Journal of Educational Technology and Learning Creativity
Vol. 3, No. 2, December 2025, pp. 596~608
ISSN: 3021-7865, DOI: 10.37251/jetlc.v3i2.2315 ❒ 596

Evaluation of Fish Sausage Product using Striped Snakehead (*Channa striata*) Species at UNICA Enterprise, Phnom Penh

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Article Info

Article history:

Received Oct 13, 2025
Revised Nov 28, 2025
Accepted Dec 19, 2025
Online First Dec 29, 2025

Keywords:

Evaluation
Fish Sausage
Striped Snakehead
Value-Added Product

ABSTRACT

Purpose of the study: This study developed and evaluated a novel fish sausage utilizing the Striped Snakehead (*Channa striata*), an abundant yet underutilized species in Cambodia, to address the limited valorization of local fishery resources and the inconsistent quality of existing products.

Methodology: Three formulations with varying concentrations of sugar, salt, and corn starch were systematically assessed through physicochemical, microbiological, and sensory analyses. Physicochemical parameters included pH, water activity, and nutritional composition (protein, fat, and caloric value). Microbiological safety was verified by testing for *E. coli, Salmonella spp.*, and total aerobic counts, while sensory attributes were evaluated by 30 panelists using a 9-point hedonic scale.

Main Findings: Results identified Treatment 3 as the optimal formulation, achieving the highest overall sensory acceptance (7.46) and significantly superior taste scores ($p < 0.001$). All formulations met international food safety standards, with pathogenic bacteria undetected. A central contribution of this research is the development and validation of a specific Hazard Analysis and Critical Control Points (HACCP) plan. Three Critical Control Points (CCPs) were identified: raw material reception, bone removal, and drying.

Novelty/Originality of this study: This study addresses the "absence of a HACCP plan" that previously hindered consumer trust. This research provides a clear pathway for the industrialization of safe, high-quality fish sausage, contributing to the economic valorization of Cambodia’s aquatic resources and offering a practical model for local food processors to meet regulatory standards.

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1. INTRODUCTION

Fish is a major source of protein and a dietary staple second only to rice for Cambodians, with approximately 61% of the nation's animal protein intake derived from fish. This is attributable to Cambodia's wealth of natural lakes, river systems, and aquaculture. Despite the abundance and essential role of these aquatic resources in the daily lives of the Cambodian people, the valorization of fish and fishery products appears limited, leading to significant opportunity losses. This shortfall can be attributed to several factors, including a lack of processing technology, insufficient investment capital, and inadequate regulatory frameworks [1]-[3].

In 2017, the Cambodian government estimated national aquaculture production at 205,300 tonnes. Aquaculture in the country is dominated by freshwater fish farming, which includes cage culture, pond culture, and rice field fish culture. Cambodia has a centuries-old tradition of processing freshwater fish into products such as fish paste, fermented fish, dry-salted fish, smoked fish, fish sauce, and dried fish for animal feed. These products serve both domestic and international markets. Although Cambodia has significant potential in fisheries and aquaculture, knowledge regarding fish sausage production is limited compared to other ASEAN countries [4]-[6].

Common food safety issues among Micro, Small, and Medium-sized Enterprises (MSMEs) in the fish processing sector include inadequate facilities, insufficient adherence to hygiene and sanitation standards, product spoilage, a lack of proper storage for finished products, and the use of additives like food colorings and flavor enhancers. Furthermore, the reported use of prohibited chemicals, such as formaldehyde/formalin to create a false appearance of freshness in fish, and banned additives like sodium cyclamate in fish sauce and other foods, poses a significant risk to consumer health. It is not uncommon for processors to prepare fish, such as removing heads and skin, directly on the floor. Some processors also source raw materials (e.g., prahok) from markets where product safety may not be a priority for traders [7]-[9]. The primary factor compromising the safety of fish products is the general lack of hygiene and sanitation within MSME facilities. This issue begins at the raw material sourcing and procurement stage. Some processors procure prepared fish from wet markets or are supplied by micro-processors, and it is crucial that they ensure their suppliers adhere to strict hygienic practices during fish preparation. The quality of the raw material directly impacts the final product's quality, as exemplified in the production of fish powder [10]-[12].

This study addresses two focal problems in the Cambodian fish sausage industry. The first problem is the lack of techniques and technologies for fish sausage development. This challenge stems from limited technical know-how in fish sausage development, inadequate technologies for fish sausage production, and insufficient experience in developing fish sausage products. These deficiencies have hindered the growth and competitiveness of the local fish sausage sector.

The second focal problem concerns the poor quality of fish sausage products currently available in the market. This issue is attributed to several contributing factors, including inadequate food packaging and labeling information that fails to meet consumer expectations and regulatory standards. Additionally, the absence of a Hazard Analysis and Critical Control Points (HACCP) plan for fish sausage production compromises product safety and quality assurance. Consequently, these deficiencies have resulted in low consumer trust in the quality of fish sausage products, further limiting market acceptance and commercial viability.

The primary aim of this study is to develop a high-quality fish sausage suitable for commercialization. To achieve this objective, the study evaluates the quality of the fish sausage based on its physicochemical and biological properties, as well as through sensory evaluation. In addition, this research aims to develop a Hazard Analysis and Critical Control Points (HACCP) plan to ensure food safety and quality throughout the fish sausage production process.

2. RESEARCH METHOD

This section outlines the materials, equipment, and procedures employed in the development and evaluation of fish sausage. The research was structured to systematically assess the effects of different formulations and processing techniques on the final product's quality, encompassing physicochemical, microbiological, and sensory attributes.

2.1 Research Materials

This study utilized high-quality raw materials to ensure the production of safe and marketable fish sausage. Striped snakehead fish was selected due to its availability and economic potential, while supporting ingredients and potable water were used to maintain product quality, safety, and consistency throughout the processing stages.

Table 1. Research Materials

Material	Description
Striped snakehead fish (Channa striata)	Selected due to its wide availability in Cambodia, affordable cost, and limited utilization in commercial processing. Fresh fish were obtained from a local supplier and transported under iced conditions to the Unica Enterprise facility for immediate processing.
Binders	Corn starch and tapioca starch used to improve texture and binding properties.
Seasonings	Sugar, salt, black pepper powder, monosodium glutamate (MSG), fried garlic, and ground coriander used to enhance flavor.
Other ingredients	Olive oil, food-grade collagen casings, and fresh eggs (egg whites) used to improve texture, structure, and product quality.
Potable water	Used throughout the production process, including cleaning of raw materials and equipment, and for formulation purposes.

2.2 Equipment and Instruments

The following equipment and instruments were utilized for the production and analysis of the fish sausage samples:

- Electronic Balance: A digital electronic balance with a minimum precision of 0.001g was used for all weighing purposes.
- Meat Grinder: A meat grinder (12.5 kg capacity, Thailand) was used to mince the fish meat.
- Mixer Grinder: A mixer was used to thoroughly combine the minced fish meat with other ingredients.
- Sausage Stuffer: A manual sausage stuffer (7 L capacity, China) was used to fill the prepared mixture into collagen casings.
- Dehydrator: A dehydrator (15-20 kg capacity, China) was employed for drying the fish sausages in the first experimental batch.
- Air Fryer: An air fryer was used for grilling and heating the fish sausages prior to sensory evaluation.
- Refrigerator/Freezer: A refrigerator and a freezer were used for the cold storage of raw materials and finished products.
- Water Bath: A water bath was used for boiling the sausages in the second experimental batch.
- Laboratory Glassware: Beakers, graduated cylinders, flasks, and pipettes were used for various analytical procedures.
- pH Meter: A digital pH meter (LAQUA F-72, HORIBA, China) was used to measure the pH of the samples.
- Refractometer: A digital refractometer (ATAGO PAL-1, Japan) was used to determine the Total Soluble Solids (°Brix).
- Water Activity Meter: An AquaLab 4TE benchtop water activity meter was used to measure the water activity (a_w) of the samples.
- Muffle Furnace: A Nabertherm B180 muffle furnace (Germany) was used for ash content determination.
- Soxhlet Extraction Unit: A Soxhlet apparatus (SZF-06G) was used for fat content analysis.
- Kjeldahl Digestion and Distillation Unit: Used for protein content analysis.
- Additional Tools: Knives, cutting boards, trays, masks, coats, gloves, paper towels, and plastic bags were used to ensure hygienic handling and processing.

2.3 Experimental Design

This research was conducted in two primary experimental batches to evaluate the effects of different ingredient formulations on the quality of the fish sausage. Each experiment was conducted with three replications to ensure the reliability of the results.

2.3.1 Batch 1: Optimization of Sugar, Salt, and Corn Starch Content

The first batch focused on determining the optimal concentrations of sugar, salt, and corn starch. Three distinct formulations (T1, T2, and T3) were prepared, as detailed in Table 2.1. The base ingredient, striped stripe snakehead fish meat, was kept constant at 1000g for all treatments.

Table 2. Formulations for Batch 1 Experiments

No.	Ingredient	Treatment 1 (T1)	Treatment 2 (T2)	Treatment 3 (T3)
1	Fish meat	1000 g	1000 g	1000 g
2	Sugar	15 g	30 g	30 g
3	Salt	5 g	10 g	10 g
4	Corn starch	150 g	150 g	200 g
5	Olive oil	20 g	20 g	20 g
6	Black pepper powder	10 g	10 g	10 g

2.3.2 Batch 2: Comparison of Starch Types

The second batch was designed to compare the effects of two different types of starch—tapioca starch and corn starch on the sausage's quality. The formulations for this batch are presented in Table 2.2.

Table 3. Formulations for Batch 2 Experiments

No.	Ingredient	Formulation A (Tapioca)	Formulation B (Corn)
1	Fish meat	1000 g	1000 g
2	Sugar	16 g	16 g
3	Salt	24 g	25 g
4	Starch	34 g (Tapioca)	34 g (Corn)
5	Olive oil	100 g	100 g
6	Black pepper powder	7 g	7 g
7	Monosodium glutamate	2 g	2 g
8	Fried garlic	10 g	10 g
9	Ground coriander	2 g	2 g
10	Egg white	4 pcs	4 pcs
11	Ice	200 g	200 g

2.4 Sausage Processing Methods

Fresh striped snakehead fish were transported under iced conditions and processed following a standardized procedure. The fish were washed, trimmed, beheaded, eviscerated, and deboned to obtain clean fish meat for further processing.

Table 4. Processing Methods of Fish Sausage

Stage	Batch 1: Drying Method	Batch 2: Boiling Method
Washing	Fish meat washed with clean water	Same as Batch 1
Grinding	Minced using a meat grinder	Same as Batch 1
Mixing	Mixed with sugar, salt, corn starch, black pepper, and olive oil according to formulation (Table 3.1)	Mixed using formulation in Table 3.2
Stuffing	Stuffed into collagen casings	Same as Batch 1
Linking	Formed into sausages (120 ± 5 mm)	Same as Batch 1
Heat treatment	Dried at 50 °C for 5 h	Boiled at 100 °C for 20 min
Cooling	Cooled at room temperature for 15 min	Ice-water cooling (5 min) followed by room temperature cooling (15 min)
Packaging & storage	Vacuum-packed and stored in a freezer	Vacuum-packed and stored in refrigerator or freezer

Two processing methods were applied to produce fish sausages: drying (Batch 1) and boiling (Batch 2). Both batches followed identical preparation, mixing, and stuffing steps, differing only in the heat treatment process. The drying method aimed to reduce moisture content, while the boiling method focused on thermal cooking. All samples were vacuum-packed and stored under cold conditions to maintain product quality prior to analysis.

2.5 Physicochemical Analysis

All physicochemical analyses were performed in triplicate to ensure accuracy and reproducibility of the results.

Table 5. Physicochemical Analyses of Fish Sausage

Parameter	Method / Instrument	Brief Procedure	Reference
pH	Digital pH meter (LAQUA F-72)	5 g sample homogenized with 20 mL distilled water; pH measured after calibration (pH 4.0 and 7.0).	[4]
Total Acidity	Titration method	Sample titrated with 0.1 N NaOH; results expressed as % lactic acid.	[5]
Salt Content	Mohr titration method	Sample titrated with 0.1 N $AgNO_3$ using K_2CrO_4 as indicator.	[6]
Total Soluble Solids (°Brix)	Digital refractometer (ATAGO PAL-1)	Homogenized sample measured after instrument calibration with distilled water.	[7]
Water Activity (aw)	AquaLab 4TE	1–2 g sample analyzed at ambient temperature after stabilization.	[8]
Moisture Content	Oven-drying method	Sample dried at 105 °C for 3 h; moisture calculated from weight loss.	[5]
Ash Content	Muffle furnace (Nabertherm B180)	Sample incinerated at 550 °C for 5 h until ash formation.	[9]

Fat Content	Soxhlet extraction (SZF-06G)	Fat extracted using hexane for 2 h and quantified gravimetrically.	[5]
Protein Content	Kjeldahl method	Nitrogen determined after digestion and distillation; protein calculated using factor 6.25.	[5]
Carbohydrate Content	By difference	Calculated as: 100 − (protein + fat + ash + moisture).	[5]
Caloric Value	Atwater system	Energy calculated from protein, fat, and carbohydrate contents.	[5]

Physicochemical properties of the fish sausage were evaluated to determine product quality, safety, and nutritional value. Standard analytical methods were applied to assess pH, acidity, salt content, moisture, ash, fat, protein, carbohydrates, and caloric value. These parameters provide essential information on the stability, composition, and overall quality of the developed fish sausage.

2.6 Microbiological Analysis

The microbiological quality of the fish sausage was evaluated to ensure its safety for consumption by determining the Total Plate Count (TPC) and Yeast and Mold Count. A 10 g sample was aseptically homogenized with 90 mL of sterile 0.85% saline solution to obtain a 10^{-1} dilution, followed by serial dilutions prepared using the same diluent. For Total Plate Count analysis, 0.1 mL of the appropriate dilution was spread onto Plate Count Agar (PCA) and incubated at 37°C for 24 hours. Colony numbers were then counted and expressed as colony-forming units per gram (CFU/g). Yeast and mold counts were determined using the spread plate method on Potato Dextrose Agar (PDA), with 0.1 mL of the diluted sample plated and incubated at 37°C for 24 hours. After incubation, colonies were enumerated and reported as CFU/g. All microbiological analyses were performed in accordance with standard microbiological procedures [18]-[20].

2.7 Sensory Evaluation

A sensory evaluation was conducted to assess consumer acceptability of the fish sausage formulations. The evaluation was carried out at the Unica Enterprise facility using 30 panelists consisting of housewives and young adults. Prior to the evaluation, all panelists received a brief orientation regarding the assessment procedure and evaluation criteria. The sausage samples were grilled using an air fryer and served warm to the panelists. Each participant evaluated the samples using a nine-point hedonic scale, where 1 indicated "dislike extremely" and 9 indicated "like extremely." The sensory attributes evaluated included appearance, size, odor, color, toughness, flavor, texture, and overall acceptability. Fresh water and tissues were provided to cleanse the palate between samples to minimize sensory bias.

All data obtained from physicochemical, microbiological, and sensory evaluations were statistically analyzed using Minitab Statistical Software (Version 20). Analysis of variance (ANOVA) was applied to determine significant differences among treatments at a significance level of $p < 0.05$. When significant differences were observed, Tukey's post hoc test was used for multiple comparisons among treatment means.

3. RESULTS AND DISCUSSION

This section presents the findings from the experimental evaluation of fish sausage produced from Striped Snakehead (*Channa striata*). The results are organized into three main sections: the first experimental batch focusing on formulation optimization, the second batch comparing different starch types, and the development of a Hazard Analysis and Critical Control Points (HACCP) plan. Each section includes a detailed analysis of the physicochemical, microbiological, and sensory properties, followed by a discussion of the findings in the context of existing literature and food science principles.

3.1. First Experimental Batch: Formulation Optimization

The first phase of the study focused on evaluating three different formulations (T1, T2, and T3) of fish sausage, which varied in their concentrations of sugar, salt, and corn starch. The sausages were processed using a drying method at 50°C for 5 hours. The following sections detail the results of the physicochemical, microbiological, and sensory analyses.

3.1.1. Physicochemical Properties

The physicochemical properties of the three fish sausage formulations were analyzed to assess their quality and characteristics. The results are summarized in Table 6, and a detailed discussion for each parameter is provided below.

Table 6. Physicochemical Properties of Fish Sausage Formulations

Parameter	Treatment 1 (T1)	Treatment 2 (T2)	Treatment 3 (T3)	P-value
pH	6.26 ± 0.01^{b}	6.32 ± 0.01^{a}	6.11 ± 0.10^{c}	< 0.05
Total Sugar (%)	1.63 ± 0.01^{c}	1.66 ± 0.01^{a}	1.65 ± 0.01^{b}	< 0.01
Total Acidity (%)	0.17 ± 0.01^{a}	0.06 ± 0.01^{c}	0.08 ± 0.01^{b}	< 0.01
Salt Content (%)	0.32 ± 0.01^{c}	0.43 ± 0.02^{b}	0.47 ± 0.01^{a}	< 0.01
Degree Brix (%)	1.10 ± 0.11^{b}	1.17 ± 0.06^{b}	1.33 ± 0.06^{a}	< 0.01
Water Activity (a_w)	0.87 ± 0.01^{a}	0.86 ± 0.01^{b}	0.86 ± 0.01^{b}	> 0.05
Moisture Content (%)	59.82 ± 0.79^{b}	60.21 ± 1.28^{a}	56.81 ± 1.68^{c}	< 0.05
Ash Content (%)	3.37 ± 0.03^{c}	4.26 ± 0.30^{b}	4.48 ± 0.05^{a}	< 0.05
Protein Content (%)	20.04 ± 0.08^{a}	19.17 ± 0.32^{b}	19.20 ± 0.13^{b}	< 0.05
Fat Content (%)	1.13 ± 0.11^{a}	1.06 ± 0.11^{a}	1.06 ± 0.11^{a}	> 0.05
Carbohydrate (g/100g)	75.05 ± 0.19^{b}	75.50 ± 0.98^{a}	75.25 ± 0.20^{ab}	> 0.05
Caloric Value (kcal/100g)	390.55 ± 0.58^{a}	388.27 ± 5.78^{a}	387.39 ± 0.66^{a}	> 0.05

Values are expressed as mean ± standard deviation. Means in the same row with different superscripts (a, b, c) are significantly different (p < 0.05) [21].

Significant differences in physicochemical properties were observed among the treatments. The pH values differed significantly ($p < 0.05$), with Treatment 2 showing the highest pH (6.32), indicating a less acidic environment, while Treatment 3 exhibited the lowest pH (6.11). Since pH plays a crucial role in microbial growth, texture, and shelf life of fish products, these variations are likely associated with differences in ingredient composition, particularly the acidic or alkaline nature of the added components [22]-[24].

Total sugar and total acidity also varied significantly among treatments. Treatment 2 showed the highest sugar content (1.66%), whereas Treatment 1 exhibited the highest total acidity (0.17%). This balance between sugar and acidity is essential for flavor development and microbial stability, as both parameters influence sensory acceptance and product preservation [25]-[27].

Salt content and total soluble solids (°Brix) were highest in Treatment 3, with values of 0.47% and 1.33%, respectively, and differed significantly from the other treatments ($p < 0.01$). These components contribute to osmotic pressure, water-binding capacity, and overall texture, thereby influencing product stability and shelf life [28].

Water activity (a_w) showed no significant difference among treatments, although Treatment 1 exhibited the highest value (0.87), while Treatments 2 and 3 had slightly lower values (0.86). In contrast, moisture content differed significantly ($p < 0.05$), with Treatment 2 showing the highest moisture level (60.21%) and Treatment 3 the lowest (56.81%). These parameters are critical for microbial control and product stability, and the observed moisture values are consistent with those reported for similar fermented fish sausages, typically ranging from 52% to 59% [29]-[31].

Regarding nutritional composition, Treatment 3 exhibited the highest ash content (4.48%), indicating a higher mineral concentration, while Treatment 1 showed the highest protein content (20.04%), which is nutritionally advantageous and higher than that reported for several comparable fish sausage products. Fat content did not differ significantly among treatments. Furthermore, carbohydrate content and caloric values were relatively similar across all treatments, indicating that variations in formulation did not substantially affect the overall energy content of the final products [32]–[34].

3.1.2. Microbiological Analysis

The microbiological safety of the fish sausage formulations was evaluated to ensure compliance with food safety standards. The results for Total Aerobic Microbial Count, Yeast and Mold, *E. coli*, and *Salmonella spp.* are presented in Table 7 [33], [35].

Table 7. Microbiological Analysis of Fish Sausage Formulations

Parameter	Treatment 1 (T1)	Treatment 2 (T2)	Treatment 3 (T3)	Specification Limit
Total Aerobic Microbial Count	3.1×10^4 CFU/g	4.6×10^2 CFU/g	4.3×10^3 CFU/g	$\leq 10^6$ CFU/g
Yeast and Mold	2.4×10^2 CFU/g	2.4×10^2 CFU/g	1.7×10^2 CFU/g	$\leq 10^3$ CFU/g
E. coli	Not Detected	Not Detected	Not Detected	$\leq 5 \times 10^2$ CFU/g
Salmonella spp.	Not Detected	Not Detected	Not Detected	Absent in 25g

The results of the microbiological analysis confirm that all three fish sausage formulations are safe for consumption and meet the established specifications. The Total Aerobic Microbial Counts for all treatments were well below the limit of 10^6 CFU/g, with Treatment 2 showing a particularly low count, indicating superior microbial control. Similarly, the Yeast and Mold counts were significantly below the maximum allowable limit

[30], [32]. Crucially, pathogenic bacteria such as E. coli and Salmonella spp. were not detected in any of the samples. These findings demonstrate the effectiveness of the processing and drying methods in controlling microbial contamination and ensuring the microbiological safety of the final product [33], [36], [37].

3.1.3. Sensory Evaluation

A sensory evaluation was conducted with 30 panelists to assess the consumer acceptability of the three fish sausage formulations. The samples were evaluated on a nine-point hedonic scale for several attributes. The results are summarized in Table 8 [38]-[40].

Table 8. Sensory Evaluation Scores for Fish Sausage Formulations

Attribute	Treatment 1 (T1)	Treatment 2 (T2)	Treatment 3 (T3)	P-value
Appearance	8.73 ± 0.79^a	8.80 ± 0.85^a	8.60 ± 0.81^a	0.63 (ns)
Size	7.60 ± 1.04^a	7.27 ± 1.11^a	7.27 ± 0.88^a	0.68 (ns)
Odor	7.60 ± 1.04^a	7.27 ± 0.87^a	7.27 ± 0.87^a	0.28 (ns)
Color	7.27 ± 1.08^a	7.07 ± 1.02^a	7.27 ± 1.08^a	0.70 (ns)
Toughness	7.93 ± 1.68^a	7.07 ± 0.87^b	7.20 ± 0.93^b	0.02*
Taste	6.47 ± 1.17^a	6.07 ± 0.79^a	7.40 ± 1.28^b	0.001**
Texture	6.20 ± 0.85^a	7.87 ± 0.63^b	7.40 ± 0.89^b	0.001**
Acceptable Level	6.07 ± 1.02^a	7.67 ± 0.80^b	7.27 ± 1.08^b	0.01*
Overall Liking	7.23 ± 0.93^a	7.39 ± 0.78^a	7.46 ± 0.47^a	0.83 (ns)

*Scores are based on a 9-point hedonic scale. Means in the same row with different superscripts are significantly different. ns = not significant ($p > 0.05$); * = significant ($p < 0.05$); ** = highly significant ($p < 0.01$)*

The sensory evaluation revealed that while all three formulations were well-received by consumers, there were significant differences in specific attributes. Treatment 3 achieved the highest overall liking score (7.46), corresponding to "like moderately" on the hedonic scale, although this was not statistically different from the other treatments [41].

No significant differences were observed for appearance, size, odor, and color, suggesting that the formulation changes did not substantially impact the visual or aromatic properties of the sausages. However, highly significant differences were found for taste and texture ($p < 0.001$). Treatment 3 was rated highest for taste, while Treatment 2 was rated highest for texture. This indicates that the specific combination of salt, sugar, and starch in each formulation had a discernible effect on the palate and mouthfeel of the product. The toughness and overall acceptable level also showed significant differences, with Treatments 2 and 3 generally outperforming Treatment 1. These results suggest that while all formulations are acceptable, Treatment 3 provides the most favorable taste profile, and Treatment 2 offers the best texture, providing valuable insights for further product refinement [42]-[44].

3.2. Second Experimental Batch: Formulation Optimization

3.1.1. Physicochemical Properties

The physicochemical properties of the three fish sausage formulations were analyzed to assess their quality and characteristics. The results are summarized in Table 9, and a detailed discussion for each parameter is provided below.

Table 9. Physicochemical Properties of Fish Sausage Formulations

Parameter	Formulation A (Tapioca)	Formulation B (Corn)
pH	5.50 ± 0.05	5.50 ± 0.05
Water Activity (a_w)	0.98 ± 0.00	0.90 ± 0.02
Moisture Content (%)	74.73 ± 0.69	76.07 ± 0.50
Protein Content (%)	14.69 ± 0.09	15.66 ± 0.01
Fat Content (%)	0.95 ± 0.05	1.42 ± 0.02
Carbohydrate (g/100g)	10.50 ± 0.05	8.39 ± 0.18
Caloric Value (kcal/100g)	100.50	100.80

Values are expressed as mean ± standard deviation. Means in the same row with different superscripts (a, b, c) are significantly different ($p < 0.05$) [21], [45].

3.2.2. Microbiological Analysis

The microbiological safety of the fish sausage formulations was evaluated to ensure compliance with food safety standards. The results for Total Aerobic Microbial Count, Yeast and Mold, *E. coli*, and *Salmonella spp.* are presented in Table 10.

Table 10. Microbiological Analysis of Fish Sausage [32]

Parameter	Formulation A (Tapioca)	Formulation B (Corn)	Specification Limit
Total Aerobic Microbial Count	<1.0 × 10 CFU/g	1.0 × 10 CFU/g	≤ 10^6 CFU/g
Total Coliform	<5.0 × 10 CFU/g	4.9 × 10 CFU/g	≤ 10^3 CFU/g
E.coli	Not Detected	Not Detected	Absent in 25g

3.2.3. Sensory Evaluation

A sensory evaluation was conducted with 103 panelists (75 female) to assess the consumer acceptability of the three fish sausage formulations. The samples were evaluated on a nine-point hedonic scale for several attributes. The results are summarized in Table 11.

Table 11.Sensory Evaluation Scores for Fish Sausage Formulations [33, 34]

Attribute	Formulation A (Tapioca)	Formulation B (Corn)
Appearance	7.10	7.10
Odor	7.00	7.00
Color	7.00	7.00
Toughness	7.45	7.45
Taste	7.24	7.24
Texture	8.10	8.10
Acceptable Level	7.36	7.36
Overall Liking	7.32	7.32

3.3. Development of a HACCP Plan for Fish Sausage Production

To ensure the safety of the newly developed fish sausage product, a Hazard Analysis and Critical Control Points (HACCP) plan was developed and implemented. This proactive food safety system is essential for identifying, evaluating, and controlling hazards that are significant for food safety. Additionally, we applied this for fish sausage production at UNICA enterprise since the product was commercialized after research and development [32], [49].

Table 12. Process step desciption

No	Process	Description
1	Receiving raw materials	Sugar, salt, black pepper, rice flour, corn starch, soybean oil and casing were received from packed in sealed plastic packaging with normal labelling delivered by bus at room temperature.
	1.2 Storing materials	All ingredients were kept in room temperature and in a dry place.
	1.3 Receiving raw fish	Raw fish was received from Kampong Cham province
2	Testing	Fish was tested for physiochemical and microbiological properties.
3	Cleaning	Fish was washed off with clean tap water.
4	Cutting	Fish was cut and unwanted processed parts of the fish were removed.
5	Fleshing out bone and skin	The bone and skin of the fish was removed manually, and only the meat is taken for further process.
6	Grinding	The fish meat was grinded using a grinder.
7	Mixing	The fish meat was mixed well with other ingredients using a mixer.
8	Stuffing	After mixing, the fish meat was stuffed into the collagen food grade casing.
9	Tying sausage	The fish sausage was tied at the end of each casing and with a length of 120±5 mm
10	Boiling	The sausages were boiled at the temperature of 100°C for 15mn in the water bath. The water temperature was regularly checked and monitored every 5 mn.
11	Cooling down	The sausages were then cooled down at the room temperature for 15 min.
12	Packing	Using plastic film and vaccume
13	Finish product	The sausages were stored in the refrigerator at 4°C.

Table 13. HACCP Study [18], [19]

Process Step	Main Hazard	Source of Hazard	Control Measure (CP / CCP)
Raw Material Reception	Biological, chemical, physical	Poor hygiene, contaminated water, feed, or handling	Use approved suppliers, temperature control, sensory inspection, proper labeling (CP)
Water Supply	Biological, chemical, physical	Untreated or contaminated water	Use treated potable water; periodic water testing (CP)
Ingredients Handling	Biological, chemical, physical	Poor storage, contamination, pesticide residues	Approved suppliers, proper storage, COA verification (CP)
Inspection	Biological	Poor personal hygiene or contaminated tools	Apply hygiene practices and clean tools (CP)
Washing	Biological, chemical	Untreated water	Use potable water only (CP)
Cutting / Eviscerating	Biological, physical	Poor hygiene, damaged tools	Sanitation, equipment inspection (CP)
Deboning / Trimming	Physical	Bone fragments	Careful trimming and visual inspection (CP)
Grinding	Biological, physical	Equipment contamination, metal fragments	Sanitation, preventive maintenance (CP)
Mixing	Biological, chemical, physical	Cross-contamination, residue	Cleaning and sanitation procedures (CP)
Stuffing & Tying	Biological, physical	Contaminated casing or tools	Use food-grade casing, hygiene control (CP)
Air Blowing	Biological, chemical	Contaminated compressed air	Filter maintenance and air quality control (CP)
Boiling	Biological	Inadequate heat treatment	Controlled time–temperature process (CCP 1)
Primary Packaging	Biological, physical	Poor hygiene or environment	Hygienic handling, clean area (CP)
Metal Detection	Physical	Metal fragments	Metal detector verification (CCP 2)
Final Packaging	Physical	Personal contamination	Personnel hygiene control (CP)
Cold Storage	Biological	Temperature abuse	Temperature monitoring (CCP 3)
Distribution	Biological	Improper transport temperature	Cold chain control and inspection (CP)

Hazard analysis identified potential biological, chemical, and physical risks throughout the fish sausage production process. Most processing steps were managed under Control Points (CPs) through hygiene practices, sanitation, and raw material control. Three Critical Control Points (CCPs) were identified: boiling (CCP1), metal detection (CCP2), and chilled storage (CCP3), as these steps are essential for ensuring product safety and preventing contamination. This simplified HACCP framework ensures effective risk management while maintaining product quality and safety.

A comprehensive hazard analysis was conducted at each stage of the production process, from raw material reception to final product storage, to identify potential biological, chemical, and physical hazards. Biological hazards primarily included pathogenic microorganisms such as *Salmonella spp.*, *Escherichia coli*, and *Staphylococcus aureus*, which may originate from raw fish or be introduced during handling and processing. Chemical hazards mainly involved the potential presence of heavy metals, such as lead and mercury, as well as chemical residues originating from contaminated water or raw materials. Physical hazards were mainly associated with fish bones, which could pose a choking risk if not properly removed during processing [50]-[52].

Based on the hazard analysis, three Critical Control Points (CCPs) were identified where effective control is essential to prevent or reduce hazards to acceptable levels. The first CCP was raw material reception, which plays a crucial role in controlling biological and chemical hazards through the selection of approved suppliers and verification of product safety using Certificates of Analysis (COA) [37], [38]. The second CCP was the fleshing or bone-removal process, identified as critical for minimizing physical hazards; this step involves careful manual inspection and removal of bones to ensure that no fragments exceeding 0.5 mm remain in the fish meat [53]. The third CCP was the drying process, conducted at 50°C for 5 hours, which serves as a key control measure to inhibit microbial growth by reducing moisture content. Strict monitoring of both temperature and drying time was applied to ensure product safety and consistency [53].

To validate the effectiveness of the implemented HACCP plan, the final fish sausage product was subjected to microbiological testing. The results, presented in Table 3.9, demonstrate that the HACCP plan was successful in controlling microbial hazards [30], [53].

Table 14. Microbial Test of Finished Product after HACCP Implementation [18], [39]

Parameter	Result	Specification Limit
Total Aerobic Microbial Count	< 10 CFU/g	≤ 10^6 CFU/g
Yeast and Mold	< 10 CFU/g	≤ 10^3 CFU/g
E. coli	Not Detected	≤ 5×10^2 CFU/g
Salmonella spp.	Not Detected	Absent in 25g

The microbial counts in the final product were significantly below the established safety limits, with pathogenic bacteria being non-detectable. This confirms that the HACCP plan, with its identified CCPs and control measures, is effective in producing a safe and high-quality fish sausage product that complies with the regulatory standards set by Cambodian authorities [55].

This study presents a novel and integrated approach to developing a value-added fish sausage product from striped snakehead (*Channa striata*) by combining formulation optimization, comprehensive physicochemical–microbiological evaluation, and the implementation of a validated HACCP system within a single production framework. Unlike previous studies that primarily focused on either product formulation or safety assessment, this research systematically links ingredient variation, processing conditions, consumer acceptability, and food safety performance under semi-industrial conditions. The study also provides empirical evidence on how formulation differences influence physicochemical properties, sensory acceptance, and microbial stability, while simultaneously demonstrating the effectiveness of HACCP implementation for small-to-medium-scale fish processing enterprises. This integrated approach contributes new insights into the development of safe, acceptable, and commercially viable fish-based products, particularly in the context of value addition to underutilized freshwater fish resources.

The findings of this study have important implications for both the food industry and public health sectors. The optimized fish sausage formulations demonstrated acceptable sensory quality, nutritional value, and microbiological safety, indicating strong potential for commercialization and market expansion of value-added fish products. The validated HACCP plan provides a practical and replicable framework that can be adopted by small- and medium-scale food processors to enhance food safety management systems and comply with regulatory standards. Furthermore, this study supports sustainable utilization of local fish resources, contributes to food security, and offers an economically feasible processing model that can improve income opportunities for small-scale producers. The integration of scientific evaluation with practical processing conditions also strengthens the applicability of the findings in real industrial settings. Despite its contributions, this study was limited by the scale of production and the relatively short evaluation period, which may not fully represent long-term storage stability or large-scale industrial conditions. Additionally, consumer acceptance was assessed within a limited demographic group, suggesting that broader sensory evaluation across diverse populations is necessary for wider market generalization.

4. CONCLUSION

This study successfully developed and evaluated a value-added fish sausage from striped snakehead (*Channa striata*), demonstrating its strong potential for commercialization. Among the tested formulations, Treatment 3 showed the most favorable overall performance, combining superior sensory acceptance with desirable physicochemical properties, while all formulations met microbiological safety standards. The implementation of a comprehensive HACCP system, including critical control points at raw material reception, bone removal, and drying, effectively ensured product safety and compliance with food safety regulations. These findings confirm that the optimized formulation and processing approach provide a reliable foundation for producing safe, high-quality, and consumer-acceptable fish sausage. Future research is recommended to evaluate product shelf life under different storage conditions, assess nutritional stability during storage, develop ready-to-eat (RTE) variants, and explore alternative ingredients or fish species to enhance product diversity and industrial scalability, thereby supporting sustainable utilization of local aquatic resources and strengthening the competitiveness of the fish processing sector.

ACKNOWLEDGEMENTS

I would like to express my deepest gratitude to the FOODI Erasmus+ Consortium Program of the European Union and the Management Board of Svay Rieng University (SRU), especially His Excellency Professor Tum Saravuth, Rector of SRU, for their steadfast support and commitment to advancing academic and research excellence. I am also sincerely thankful to the CAPFISH-CAPTURE: Post-Harvest Fisheries Development Project, funded by the United Nations Industrial Development Organization (UNIDO), for awarding the grant that enabled this research on "Evaluation of Fish Sausage Product Using Stripe Snakehead (Channa striata) Species" at UNICA Enterprise in Phnom Penh, Cambodia. My profound appreciation goes to my supervisor, Dr. Chhe Chinda, and my co-advisor, Associate Professor Dr. Serey Mardy, for their exceptional mentorship, insightful guidance, and unwavering encouragement throughout this research. Their expertise spanning both theoretical foundations and practical applications—has been instrumental in shaping this study and strengthening my development as a researcher. I also extend my heartfelt thanks to Ms. Srun Marnick for her thoughtful feedback and invaluable assistance in refining the language and clarity of this manuscript. Finally, I gratefully acknowledge the UNICA Enterprise team for providing access to their facilities and for their continuous support during the experimental phase of this project. Their collaboration was essential to the successful completion of this work.

USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

The authors declare that no artificial intelligence (AI) tools were used in the preparation, analysis, or writing of this manuscript. All aspects of the research, including data collection, interpretation, and manuscript preparation, were carried **out** entirely by the authors without the assistance of AI-based technologies.

REFERENCES

[1] United Nations Industrial Development Organization, *Agro-value chain analysis and development: The fish processing sector in Cambodia*. Phnom Penh, Cambodia: UNIDO, 2022.

[2] Saindah, S. N., "The power of visual learning: Audio-visual health education to combat stunting in toddlers," *Journal of Health Innovation and Environmental Education*, vol. 2, no. 1, pp. 68–75, 2025, doi: 10.37251/jhiee.v2i1.2008.

[3] Afandi, R., "Practical spectrophotometry: Exploring maximum absorption peaks of $Fe(SCN)_3$ and $CuSO_4$ solutions using visible light," *Journal of Chemical Learning Innovation*, vol. 2, no. 1, pp. 68–72, 2025, doi: 10.37251/jocli.v2i1.1932.

[4] Food and Agriculture Organization of the United Nations, "National aquaculture sector overview: Cambodia," FAO Fisheries and Aquaculture Department, 2019. [Online]. Available: https://www.fao.org/fishery/countrysector/naso_cambodia/en

[5] Rahajo, M. S. and Kumyat, A., "Analysis of driving factors for the implementation of clean technology to optimize green manufacturing in the Wiradesa batik small and medium enterprises (SMEs)," *Integrated Science Education Journal*, vol. 6, no. 3, pp. 258–268, 2025, doi: 10.37251/isej.v6i3.2115.

[6] Hidayah, A. N. and Pujiarti, P., "Sociological aspects of *Eyes in the Land of Melus* and their relevance to Indonesian language learning," *Journal of Language, Literature, and Educational Research*, vol. 2, no. 1, pp. 106–112, 2025, doi: 10.37251/jolle.v2i1.1991.

[7] Espejo-Hermes, N., *Food safety and quality management in micro, small and medium-sized fish processing enterprises in Cambodia*. Rome, Italy: Food and Agriculture Organization of the United Nations, 2022.

[8] Sethanant, P., Kim, J., and Brain, M. M. C., "Molecular docking-based *in silico* evaluation of leaf compounds from *Coleus blumei* against MRSA," *Journal of Academic Biology and Biology Education*, vol. 2, no. 1, pp. 7–15, 2025, doi: 10.37251/jouabe.v2i1.1660.

[9] Khotimah, N., Tleumuratov, G., and Tanasavate, K., "Discrimination of Chinese female characters in the latest *Dimsum* novel by Clara Ng," *Journal of Language, Literature, and Educational Research*, vol. 2, no. 1, pp. 85–91, 2025, doi: 10.37251/jolle.v2i1.1912.

[10] Niimi, J. and Shiokawa, Y., "Quality evaluation of fish sausage during storage," *Journal of Food Science and Technology*, vol. 52, no. 8, pp. 5172–5178, Aug. 2015, doi: 10.1007/s13197-014-1589-3.

[11] Afriani, H. N. and Widodo, A., "Designing a green chemistry-based practical guide: Enhancing learning on reaction rates and chemical equilibrium," *Journal of Chemical Learning Innovation*, vol. 2, no. 1, pp. 73–80, 2025, doi: 10.37251/jocli.v2i1.1922.

[12] Noroozi, Z. and Van Iii, J. D., "Teratogenic effects of ethanolic *Cinnamomum burmanni* leaf extract on fetal development in white mice (*Mus musculus* L.)," *Journal of Academic Biology and Biology Education*, vol. 2, no. 1, pp. 1–6, 2025, doi: 10.37251/jouabe.v2i1.1657.

[13] AOAC International, *Official Methods of Analysis of AOAC International*, 18th ed. Gaithersburg, MD, USA: AOAC International, 2005.

[14] Indian Standards Institution, *ISI Handbook of Food Analysis, Part XIII: General Methods*. New Delhi, India: Indian Standards Institution, 1984.

[15] Jin, S. K., Kim, J. S., and Yoon, W. B., "Effect of drying temperature on moisture content, water activity, and color of fish jerky," *Journal of Food Processing and Preservation*, vol. 43, no. 7, p. e13987, Jul. 2019, doi: 10.1111/jfpp.13987.

[16] Montes, C., Vicario, I. M., and Heredia, F. J., "Water activity and color properties of spray-dried paprika oleoresin with different carrier agents," *Journal of Food Processing and Preservation*, vol. 39, no. 6, pp. 1866–1874, Dec. 2015, doi: 10.1111/jfpp.12437.

[17] AOAC International, *Official Methods of Analysis of AOAC International*, 19th ed. Gaithersburg, MD, USA: AOAC International, 2012.

[18] Krisnaningsih, E., Rosyidi, D., Radiati, L. E., and Thohari, I., "Microbiological and physicochemical properties of chicken sausage with the addition of konjac flour," *Journal of Applied Food Technology*, vol. 6, no. 1, pp. 1–5, 2019, doi: 10.17728/jaft.3588.

[19] Mayssara, A. A., Ashraf, A. K., and Nagwa, S. A., "Microbiological quality and safety of processed meat products in Egyptian markets," *Advances in Animal and Veterinary Sciences*, vol. 7, no. 1, pp. 52–58, Jan. 2019, doi: 10.17582/journal.aavs/2019/7.1.52.58.
[20] A. Nisah, Q.-U. Jatoi, and G. Tleumuratov, "Procedure text writing skills using silent film media in grade VII students of State Junior High School 10 South Tangerang," *J. Lang. Lit. Educ. Res.*, vol. 2, no. 1, pp. 1–9, 2025, doi: 10.37251/jolle.v2i1.1574.
[21] K. Amano, "Fish sausages," in *Fish in Nutrition*, E. Heen and R. Kreuzer, Eds. London, UK: Fishing News (Books) Ltd., 1965, pp. 398–405.
[22] S. You *et al*., "Processing technology and quality change during storage of fish sausage," *Foods*, vol. 11, no. 23, p. 3789, Nov. 2022, doi: 10.3390/foods11233789.
[23] P. Chuapoehuk and N. Raksakulthai, "Process development of fish sausage," *J. Food Process. Preserv.*, vol. 25, no. 3, pp. 215–231, 2001, doi: 10.1111/j.1745-4549.2001.tb00460.x.
[24] J. Emmanuel, R. J. Bawang, and U. Axunov, "As a strategy to boost tourism in the Philippines during the new normal," *Multidiscip. J. Tour. Hosp. Sport Phys. Educ.*, vol. 2, no. 1, pp. 83–89, 2025, doi: 10.37251/jthpe.v2i1.1914.
[25] N. Raksakulthai, "Production and storage of Chinese style fish sausage from hybrid catfish," *Kasetsart J. (Nat. Sci.)*, vol. 35, pp. 349–356, 2001.
[26] S. Sampels, "The effects of processing technologies and preparation on the final quality of fish products," *Trends Food Sci. Technol.*, vol. 44, no. 2, pp. 131–146, 2015, doi: 10.1016/j.tifs.2015.04.003.
[27] S. Charlize, G. R. Semilla, and M. E. Hossain, "Reserving cultural heritage through traditional Filipino games," *Multidiscip. J. Tour. Hosp. Sport Phys. Educ.*, vol. 2, no. 1, pp. 76–82, 2025, doi: 10.37251/jthpe.v2i1.1915.
[28] G. L. Russo *et al*., "Emerging technologies in seafood processing: An overview of high-pressure processing, ultrasound, pulsed electric field, and plasma technologies," *Compr. Rev. Food Sci. Food Saf.*, vol. 23, no. 1, p. e13281, 2024, doi: 10.1111/1541-4337.13281.
[29] U.S. Food and Drug Administration, "Seafood HACCP," 2025. [Online]. Available: https://www.fda.gov/food/hazard-analysis-critical-control-point-haccp/seafood-haccp
[30] A. M. King, "Implementation of hazard analysis critical control point (HACCP) system to the fish/seafood industry: A review," *Food Rev. Int.*, vol. 17, no. 3, pp. 293–323, 2001, doi: 10.1081/FRI-100100290.
[31] M. R. A. Islami, M. Zafari, and S. Anjum, "Wearable energy harvester: Application of piezoelectric sensors in shoes as a portable power source," *Integr. Sci. Educ. J.*, vol. 6, no. 3, pp. 249–257, 2025, doi: 10.37251/isej.v6i3.2117.
[32] U.S. Food and Drug Administration, "Microbiological surveillance sampling," 2025. [Online]. Available: https://www.fda.gov/food/sampling-protect-food-supply/microbiological-surveillance-sampling
[33] S. E. Pierce *et al.*, "Detection and identification of *Salmonella enterica*, *Escherichia coli*, *Shigella*, and *Listeria monocytogenes* with a multiplex PCR-based assay," *Clin. Microbiol. Infect.*, vol. 18, no. 11, pp. 1083–1089, 2012, doi: 10.1111/j.1469-0691.2011.03698.x.
[34] D. R. Peryam and N. F. Girardot, "The 9-point hedonic scale," *Food Technol.*, vol. 6, pp. 9–14, 1952.
[35] J. Lim, "Hedonic scaling: A review of methods and theory," *Food Qual. Prefer.*, vol. 22, no. 8, pp. 733–747, 2011, doi: 10.1016/j.foodqual.2011.05.008.
[36] U.S. Food and Drug Administration, "Water activity (aw) in foods," 2014. [Online]. Available: https://www.fda.gov/inspections-compliance-enforcement-and-criminal-investigations/inspection-technical-guides/water-activity-aw-foods
[37] E. Sandulachi, "Water activity concept and its role in food preservation," *Meridian Ingineresc*, no. 2, pp. 43–48, 2012.
[38] T. T. N. Bich *et al*., "Productivity and economic viability of snakehead *Channa striata* culture using an aquaponics approach," *Aquaculture*, vol. 516, p. 734629, 2020, doi: 10.1016/j.aquaculture.2019.734629.
[39] S. Khalili Tilami and S. Sampels, "Nutritional value of fish: lipids, proteins, vitamins, and minerals," *Rev. Fish. Sci. Aquac.*, vol. 26, no. 2, pp. 243–253, 2018, doi: 10.1080/23308249.2017.1399104.
[40] F. R. Putri, C. A. Osunla, and R. A. Sen, "Bridging healthcare and technology: Management systems in radiology services," *J. Health Innov. Environ. Educ.*, vol. 2, no. 1, pp. 31–42, 2025, doi: 10.37251/jhiee.v2i1.1726.
[41] S. Balami, A. Sharma, and R. Karn, "Significance of nutritional value of fish for human health," *Malaysian J. Halal Res.*, vol. 2, no. 1, pp. 12–15, 2019, doi: 10.2478/mjhr-2019-0012.
[42] International Organization for Standardization, *ISO 22000:2018 Food Safety Management Systems—Requirements for Any Organization in the Food Chain*, 2018. [Online]. Available: https://www.iso.org/standard/65464.html
[43] J. A. Hollingworth, "The role of auditing, food safety, and food quality standards in the food industry: A review," *Compr. Rev. Food Sci. Food Saf.*, vol. 17, no. 2, pp. 341–354, 2018, doi: 10.1111/1541-4337.12293.
[44] R. R. Cortés, W. Thanjangreed, and T. Chertenko, "Relationship between environmental sanitation and dengue hemorrhagic fever incidents," *J. Health Innov. Environ. Educ.*, vol. 2, no. 1, pp. 43–51, 2025, doi: 10.37251/jhiee.v2i1.1736.
[45] B. A. Nummer, "Historical origins of food preservation," National Center for Home Food Preservation, 2002. [Online]. Available: https://nchfp.uga.edu/publications/nchfp/factsheets/food_pres_hist.html
[46] S. K. Jin, I. S. Kim, S. J. Kim, and H. S. Yang, "Effects of sugar and salt on the quality of fish sausage," *J. Anim. Sci. Technol.*, vol. 50, no. 6, pp. 885–892, 2008, doi: 10.5187/JAST.2008.50.6.885.
[47] H. Lawless and H. Heymann, *Sensory Evaluation of Food: Principles and Practices*, 2nd ed. New York, NY, USA: Springer, 2010.
[48] S. S. Nielsen, Ed., *Food Analysis*, 5th ed. West Lafayette, IN, USA: Springer, 2017.
[49] G. M. Hall, Ed., *Fish Processing Technology*, 2nd ed. London, UK: Blackie Academic & Professional, 1997.
[50] D. P. Sen, *Advances in Fish Processing Technology*. Mumbai, India: Allied Publishers, 2005.
[51] S. Wichchukit and M. O'Mahony, "The 9-point hedonic scale and hedonic ranking in food science: Some reappraisals and alternatives," *J. Sci. Food Agric.*, vol. 95, no. 11, pp. 2167–2178, 2015, doi: 10.1002/jsfa.6993.

[52] T. T. T. Linh, T. T. M. Huong, and N. Thammachot, "Sustainable nutrient management for NFT hydroponic lettuce: Integrating kipahit (*Tithonia diversifolia*) liquid organic fertilizer with AB-mix," *Integr. Sci. Educ. J.*, vol. 6, no. 3, pp. 240–248, 2025, doi: 10.37251/isej.v6i3.2118.

[53] S. K. Amit, M. M. Uddin, R. Rahman, S. M. R. Islam, and M. S. Khan, "A review on mechanisms and commercial aspects of food preservation and processing," *Agric. Food Secur.*, vol. 6, no. 1, p. 51, 2017, doi: 10.1186/s40066-017-0130-8.

[54] G. T. Adeyanju and O. Ishola, "Salmonella and *Escherichia coli* contamination of poultry meat from a processing plant and retail markets in Ibadan, Oyo State, Nigeria," *SpringerPlus*, vol. 3, no. 1, p. 139, 2014, doi: 10.1186/2193-1801-3-139.

[55] E. J. Rifna, M. Dwivedi, and O. P. Chauhan, "Role of water activity in food preservation," in *Food Preservation: Principles, Processing and Preservation*. Singapore: Springer, 2022, pp. 21–42.