(6), 4573-4609. <https://doi.org/10.1111/1541-4337.13030>
- Sendhil, R., C R, B., Yadav, S., G, G., Ragupathy, R., A, P., & Ramasundaram, P. (2024). Consumer perception and preference toward plant-based meat alternatives – Bibliometric trends and policy implications. *Food and Humanity*, 2, 100229. <https://doi.org/10.1016/j.foohum.2024.100229>
- Sharma, V., Tsai, M.-L., Sun, P.-P., Chen, C.-W., Nargotra, P., & Dong, C.-D. (2023). Sequential ultrasound assisted deep eutectic solvent-based protein extraction from Sachu inchi meal biomass: towards circular bioeconomy. *Journal of Food Science and Technology*, 60, 1-10. <https://doi.org/10.1007/s13197-023-05689-0>
- Sierra, D., Rave, L., & Soto, J. (2021). Biological activity of Sachu Inchi (*Plukenetia volubilis* Linneo) and potential uses in human health: A review. *Food Technology and Biotechnology*, 59. <https://doi.org/10.17113/ftb.59.03.21.6683>
- Singh, R., Langyan, S., Sangwan, S., Rohtagi, B., Khandelwal, A., & Shrivastava, M. (2022). Protein for human consumption from oilseed cakes: A review. *Frontiers in Sustainable Food Systems*, 6. <https://doi.org/10.3389/fsufs.2022.856401>

- Singh, R., Sa, A. G. A., Sharma, S., Nadimi, M., Paliwal, J., House, J. D., . . . Koksel, F. (2024). Effects of feed moisture content on the physical and nutritional quality attributes of sunflower meal-based high-moisture meat analogues. *Food Bioproc Tech*, 17(7), 1897-1913.
<https://doi.org/10.1007/s11947-023-03225-8>
- Soares, S., Brandão, E., Guerreiro, C., Soares, S., Mateus, N., & de Freitas, V. (2020). Tannins in food: Insights into the molecular perception of astringency and bitter taste. *Molecules*, 25(11), 2590.
<https://doi.org/10.3390/molecules25112590>
- Sun, C., Ge, J., He, J., Gan, R., & Fang, Y. (2021). Processing, quality, safety, and acceptance of meat analogue products. *Engineering*, 7(5), 674-678.
<https://doi.org/10.1016/j.eng.2020.10.011>
- Szejda, K., Stumpe, M., Raal, L., & Tapscott, C. (2021). South African consumer adoption of plant-based and cultivated meat: A segmentation study. *Frontiers in Sustainable Food Systems*, 5, 744199.
<https://doi.org/10.3389/fsufs.2021.744199>
- Szenderák, J., Fróna, D., & Rákos, M. (2022). Consumer acceptance of plant-based meat substitutes: A narrative review. *Foods*, 11, 1274.
<https://doi.org/10.3390/foods11091274>
- Tabarestani, H. S., Mahoonak, A. S., & Ghorbani, M. (2024). Formulating low-fat beef burger with fenugreek seed gum: Impact on texture, chemistry, and sensory characteristics. *Food and Humanity*, 2, 100260.
<https://doi.org/10.1016/j.foohum.2024.100260>
- Tompa, O., Kiss, A., Soós, S., Lakner, Z., Raner, A., Kasza, G., . . . Szakos, D. (2025). Fifteen years of NOVA food-processing classification: “Friend or Foe” among sustainable diet indicators? A scoping review. *Nutrition Reviews*, 83(4), 771-791. <https://doi.org/10.1093/nutrit/nuae207>
- Tonheim, L. E., Austad, E., Torheim, L. E., & Henjum, S. (2022). Plant-based meat and dairy substitutes on the Norwegian market: Comparing macronutrient content in substitutes with equivalent meat and dairy products. *Journal of Nutritional Science*, 11, e9. <https://doi.org/10.1017/jns.2022.6>

- Torres-Sanchez, E., Hernandez-Ledesma, B., & Gutierrez, L. F. (2023). Isolation and characterization of protein fractions for valorization of sachu inchi oil press-cake. *Foods*, 12(12), 2401. <https://doi.org/10.3390/foods12122401>
- Torres Sánchez, E. G., Hernández-Ledesma, B., & Gutiérrez, L.-F. (2021). Sachu inchi oil press-cake: Physicochemical characteristics, food-related applications and biological activity. *Food Reviews International*, 39(1), 148-159. <https://doi.org/10.1080/87559129.2021.1900231>
- Trevino, S. R., Scholtz, J. M., & Pace, C. N. (2007). Amino acid contribution to protein solubility: Asp, Glu, and Ser contribute more favorably than the other hydrophilic amino acids in RNase Sa. *J Mol Biol*, 366(2), 449-460. <https://doi.org/10.1016/j.jmb.2006.10.026>
- Tuccillo, F., Kantanen, K., Wang, Y., Martin Ramos Diaz, J., Pulkkinen, M., Edelmann, M., . . . Katina, K. (2022). The flavor of faba bean ingredients and extrudates: Chemical and sensory properties. *Food Res Int*, 162(Pt A), 112036. <https://doi.org/10.1016/j.foodres.2022.112036>
- United Nations, D. O. E. A. S. A., Population Division. (2024). *World population prospects 2024: Summary of results*. U. Nations. <https://www.unpopulation.org>
- van Esbroeck, T., Sala, G., Stieger, M., & Scholten, E. (2024). Effect of structural characteristics on functional properties of textured vegetable proteins. *Food Hydrocolloids*, 149, 109529. <https://doi.org/10.1016/j.foodhyd.2023.109529>
- van Vliet, S., Bain, J., Muehlbauer, M., Provenza, F., Kronberg, S., Pieper, C., . . . Huffman, K. (2021). A metabolomics comparison of plant-based meat and grass-fed meat indicates large nutritional differences despite comparable Nutrition Facts panels. *Scientific Reports*, 11, 13828. <https://doi.org/10.1038/s41598-021-93100-3>
- Vanegas-Azuero, A.-M., & Gutiérrez, L.-F. (2018). Physicochemical and sensory properties of yogurts containing sachu inchi (*Plukenetia volubilis* L.) seeds and β -glucans from *Ganoderma lucidum*. *Journal of Dairy Science*, 101(2), 1020-1033. <https://doi.org/10.3168/jds.2017-13235>

- Vera, E., Villacrés, E., Ojeda, K., Guadalupe-Moyano, V., Tobar, M., Quelal, M., . . . Ruales, J. (2024). Evaluation of antinutrients, nutritional, and functional properties in sacha inchi (*Plukenetia volubilis* L.) cake treated with hydrothermal processes. *Heliyon*, *10*, e37291. <https://doi.org/10.1016/j.heliyon.2024.e37291>
- Verheyen, C., Jorkowski, J., & Martin, A. (2022). *Extrusion: Traditional structuring and texturizing processes for the food production of the future*. <https://www.dlg.org/en/mediacenter/alle-publikationen/dlg-expertenwissen/lebensmitteltechnologie/dlg-expert-report-02-2022-extrusion>
- Verified Market Research. (2024). *Sacha inchi oil market size, share, trends, growth, & forecast*. <https://www.verifiedmarketresearch.com/product/sacha-inchi-oil-market/>
- Vila-Clarà, G., Vila-Martí, A., Vergés-Canet, L., & Torres-Moreno, M. (2024). Exploring the role and functionality of ingredients in plant-based meat analogue burgers: A comprehensive review. *Foods*, *13*(8). <https://doi.org/10.3390/foods13081258>
- Wang, S., Zhu, F., & Kakuda, Y. (2018). Sacha inchi (*Plukenetia volubilis* L.): Nutritional composition, biological activity, and uses. *Food Chemistry*, *265*, 316-328. <https://doi.org/10.1016/j.foodchem.2018.05.055>
- Wang, Z., Tian, Y., Lou, F., & Guo, Z. (2024). Effect of pea protein isolate–soybean meal ratio on fiber structure and texture properties of high-moisture meat analogs. *Foods*, *13*, 3818. <https://doi.org/10.3390/foods13233818>
- WHO. (2007). *Protein and amino acid requirements in human nutrition*. World Health Organization.
- Wichchukit, S., & O'Mahony, M. (2014). The 9-point hedonic scale and hedonic ranking in Food Science: some reappraisals and alternatives. *Journal of the Science of Food and Agriculture*, *95*(11), 2167-2178. <https://doi.org/10.1002/jsfa.6993>
- Xavier, J. R., Shashikumar, S. H., Vats, D., & Chauhan, O. P. (2025). Future trends in plant-based meat: Consumer perception, market growth and health benefits. *Future Foods*, *11*, 100551. <https://doi.org/10.1016/j.fufo.2025.100551>

- Xue, C., Rudge, R. E. D., Ngo, J., Hassall, E., Hoffman, L. C., Stokes, J. R., . . . Smyth, H. E. (2025). Oil distribution and stability modulate textured vegetable protein hydration and juiciness perception in plant-based meat analogues. *Food Structure*, 46, 100491. <https://doi.org/10.1016/j.foostr.2025.100491>
- Ye, J., Hu, X., Luo, S., Liu, W., Chen, J., Zeng, Z., . . . Liu, C. (2017). Properties of starch after extrusion: A review. *Starch - Stärke*, 70, 1700110. <https://doi.org/10.1002/star.201700110>
- Yeghiayan, S. K., Luo, S., Shukitt-Hale, B., & Lieberman, H. R. (2001). Tyrosine improves behavioral and neurochemical deficits caused by cold exposure. *Physiology & Behavior*, 72(3), 311-316. [https://doi.org/10.1016/S0031-9384\(00\)00398-X](https://doi.org/10.1016/S0031-9384(00)00398-X)
- Yi, H. C., Cho, H., Hong, J. J., Ryu, R. K., Hwang, K. T., & Regenstein, J. M. (2012). Physicochemical and organoleptic characteristics of seasoned beef patties with added glutinous rice flour. *Meat Science*, 92(4), 464-468. <https://doi.org/10.1016/j.meatsci.2012.05.012>
- Zaman, Q. U., Rossetto, L., & Cei, L. (2026). Upcycled foods: What influences consumer responses to a circular economy-based consumption strategy? insights from a systematic literature review. *Foods*, 15(2), 364. <https://doi.org/10.3390/foods15020364>
- Zhao, D., Huang, L., Li, H., Ren, Y., Cao, J., Zhang, T., . . . Liu, X. (2022a). Ingredients and process affect the structural quality of recombinant plant-based meat alternatives and their components. *Foods*, 11(15), 2202. <https://doi.org/10.3390/foods11152202>
- Zhao, D., Huang, L., Li, H., Ren, Y., Cao, J., Zhang, T., . . . Liu, X. (2022b). Ingredients and process affect the structural quality of recombinant plant-based meat alternatives and their components. *Foods*, 11, 2202. <https://doi.org/10.3390/foods11152202>

APPENDIX

SENSORY ACCEPTABILITY AND CONSUMER PERCEPTION EVALUATION FORM

Section 1: Sensory Acceptability Evaluation

1.1 Panelist Information

Panelist ID:

Age: _____

Gender: ☐ Male ☐ Female ☐ Other

Any dietary restrictions or allergies? ☐ Yes ☐ No

If yes, please specify:

1.2 Sensory Evaluation Procedure

- You will participate in three sessions, evaluating multiple replications of each sample.
- Each sample will be presented on a white plate in an individual booth.
- Mineral water will be provided for palate cleansing between samples.
- Please refrain from consuming strong-flavored foods or beverages at least one hour before the session.

1.3 Sensory Attributes Rating (9-Point Hedonic Scale)

Please rate each attribute using the scale below:

1 = Dislike extremely | 9 = Like extremely

Sample Code	Appearance	Aroma	Chewiness	Juiciness	Taste	Overall Acceptability

Section 2: Consumer Perception Survey

2.1 Participant Information

Participant ID: _____

Age: _____

Gender: ☐ Male ☐ Female ☐ Other

Current diet:

☐ Omnivore ☐ Flexitarian ☐ Pescatarian ☐ Vegetarian ☐ Vegan

2.2 Meat Consumption Frequency

Product Category	Several times per day	Daily	4–6 times per week	1–3 times per week	1–3 times per month	Seldom/Never
Cold cuts						
Sausages						
Pork						
Beef						
Poultry						
Lamb						
Tofu						
Lentils						
Plant-based meat alternatives						

2.3 Consumer Attitudes and Perceptions

2.3.1 Product Association

- You will be assigned to one of two groups:
 - Group 1: Associations with meat
 - Group 2: Associations with SP-based burger patties
- Please describe your first thoughts when you hear about: _____

2.3.2 Perceived Attributes of Meat vs. SP-based burger patties

Attribute	Meat	SP-based burger patties
Healthy – Unhealthy		
Modern – Traditional		
Affordable – Expensive		
Natural – Artificial		

2.3.3 Acceptability of SP-based burger patties

Please rate the following on a 5-point scale (1 = Very Inappropriate, 5 = Very Appropriate)

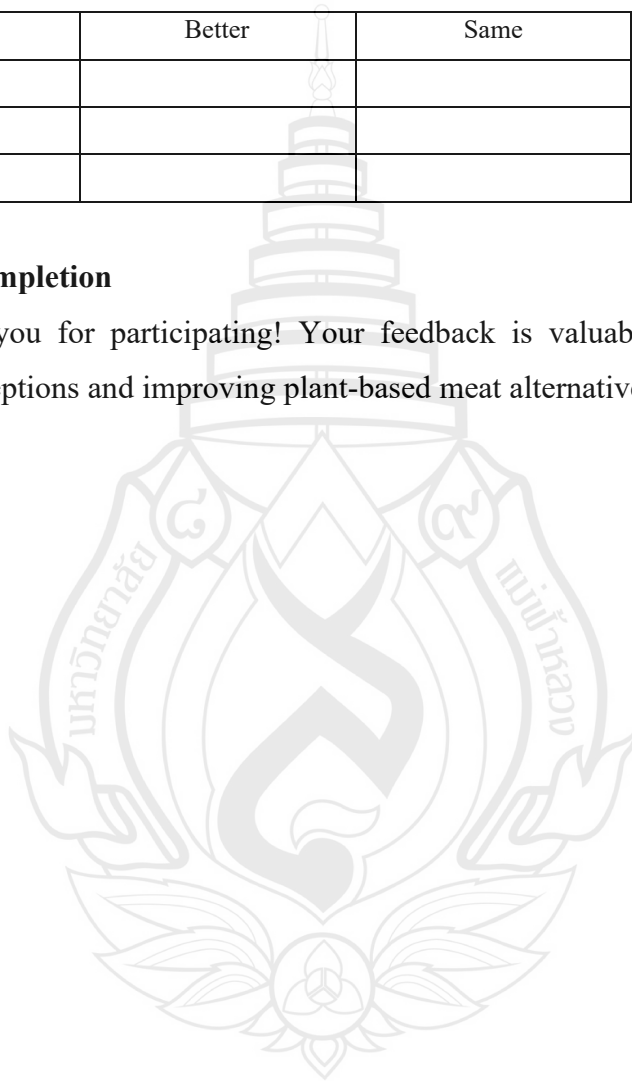
- How acceptable do you find eating SP-based burger patties ? ____
- How acceptable do you find offering SP-based burger patties ? ____

2.3.4 Expectations Regarding Product Attributes

Attribute	Better	Same	Worse
Taste			
Texture			
Price			

2.4 Survey Completion

Thank you for participating! Your feedback is valuable for understanding consumer perceptions and improving plant-based meat alternative



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Njoroge, J., Ketnawa, S., & Donlao, N. (2026, February 5–6). From by-product to value-added protein: Extruded TVP development from Sacha inchi press cake [Poster presentation]. International Conference on Food and Applied Bioscience (FAB 2026), Chiang Rai, Thailand.