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DESIGN, FABRICATION, AND EVALUATION OF A LOW-COST AND MOBILE FISH SMOKEHOUSE FOR SMOKED SOFT-BONED MILKFISH

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ABSTRACT

This study details the design, fabrication, and evaluation of a low-cost (PhP 20,867.63), mobile fish smokehouse to support livelihood programs in Naic, Cavite, Philippines. The unit, built from a recycled 200-liter drum, was tested using a 2 x 2 factorial experiment. Results showed smoking time significantly impacted moisture removal ($p < 0.01$), achieving an average rate of 52.63 ± 2.86 %/hr. A cost-benefit analysis demonstrated high financial viability, with a 167% ROI and a 7.19-month payback period. A key limitation was identified: comparative testing showed the unit had a significantly lower moisture removal rate ($p=0.004$) and received lower sensory acceptability scores ($p=0.045$) than a conventional smokehouse, likely due to suboptimal thermal efficiency and smoke distribution. Despite these performance trade-offs, the smokehouse proves to be a financially viable and portable solution for community-level extension and supplementary livelihood.

I. INTRODUCTION

Fish is one of the most popular and widely consumed protein foods in the world. This aquatic resource includes several species that people commonly buy for consumption. Fresh fish are in demand among people of all social groups. High production that causes surplus supplies and spoilage is one of the key reasons for developing post-harvest products or practicing fish preservation. Fish smoking is one of the most popular preservation techniques in developing countries due to its simplicity and low operational inputs, holding significant economic importance for the seafood sector [1]. This process not only mitigates high production leading to surplus supplies and spoilage but also extends the market reach of fish products. Smoking is highly adaptable to small-scale and community operations, even in coastal regions and inland communities close to water bodies. This method, a cornerstone of coastal livelihoods in the Philippines, often faces constraints due to available technology [2].

Fish processing is a vital source of supplementary income in the province of Cavite, particularly in coastal municipalities like Naic. The Cavite State University Naic (CvSU Naic) research and extension unit is mandated to convert research into sustainable extension projects that will help improve the lives of the people in its service areas, aligning with national fishery objectives to upgrade post-harvest technologies. A continuous extension project that promotes smoked soft-boned milkfish technology has identified a pressing need for an innovative processing solution. This project specifically targets groups like the Naic Solo Parents Association to provide livelihood and increase income. However, significant socioeconomic barriers hinder the adoption and scaling of this technology. High initial capital—conventional smokehouses, even simplified local models, require a substantial initial investment [3], [4]. Logistical constraints & lack of portability—existing smokehouse designs are typically bulky, stationary, and non-modular [2]. This lack of portability makes it impractical for extension workers to conduct hands-on training across different barangays (villages) in Naic, and it also prevents beneficiaries from relocating their production to match seasonal fish landings or access different local markets.

Livelihood barriers—the combination of high cost and immobility means that traditional smoking technology is not accessible as a supplementary livelihood, which requires low-risk, low-cost, and flexible solutions. This technology gap directly impedes sustainable livelihood improvement and economic empowerment at the community level. Addressing this gap aligns with broader development goals, including Sustainable Development Goal 8 (Decent Work and Economic Growth) by fostering local entrepreneurship and SDG 2 (Zero Hunger) by improving food preservation, adding value to local products, and reducing post-harvest losses [5]. Therefore, this research directly addresses this identified gap by focusing on the innovative design, efficient fabrication, and rigorous evaluation of a novel low-cost and mobile fish smokehouse. This unit was made to help small-scale fish processors to overcome the financial and logistical problems they face. It provides a practical, portable, and affordable way to make high-quality smoked soft-boned milkfish at the community level.While various "improved" smoking kilns, such as the Chorkor oven, FTT (FAO-Thiaroye Technique), and other locally modified cabinet-type smokers, have been developed, many still face challenges of high fabrication cost, lack of portability, or complex operation [2], [6-8].

Conventional models are often stationary, limiting their use to a central processing facility [3], [9], [10]. The primary novelty of the smokehouse proposed in this study lies not in a new smoking chemistry but in its synthesis of critical design features tailored for community extension and small-scale entrepreneurship: (1) affordability—the design prioritizes the use of locally sourced, low-cost, and recycled materials, primarily a 200-liter food-grade steel drum, achieving a final fabrication cost of PhP 20,867.63—well below many standardized 'improved' models; (2) mobility—unlike stationary kilns, this unit is integrated onto a wheeled frame, transforming it from a fixed piece of equipment into a portable technology-demonstration tool, this directly addresses the logistical challenges of extension work, allowing the smokehouse to be brought to different barangays for on-site training; (3) specific applicability—the combination of low cost and mobility makes it a highly applicable solution for supplementary livelihood programs, it lowers the barrier to entry for beneficiaries (e.g., Naic Solo Parents Association) and provides a flexible asset that can be shared or moved as needed. This design explicitly prioritizes financial accessibility and logistical flexibility over achieving maximum thermal efficiency or throughput, differentiating its application from larger, stationary kilns designed for established commercial operations [11], [10].

II. MATERIALS AND METHODS

II.1 DESIGN AND FABRICATION OF THE MOBILE SMOKEHOUSE

The low-cost, mobile fish smokehouse was designed as a vertical, indirect smoking system to prevent direct contact between the fish and fire/ash. The design prioritized two key factors: extreme affordability and portability, differentiating it from high-throughput industrial kilns [4], [12]. The main smoking chamber was fabricated from a readily available, recycled 200-liter food-grade steel drum. The total fabrication cost was documented as PHP 20,867.63. Figure 1 shows the major components, and Figure 2 displays the finalized fabricated unit.

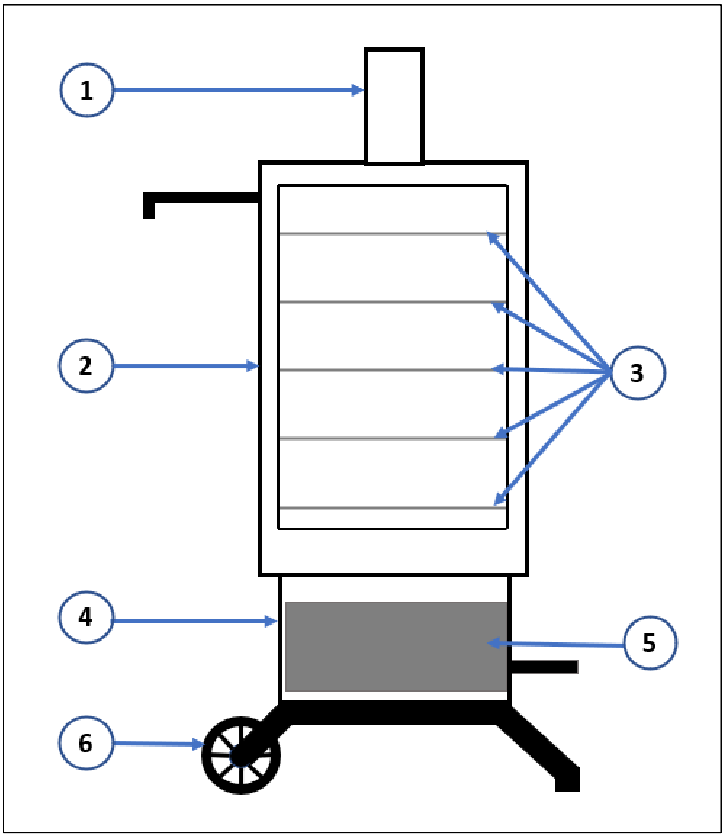

Figure 1: The major components of the low-cost fish smokehouse include: (1) chimney; (2) smoking chamber; (3) smoking trays; (4) heating chamber; (5) charcoal pot; and (6) mobility frame.
Source: Authors (2026).

Figure 3 demonstrates the functionality of the mobility features incorporated into the design and fabrication of the fish smokehouse. It demonstrates that the wheels and push handle allow for the relatively easy movement of the assembled unit by a single person, highlighting the successful implementation of the "mobile" design consideration. This portability would be advantageous for transporting the smokehouse to different locations for use, cleaning, or storage, potentially increasing its practicality for small-scale fish processors.

Figure 2: The low-cost and mobile fish smokehouse.
Source: Authors (2026).

Figure 3: Mobility testing of the fabricated fish smokehouse.
Source: Authors (2026).

Table 1 presented the established specifications of the major components of the low-cost and mobile fish smokehouse. The material selections for each component of the low-cost and mobile fish smokehouse were considered in its design considerations of low cost, local availability, food-grade suitability, ease of operation, and portability. The simple pipe design of the chimney facilitated unobstructed airflow, and the adjustable damper provided basic control over smoke and heat regulation. The 200-liter food-grade steel drum indicates an emphasis on low cost and the potential for using readily available recycled materials. The notable features included a hinged door with a latch. The five levels of tray support allowed for smoking multiple layers of fish simultaneously, increasing capacity. The hinged door with a latch ensured easy access for loading and unloading while maintaining a sealed environment during smoking. The fabrication of the heating chamber utilizing steel plate with heat-resistance paint reflected the ability to withstand the direct heat source. The key features of the heating chamber included its separate location below the smoking chamber and smoke vents positioned between the chambers. The charcoal pot was tailored to fit within the heating chamber, ensuring efficient heat transfer and heat resistance from charcoal.

Table 1: Specifications of the major components of the low-cost and mobile fish smokehouse.

MAJOR COMPONENTS	SPECIFICATION		
	Material	**Dimension**	**Features**
1. Chimney	• rounded steel plate • heat resistance paint	• 125 mm diameter • 250 mm height • 2 mm thick	• adjustable damper at the top
2. Smoking chamber	• 200-liter food-grade steel drum • heat resistance paint	• 584 mm diameter • 901.7 mm height • 2 mm thick • 150 mm vertical distance of tray support	• hinged door with latch • five levels of tray support (stainless)
3. Smoking trays	• 304-stainless steel rod	• 500 mm diameter	• with two handles
4. Heating chamber	• steel plate • heat resistance paint	• 500 mm width • 300 mm length • 300 mm height • 2 mm thick	• separate chamber below the smoking chamber • smoke vents in between chambers
5. Charcoal pot	• steel plate • heat resistance paint • steel pipes	• 450 mm width • 250 mm length • 250 mm height • 2 mm thick	• fabricated to fit inside the heating chamber • with two handles
6. Mobility frame	• angular steel bars • steel rod • rubber rim and bearings (wheel)	• various lengths on the parts for the mobility smokehouse	• with two wheels • base frame • stand • push handle

Source: Authors (2026).

II.2 EXPERIMENTAL DESIGN AND PERFORMANCE EVALUATION

The performance evaluation of the mobile smokehouse focused on its efficiency in removing moisture, a critical parameter for quality and shelf life [13]. Preliminary testing was conducted at the CvSU Naic Mabolo Annex to evaluate the operative conditions for processing smoked soft-boned milkfish in the fabricated fish smokehouse. The preliminary testing of the low-cost and mobile fish smokehouse involved the observation and recording of the duration required to achieve the moisture removal rate (%/hr) and the intended golden-brown color of the smoked fish. The study employed a 2x2 factorial experiment in a Completely Randomized Design (CRD) to investigate the effects of smoking time and loading capacity on the moisture removal rate of soft-boned milkfish processed in the fabricated low-cost fish smokehouse. Two independent variables were examined: smoking time at two levels (30 minutes and 60 minutes) and loading capacity at two levels (10 kg and 15 kg). The experimental unit consisted of a batch of five (5) individual soft-boned milkfish samples.

These samples were grouped according to the four combined levels of the independent variables, creating four distinct experimental treatments. The assignment of experimental treatments to different batches of fish was randomized. Furthermore, each of the four treatment combinations was replicated three (3) times. This resulted in a total of twelve (12) experimental units (batches of fish) being processed and analyzed. The dependent variable measured in this experiment was the average moisture removal rate (%/hr) for each batch of smoked soft-boned milkfish under the specified treatment conditions. A protocol was established to facilitate the production of smoked soft-boned milkfish using a fabricated fish smokehouse. The main phases of the protocol to facilitate the production of smoked soft-boned milkfish using a mobile and low-cost fish smokehouse are illustrated in Figure 4. The subsequent processes are as follows: (1) freezing, (2) thawing, (3) cleansing, (4) soaking in brine solution, (5) pressure cooking, (6) drying, (7) smoking, (8) packaging, and (9) storing.

II.3 SENSORY EVALUATION

The finished smoked milkfish products from both the mobile unit and the conventional smokehouse were subjected to a consumer acceptability test. A preference or acceptance test, utilizing a 5-point hedonic scale, was adopted as the sensory testing method [14], [15] Thirty (30) participants were recruited for the taste tests, comprising ten (10) experienced smoked soft-boned processors, ten (10) instructors/professors (five from the Fisheries and Aquatic Sciences Department (FASD) and five from the Management Department (MD), and ten (10) Bachelor of Science in Fisheries and Aquatic Sciences students. The organoleptic parameters assessed during the taste test included color, taste, aroma, texture, and general acceptability. For each parameter, participants indicated their preference using the 5-point hedonic scale. The taste tests were carried out in the Conference Room, CvSU Naic. Prior to the evaluation, a brief orientation was conducted by the study staff to explain the procedure, duration, and materials involved. The evaluation form was also thoroughly explained to each participant. Each participant was assigned a designated taste test booth equipped with the test samples, rating forms, a pencil with an eraser, clean drinking water, a comfortable adjustable chair, a spoon, a fork, and a small knife.

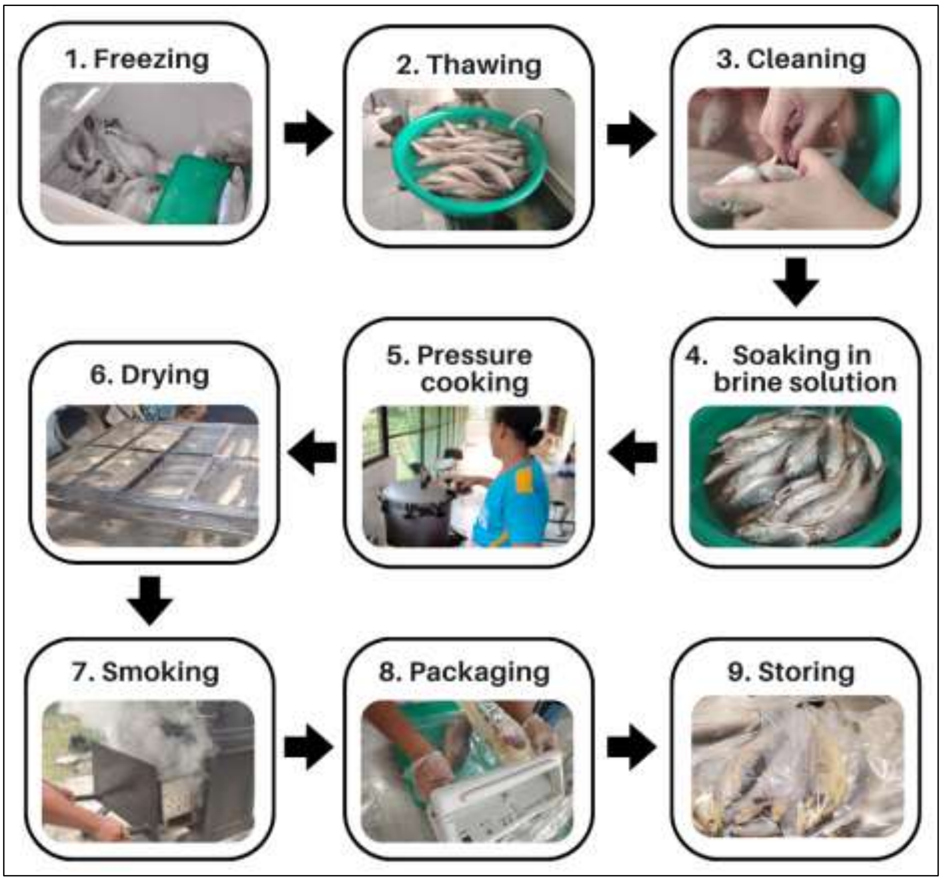

Figure 4: Main phases of the protocol for smoked soft-boned milkfish production.
Source: Authors (2026).

II.4 STATISTICAL ANALYSIS AND COST-BENEFIT ANALYSIS

The data collected from the various stages of the study were subjected to appropriate statistical analyses to address the research objectives. For objectives that focused on the design, fabrication, and evaluation of the newly developed low-cost fish smokehouse, descriptive statistics (means and standard deviations) were calculated to summarize the moisture removal rate under different loading capacities (10 kg and 15 kg) and smoking times (30 minutes and 60 minutes). A two-way analysis of variance (ANOVA) was employed to determine the significant effects of loading capacity and smoking time, as well as their interaction, on the moisture removal rate. The significance level was set at $p < 0.05$. For objectives that involved a comparative performance evaluation of the existing and newly developed fish smokehouses, the average moisture removal rate of the existing smokehouse was calculated using descriptive statistics. An independent samples t-test was used to see how the two smokehouses' moisture removal rates compared. The p-value for significance was set at 0.05. The sensory acceptability data, obtained from the preference tests, were analyzed using descriptive statistics for each sensory attribute for the smoked soft-boned milkfish produced by both the newly developed and the existing smokehouses. To determine if there were significant differences in the overall acceptability between the products of the two smokehouses, an independent samples t-test was performed, with the significance level set at $p < 0.05$. A simple cost analysis was performed for the newly constructed smokehouse. This analysis involved the calculation of the payback period (PBP), breakeven point (BEP), benefit-cost ratio (BCR), and return on investment (ROI) based on the estimated costs of materials, fabrication, and potential income from the smoked fish production.

III. RESULTS AND DISCUSSIONS

III.1 OPERATING CONDITIONS TO PROCESS SMOKED SOFT-BONED MILKFISH

Figure 5 illustrates the moisture removal rate and change in the color of the smoked soft-boned milkfish over time. The findings indicated that the newly developed low-cost smokehouse could achieve the desired "golden brown" color for smoked soft-boned milkfish within a relatively short smoking time of approximately 30 minutes. This suggested efficient heat and smoke transfer within the smoking chamber. Table 2 shows how the loading capacity (10 kg and 15 kg) and smoking time (30 minutes and 60 minutes) affect the moisture removal rate (%/hr) of the smoked soft-boned milkfish. The results showed that, regardless of the loading capacity, the average moisture removal rate was notably higher for the 30-minute smoking time (52.63 ± 2.86 %/hr) compared to the 60-minute smoking time (27.42 ± 2.21 %/hr). The total average moisture removal rates for the 10 kg loading capacity (40.81 ± 14.49 %/hr) and the 15 kg loading capacity (39.24 ± 13.53 %/hr) were relatively similar. The significantly higher moisture removal rate observed at the 30-minute smoking time compared to the 60-minute smoking time, irrespective of the loading capacity, suggested that the initial stage of smoking was more effective in removing moisture.

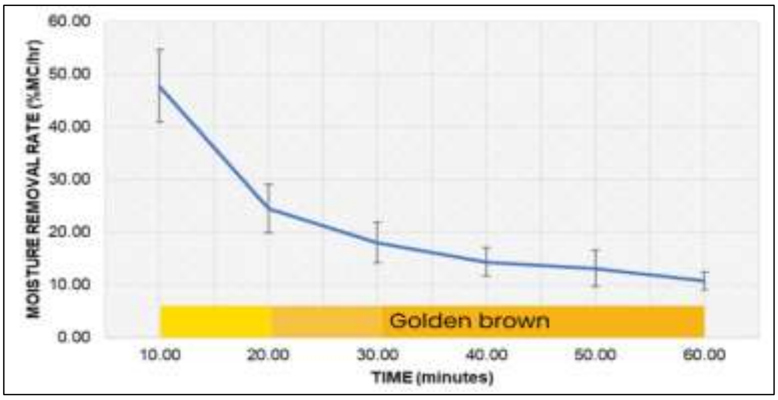

Figure 5: The change in the color and moisture removal rate of the smoked soft-boned milkfish over time.
Source: Authors (2026).

Table 2: Effects of loading capacity and smoking time on the moisture removal rate of smoked soft-boned Milkfish.

LOADING CAPACITY (kg)	SMOKING TIME (min)	MOISTURE REMOVAL RATE (%/hr) Mean	± S.D.	BATCH (Samples)
10.00	30.00	53.76	± 3.86	3 (15)
	60.00	27.86	± 2.64	3 (15)
	Total	40.81	± 14.49	6 (30)
15.00	30.00	51.50	± 1.30	3 (15)
	60.00	26.97	± 2.15	3 (15)
	Total	39.24	± 13.53	6 (30)
Total	30.00	52.63	± 2.86	6 (30)
	60.00	27.42	± 2.21	6 (30)
	Total	40.02	± 13.39	12 (60)

Source: Authors (2026).

III.2 ACCEPTABILITY OF SMOKED SOFT-BONED MILKFISH PRODUCED USING THE EXISTING AND NEWLY DEVELOPED FISH SMOKEHOUSE

Table 3 presents the sensory acceptability scores for smoked soft-boned milkfish produced using both the newly developed and the existing smokehouses, evaluated across five attributes. The scores were based on a 5-point hedonic scale, where 5 represented "Like Extremely" or the most desirable attribute, and 1 represented "Dislike Extremely" or the least desirable.

Table 3: Sensory acceptability scores for smoked soft-boned milkfish produced using both the newly developed and the existing smokehouses.

Attributes	Acceptability	
	Newly developed smokehouse	**Existing smokehouse**
Color	3.33 ± 0.96 (Slightly uneven)	4.58 ± 0.61 (Very appealing)
Taste	3.94 ± 0.70 (Balanced)	4.42 ± 0.71 (Delicious)
Aroma	4.09 ± 0.63 (Pleasant smoky aroma)	4.42 ± 0.56 (Very Appealing)
Texture	4.06 ± 0.66 (Firm, moist and flaky texture)	4.03 ± 0.77 (Firm, moist and flaky texture)
General acceptability	4.03 ± 0.82 (Like Moderately)	4.42 ± 0.75 (Like Extremely)

Source: Authors (2026).

For color, the smoked milkfish from the existing smokehouse received a significantly higher mean score of 4.58 ± 0.61, corresponding to "Very Appealing," compared to the newly developed smokehouse, which had a mean score of 3.33 ± 0.96, categorized as "Slightly uneven." In terms of taste, the existing smokehouse also yielded a higher mean score of 4.42 ± 0.71 ("Delicious") compared to the newly developed smokehouse, which received a mean score of 3.94 ± 0.70 ("Balanced"). Similarly, the aroma of the smoked milkfish from the existing smokehouse was rated higher with a mean of 4.42 ± 0.56 ("Very Appealing") compared to the newly developed smokehouse, which had a mean of 4.09 ± 0.63 ("Pleasant smoky aroma"). Regarding texture/mouthfeel, the mean scores were comparable between the two smokehouses. The existing smokehouse received a score of 4.03 ± 0.77 ("Firm, moist, and flaky texture"), while the newly developed smokehouse was rated at 4.06 ± 0.66 ("Firm, moist, and flaky texture"). Finally, for overall acceptability, the smoked soft-boned milkfish produced by the existing smokehouse received a significantly higher mean score of 4.42 ± 0.75 ("Like Extremely") compared to the newly developed smokehouse, which had a mean score of 4.03 ± 0.82 ("Like Moderately").

III.3 DIFFERENCE IN THE MOISTURE REMOVAL RATE (%/HR) BETWEEN THE EXISTING AND NEWLY DEVELOPED FISH SMOKEHOUSE

The newly developed smokehouse exhibited a mean moisture removal rate of 53.76 ± 3.86 %/hr, while the existing smokehouse had a mean rate of 59.13 ± 3.53 %/hr. There was a statistically significant difference in the moisture removal rate between the two smokehouses. Specifically, the average rate of moisture removal from the existing smokehouse (59.13 ± 3.53 %/hr) was significantly higher than that of the newly developed smokehouse (53.76 ± 3.86 %/hr). The statistical analysis revealed a significant difference in the efficiency of moisture removal between the newly developed and the existing fish smokehouses. Results suggested the existing smokehouse was more effective at reducing the moisture content of the fish under a loading capacity of 10 kg and a smoking time of 30 minutes (table 4).

Table 4: Independent samples t-test results comparing the average moisture removal rate.

Smokehouses	Average Moisture Removal Rate (%/hr)		t-statistics	df	p-value
	Mean	± S.D.			
Newly developed	53.76	± 3.86	-3.210	25	0.004
Existing	59.13	± 3.53			

Source: Authors (2026).

III.4 DIFFERENCE IN THE OVERALL ACCEPTABILITY OF THE EXISTING AND NEWLY DEVELOPED FISH SMOKEHOUSE'S SMOKED SOFT-BONED MILKFISH PRODUCTS

The mean overall acceptability score for the milkfish from the newly developed smokehouse was 4.03 ± 0.82 ("Like Moderately"), while the milkfish from the existing smokehouse had a mean score of 4.42 ± 0.75 ("Like Extremely"). The statistical analysis revealed a significant difference in the overall sensory acceptability of the smoked soft-boned milkfish produced by the two types of smokehouses. The panelists, comprising experienced smoked fish processors, fisheries experts, and students, exhibited a significantly higher preference for the product originating from the existing smokehouse compared to the product from the newly developed one.

Table 5: Independent samples t-test comparing the overall acceptability.

Smokehouses	Overall acceptability		t-statistics	df	p-value
	Mean	± S.D.			
Newly developed	4.03 (Like Moderately)	± 0.82	-2.049	64	0.045
Existing	4.42 (Like Extremely)	± 0.75			

Source: Authors (2026).

III.5 SIMPLE COST ANALYSIS

A simple cost analysis was done to present the economic viability of fabricating the low-cost mobile smokehouse. The total cost of constructing one unit of the developed smokehouse is PHP 20,867.63. Table 6 outlines the key financial assumptions used in the cost analysis. These assumptions provide the foundation for understanding the economic viability of the low-cost fish smokehouse. Table 7 presents the results of the cost analysis, derived from the assumptions in Table 6. These results provide key metrics for evaluating the financial feasibility of the smokehouse.

Table 6: Basic assumptions for the simple cost analysis of the smokehouse.

Basic Assumptions	Value
Initial capital investment (IC) (PHP)	20,867.63
Useful life (years)	5
Estimated salvage value, 10% IC (PHP)	2,086.76
Repair and maintenance, 5% per year (PHP)	1,043.38
Cost of goods sold per batch (PHP)	4,350
Smokehouse capacity per batch (kg)	15
Number of batches per year	24
Selling price of smoked soft-boned bangus per kg (PHP)	400/kg
Revenue per batch (PHP)	6,000
Annual depreciation (PHP)	3,756.17
Annual gross profit (PHP)	39,600
Annual net profit (PHP)	34,800.45

Source: Authors (2026).

The simple cost analysis reveals promising economic viability for the low-cost fish smokehouse. The payback period of approximately 7.19 months indicates a rapid recovery of the initial investment of PHP 20,867.63. The substantial annual net profit of PHP 34,800.45 primarily contributes to this swift return. The breakeven point analysis demonstrates that the smokehouse operation will start generating profit after producing and selling around 13 batches of smoked fish, with a corresponding revenue of PHP 75,900. Based on the assumptions, the business is expected to make more money than it costs to run in the first year. The benefit-cost ratio (BCR) of 1.32 signifies a highly favorable return. For every peso invested in the fish smokehouse, approximately PHP 1.32 in benefits (revenue) is generated. Since the BCR exceeds 1, the project is considered economically viable and generates more benefits than costs.

Furthermore, the return on investment (ROI) of 167% indicates that the smokehouse is expected to yield a very high return relative to the initial capital invested. This suggests that the low-cost fish smokehouse has the potential to be a financially attractive venture.

Table 7: Simple cost analysis results.

Parameters	Value
Payback period (PBP)	
PBP, months	7.19
PBP, years	0.599
Breakeven Point (BEP)	
BEP, batches	12.65 ≈ 13
BEP, PHP	75,900.00
Benefit-Cost Ratio	1.32
Return on Investment, % (ROI)	167

Source: Authors (2026).

When compared to other low-cost smoking devices, the findings of this study are highly consistent with the trade-offs observed in technology scaling. For instance, the PHP 20,867.63 fabrication cost (approx. $350 USD) is extremely competitive. Bartolome et al. [4] reported an automated village-level machine with a higher capacity but a significantly higher cost of PHP 170,000.00. Other locally modified drum-type kilns have shown similar challenges in balancing initial investment, portability, and performance [9]. This comparison highlights that while our mobile unit trades some thermal performance (lower MRR and sensory scores) for a drastic reduction in cost and an increase in mobility, its financial viability (167% ROI) presents a unique and necessary advantage for the target socioeconomic context. The novelty lies not in technological perfection, but in optimizing the design for accessibility and extension work, thereby lowering the barrier to entry for marginalized groups in coastal communities.

III.6 DESIGN LIMITATIONS

A significant finding of this study was the trade-off between the primary goals of low cost and mobility and the resulting product quality. The sensory evaluation revealed that while the smoked milkfish from the mobile unit was acceptable (rated "Like Moderately"), it scored significantly lower in overall acceptability, color, taste, and aroma compared to the product from the existing, conventional smokehouse. This outcome is likely attributable to several key technical factors inherent in the prototype's design. Airflow Dynamics and Smoke Distribution—the mobile unit employs an indirect smoking method, where the smoke generator is separate from the main 200-liter drum chamber. While this design (shown in Figure 1) successfully separates the heat source from the food, it relies on natural convection to carry smoke to the fish. Without optimized baffles or a fan, the smoke and heat likely flowed unevenly through the cylindrical chamber. This hypothesis is strongly supported by the "slightly uneven" color noted in the sensory results (Table 7). Conventional, larger kilns often have a more optimized geometry or baffling systems to ensure uniform smoke contact [2], [11]. Smoke Density and Thermal Efficiency—in an indirect system, the smoke must travel from the heating chamber to the smoking drum.

This travel path can allow the smoke to cool, which may cause some of the "heavy" phenolic compounds responsible for desirable, rich smoke flavor and aroma to condense before reaching the fish [15]. Furthermore, the design's focus on low-cost materials (a single-walled steel drum) results in poor heat retention (low thermal efficiency) compared to insulated or thicker-walled kilns [16], [8]. The consequent lower, and potentially less stable, temperature profile within the smoking chamber could inhibit the Maillard reactions responsible for developing a deep, uniform golden-brown color, leading to the "slightly pale" appearance. Implications for Future Design—These results are crucial for guiding future improvements, as suggested by the reviewer. The lower sensory scores are not a failure of the concept but a clear indication of a performance trade-off. Future iterations should focus on optimizing the smoke-heat delivery system. As noted in the recommendations, integrating a simple baffling system, improving the insulation of the drum (e.g., a "drum-in-drum" design or external clay insulation), or even incorporating a small, low-cost solar-powered fan to regulate airflow could significantly improve smoke density and thermal distribution. These enhancements would directly address the uneven color and milder flavor profile, bridge the quality gap while maintaining the core benefits of low cost and mobility.

V. CONCLUSIONS

The results indicate that the low-cost and mobile fish smokehouse successfully met the basic design objectives of portability, affordability, and food safety. Its construction using locally sourced materials and its integration of indirect smoking principles provide a practical and replicable model for small-scale applications. Nevertheless, the evaluation revealed that the moisture removal efficiency and sensory quality of the smoked products were significantly lower than those produced by the existing conventional smokehouse. These findings highlight the need for further design refinements, particularly in improving thermal efficiency and smoke distribution within the chamber. Integrate a simple, low-cost baffling system within the smoking chamber to ensure a more uniform distribution of heat and smoke, which would directly address the "slightly uneven" color noted by panelists. Enhance the insulation of the smoking chamber. A low-cost "drum-in-drum" design or an outside layer of insulating material could be used to keep the heat in and keep the temperature inside stable. Explore the integration of a small, low-cost, solar-powered fan to create a forced-draft system. This would provide better control over smoke density and airflow, potentially improving both the moisture removal rate and the sensory profile. Future design iterations should employ advanced analysis tools to improve rigor. Integrating thermal imaging can visualize heat distribution in real-time, while Computational Fluid Dynamics (CFD) simulation can be used to model and optimize internal airflow and smoke distribution before fabrication.

VI. AUTHOR'S CONTRIBUTION

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