



Participatory Extension Approaches for Good Manufacturing Practices (GMP) Adoption in Rural Fish Processing: Evidence from Southern Thailand

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Abstract: Dry-fermented catfish (pla-duk-ra) is a potential value-added product in Southern Thailand; however, it faces food safety hazards because small-scale backyard operations dominate and lack supporting regulations. This study evaluated a participatory extension approach to promote Good Manufacturing Practices (GMP) within the Banphabontam Agricultural Innovation Community Enterprise (BAICE). The original GMP evaluation involved the design of facilities, control of equipment, process operations, cleanliness and sanitation, maintenance, and personnel practices. None of the six domains achieved a score of 60%, indicating that all areas remained below the minimum acceptable level. Participatory extension led to the implementation of various improvements, such as facility redesign, workflow zoning, hygiene training, and basic sanitation systems. Following the upgrade, BAICE achieved GMP certification and formal recognition as a licensed food producer. The refined layout separated wet and dry zones, improved drainage and pest control, and established distinct storage and preparation spaces. These interventions increased workers' hygiene awareness and responsibility without altering the sensory characteristics or cultural identity of pla-duk-ra. This initiative exemplifies community-driven food safety enhancement through participatory extension. It demonstrates how scientific principles and traditional knowledge can align to improve product quality, regulatory compliance, and market potential. Findings from the BAICE case provide practical, context-specific evidence that may inform GMP implementation and rural food system improvement in similar community-based food enterprises. The results align with national agendas to support the development of sustainable food and highlight that extension work plays a crucial role in making traditional foods safe, competitive, and sustainable products.

Keywords: Participatory extension; GMP; rural fish processing; technology transfer, food safety

1. Introduction

Aquaculture is very important for agricultural diversification and food security in Southeast Asia. Among the freshwater species in Thai aquaculture, hybrid catfish (pla-duk-big-oui) is the second-most successful species being

raised in central and southern Thailand. Thailand has become a regional model for coupling sustainable fish culture with value-added processing to improve marketability and create economic gains. In 2024, Thailand produced approximately 91,095 metric tons of catfish, which accounted for around 20% of the country's overall freshwater aquaculture production. This has derived an annual income of around 121 million USD [1].

Pla-duk-ra is a processed fish product with a strong cultural heritage and significant economic importance to the southern Thai population. As one of the most popular value-added catfish products, it is a good example of maximizing available natural resources and enhancing local people's livelihoods. The amount of pla-duk-ra produced is a good example of combining the tradition of fish farming with indigenous knowledge over the generations. The preparation process begins with selecting fresh catfish of appropriate size, followed by removing the head, internal organs, and excess fat. The cleaned fish are then washed thoroughly before being mixed with salt and sugar for fermentation. Fermentation typically lasts 1 to 2 days, after which the fish are dried in the sun or under a controlled heat source. This process results in a distinct salty-sweet flavor and a mild fermented aroma, which differentiate pla-duk-ra from other forms of salted fish [2]. According to a recent market report by our research team, pla-duk-ra had a potential estimated annual market value of approximately USD 5.4–8.1 million in 2024. This indicates that it represents a major component of the regional fish-processing industry. In Phatthalung province, community-based businesses that combined catfish farming and the processing of pla-duk-ra recorded the highest profit increase. The monthly income of this family increased from about USD 620 to USD 2,600, and net profit increased by 346% as a result of adding value production methods based on the fry pla-duk-ra paste product form (chili paste, sweet fish sauce, and rice seasoning powder) that were practiced in the process line [3].

The Banphabontam Agricultural Innovation Community Enterprise (BAICE) is one example of such a local innovation ecosystem in Phatthalung province. Traditional techniques are what the company has staked its name on. In 2023, the business earned only 1,860 USD in sales and netted just 744 USD in profits, with average monthly production at a very low level of about 200 kg. However, it struggled to scale up production, comply with regulations, and develop marketable derivatives. These questions illuminate the general problem of reconciling traditional food processing methods with modern requirements for food safety, a pressing issue in much of the developing world's community-based agricultural production. Small-scale community-processed food manufacturers must meet the Good Manufacturing Practices (GMP) prescribed by the Thai FDA. For these producers, this is a key step forward. Basic food safety regulations include the following: cleanliness in production spaces and equipment, proper personal hygiene, safe product preparation, clear boundaries between clean and dirty areas, and good organization of storage and transportation [4]. For a community enterprise like BAICE, achieving GMP certification offers easier entry into new markets, an added layer of customer trust, and the ability to register with the FDA. To ensure food safety and quality in the aquaculture and fish processing sectors, GMPs are essential. In agricultural extension terms, GMP constitutes both a technical intervention and a participatory-action process that builds on the capacity of community-based enterprise, elicits change in producer behavior, and triggers development in the rural economy.

The GMP provides guidelines for small-scale producers on sanitation, process control, and equipment management. This enables them to maintain an amazing practice in fish processing, on the one hand, observe formal food safety standards, maintain a competitive edge over competitors, and increase consumers' confidence, on the other. The empirical experience across Southeast Asia has demonstrated that GMP can have a transformative effect on the safety and market value of aquatic products. For instance, the adoption of GMP in the production of pla-duk-ra in Phatthalung province (Thailand) has made the microbiological process safer, more efficient, and more cost-effective. Their monthly profits from local manufacturers were more than 300% higher after adding the ready-to-eat and by-product lines [5]. Analogous actions were applied to Indonesian small-scale fish production, resulting in reduced contamination and spoilage and making the certification process more applicable [6]. In terms of extension systems, the GMP training and certification cycles indicate that the transfer of agricultural technology can increase productivity and sustainability while preserving cultural knowledge. Participatory GMP (hygienic) upgrading (including sanitation, process flow design, and environmental management) is an instance of a science-and-practice-driven integrated rural

development model [3]. By shifting the focus of agricultural extension work from productivity-driven interventions to public health- and environmental-sustainability-oriented initiatives, GMP drives important systems-level changes that improve local business capabilities and foster more inclusive food value chains. The implementation of GMP to improve the quality of traditional beverages also aligns with the Thai government's National Strategic Framework (2018–2037) for enhancing competitiveness. This structure advocates for security and safe, sustainable agriculture to increase farmers' Gross Domestic Product [7]. Strategically, this linkage underscores the relevance of GMP-related interventions to other overriding national development objectives and to the convergence of extension policy.

This research examined technical interventions in community-based catfish processing establishments regarding the extent of GMP compliance. It also examined the role of GMP in disseminating innovation, facilitating knowledge transfer, and promoting sustainable rural development. It investigates BAICE's work in Phatthalung Province and adds to a growing body of evidence on extension strategies that successfully combine traditional knowledge systems with contemporary food safety standards. This integration enriched cultural identity and strengthened the economic viability of community-based agro-enterprises.

2. Materials and Methods

This study hypothesizes that a participatory extension approach can significantly elevate traditional pla-duk-ra production to GMP-compliant standards, yielding safer and more uniform products, broader consumer acceptance, and sustainable community income. To test this hypothesis, the study draws on Participatory Action Research (PAR), agricultural extension theory, and food-safety management principles, conceptualizing Good Manufacturing Practices (GMP) adoption not as one-way technology transfer but as an iterative, multi-stakeholder learning process in which scientific knowledge and indigenous wisdom are jointly mobilized. The framework comprises four interconnected components (Figure 1). Contextual inputs capture the pre-intervention state of the Banphabontam Agricultural Innovation Community Enterprise (BAICE): indigenous fermentation know-how, baseline GMP compliance below 60 %, limited food-safety infrastructure, absence of regulatory registration, and restricted market access. The participatory intervention process engages three stakeholder groups - university researchers, BAICE processors, and public health consultants - through a 30-month PAR cycle of diagnosis, co-design, trial, and reflection spanning four functional domains: facility redesign, hygiene control, packaging design, and regulatory documentation. Measurable outputs are evaluated across regulatory compliance, product safety, product quality, and economic performance, while outcomes and wider impact unfold at enterprise, community, and systems levels, aligning with Thailand's National Strategic Framework and the Sustainable Development Goals. Participatory extension thus serves as the bridge between traditional wisdom and modern regulation, allowing cultural identity and regulatory compliance to advance together through bidirectional knowledge flows.

2.1 Study area, research design, and general approach

The study was conducted at the Banphabontam Agricultural Innovation Community Enterprise (BAICE), located in Phabon District, Phatthalung Province, Thailand, over 30 months from March of 2023 to August of 2025. It employed a mixed-methods design, using (i) Participatory Action Research (PAR), (ii) laboratory assessment of product quality, and (iii) questionnaire-based evaluation. We chose PAR as the study design because addressing our research question required a cycle of action (a trial production run with modified procedures) followed by critical reflection and revision with stakeholders before moving on to the next round of interventions between researchers and community processors.

2.2 Participants & Sampling Strategy

This study comprised three stakeholder groups: (1) Research team, five researchers and research assistants from Thaksin University who facilitated the study, conducted laboratory work, and prepared documentation; (2) BAICE processors, five members, selected through purposive complete enumeration, as they represented the entire active workforce involved in pla-duk-ra processing at the time of the study. The inclusion criteria were: (i) at least two years of experience in processing pla-duk-ra; (ii) a primary role in at least one step of production, including preparation, salting, drying, or packaging; and (iii) agreement to

participate throughout the duration of the project. Because the sample size was small ($n = 5$), this group was considered a census of the target enterprise rather than a randomly drawn sample from a larger population. This structural feature and limitation of single-enterprise PAR studies are elaborated on in Section 2.3; and (3) Regulatory consultants—two food-safety officers from the Phatthalung Provincial Public Health Office, who provided regulatory advice and assisted with the FDA submission.

2.3 Participatory process and intervention/treatment timeline

The participatory process lasted 30 months, during which 30 site visits to BAICE were conducted. Engagement activities included: (1) 10 group meetings-situational analysis, joint planning, and post-cycle reflection meetings (approximately 2–3 h each); (2) five hands-on training workshops outlining GMP principles, hygienic processing, packaging, labelling, and microbiology (one day each); (3) five semi-structured in-depth interviews with BAICE members, using an interview guide addressing processing history, perceived problems, willingness to change, and post-intervention experiences; and (4) 10 on-site demonstrations of revised processing procedures performed jointly by researchers and BAICE member(s).

The different roles within the PAR cycles were clearly defined. (1) BAICE members selected locally relevant production challenges, designed changes to processing, carried out trials following modified protocols, and reported sensory and operational observations at the end of each experimental round. (2) Researchers and research assistants conducted workshops and facilitated reflection sessions, while all laboratory analyses, preparation of regulatory documents, and quantitative and qualitative data analyses were completed by the research team. (3) Public health consultants provided recommendations on good manufacturing practices and Thai FDA-compliant facility upgrades, as well as investigations of labeling and registration submissions.

2.4 Stage 1 Refined production of pla-duk-ra aligned with GMP

All production processes, equipment, tools, and storage practices at BAICE were evaluated and modified according to the Manual for Inspection of Food Production Facilities Based on Legally Mandated Good Manufacturing Practice Criteria 420 [8], issued under the Ministry of Public Health Notification No. 420, B.E. 2563 (2020), hereinafter referred to as “GMP 420.” Non-conformities identified during the baseline audit were considered jointly with BAICE members and public health consultants, followed by the co-design of corrective actions that were implemented before the next production cycle.

2.5 Stage 2 Laboratory and sensory quality assessment of pla-duk-ra

Pla-duk-ra samples were collected from BAICE both before the GMP intervention (baseline) and after implementation (post-intervention), allowing the same enterprise to serve as its own control. A total of three subsamples were randomly selected from at least a 1 kg production batch and analyzed in triplicate within 7 days of production at the Food Science and Technology Laboratory, Thaksin University.

Chemical and microbiological analyses included: (1) water activity (a_w), measured using an AQUA LAB Model 050796243 water-activity meter, calibrated against saturated salt standards on each day of use; and (2) enumeration of yeasts and molds, *Escherichia coli*, and *Staphylococcus aureus*, conducted according to the Bacteriological Analytical Manual (BAM, 2001) [9].

The Community Product Standards (TCPS, 2005) were followed for sensory evaluation [10]. Sensory evaluation of general appearance, color, flavor, and texture was performed according to the indicated testing protocol. At least five assessors trained in the evaluation of pla-duk-ra were assigned to the sensory evaluation panel. The samples were reviewed and scored independently by each assessor. The general appearance and color of the pla-duk-ra samples were visually assessed by placing them on white ceramic plates. The samples were fried under suitable temperature and time conditions, after which flavor and texture were assessed organoleptically. The scoring criteria were applied with sufficient evaluative instructions [10].

2.6 Stage 3 Packaging design and Thai FDA certification

The packaging and labeling of pla-duk-ra products were developed in accordance with the Ministry of Public Health Notification No. 367, B.E. 2557 (2014). Six products were submitted for Thai FDA certification in cooperation with the Phatthalung Provincial Public Health Office: (1) dry-fermented catfish, (2) ready-to-

eat fried pla-duk-ra, (3) sweet fish sauce, (4) khao yam sauce, (5) rice seasoning, and (6) dry-fermented catfish chili paste. The products were categorized by regulatory food category, including processed foods requiring labels, ready-to-cook foods, and ready-to-eat foods.

Thai FDA certification involved both the issuance of a food production facility license and the assignment of individual product registration numbers for each product and manufacturer via Form SB applications. The Thai FDA e-submission system then assessed the ingredient composition and permitted use levels. [8] The Phatthalung Provincial Public Health Office issued final certification.

2.7 Stage 4 Economic analysis

Upon completion of the intervention, a systematic cost-benefit analysis was conducted using project data through August 2025. Three financial indicators were calculated for each of the six FDA-certified products: (i) monthly income, (ii) cost of production, and (iii) net profit. Cost components included raw materials, packaging, labor, utilities, equipment depreciation, and certification fees, allocated to each product based on the selected allocation method.

2.8 Statistical analysis

All data were analyzed using IBM SPSS Statistics (version 26.0; IBM Corp., USA). Continuous variables are expressed as mean $\pm$ standard deviation of triplicate measurements. As BAICE served as its own control, paired comparisons between baseline and post-intervention values were performed. Water activity and sensory scores (general appearance, color, flavor, and texture) were compared using the paired-samples t-test, while log₁₀-transformed microbial counts (yeasts, molds, *E. coli*, and *S. aureus*) were compared using the Wilcoxon signed-rank test. Differences were considered statistically significant at $p < 0.05$. GMP compliance percentages, Thai FDA registration outcomes, and economic indicators are reported descriptively.

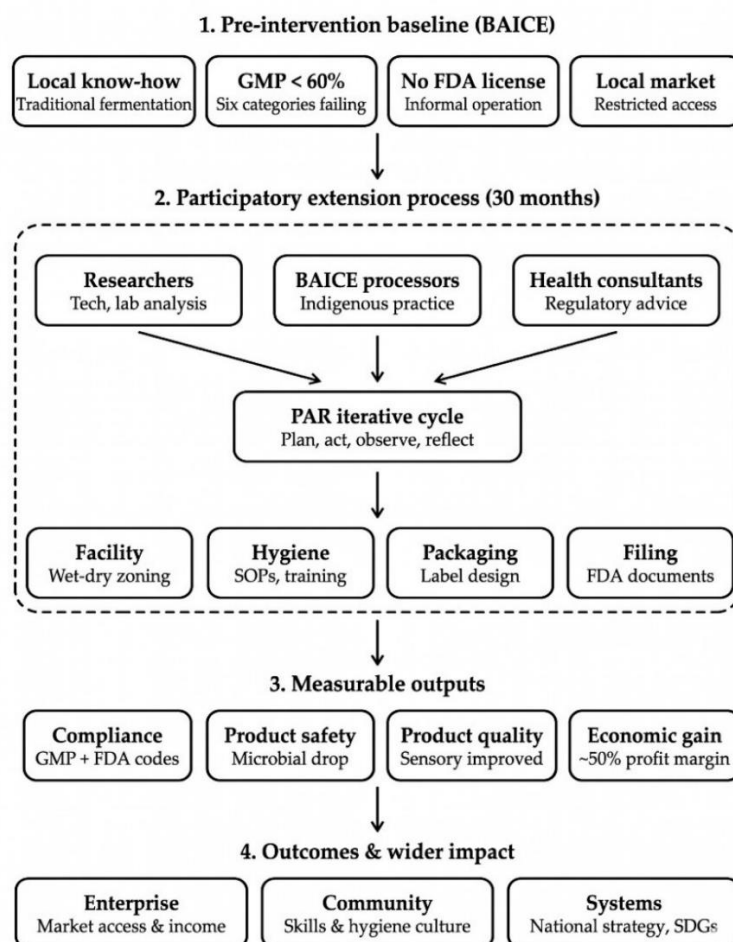


Figure 1. Conceptual framework

3. Results and Discussion

3.1. Development of pla-duk-ra products to GMP

BAICE was ready to go on facilities, as it already had a production site that could be improved to meet GMP standards. It also had a strong community with members who could keep the business running. A detailed study was conducted to inspect the production method using the food production facility inspection and evaluation form, according to the Ministry of Public Health Notification for BAICE, before and after improvements to meet GMP standard production systems. The GMP assessment of BAICE revealed that the pla-duk-ra production system faced food safety vulnerabilities at the pre-intervention stage. There were six aspects to be concerned about: 1) Locations and production buildings, 2) Production equipment and utensils, 3) Process control, 4) Sanitation, 5) Maintenance and cleaning, and 6) Personnel. The BAICE factory was not a factory under statistical classification, as it had less than 20 HP from aggregate machinery and/or fewer than 7 workers. Form SB. 1 was applied to matters that did not originate from a factory. However, the facility had to adhere to the Ministry of Public Health Notification (No. 342) B.E. 2555 (2012), which pertains to how food is prepared, which equipment and utensils should be used, and how processed food in containers offered for retail sale is stored. To pass the inspection evaluation, the total score for each topic and the overall total score must be at least 60%, and there must not be any significant problems.

Quantitative evaluation showed that overall compliance across six GMP categories was below 60%, indicating substantial non-conformities and a high level of risk requiring corrective action (Table 1). The lowest score was attributed to maintenance and cleaning (30.10%), with sanitization next (30.71%). Personnel were rated with the highest average percent (41.91%), but still below the acceptance level for GMP certification. These initial results are consistent with longstanding weaknesses in rural and small-scale food processing businesses, which often operate with little technical support. The small and medium-sized processors often struggle to meet the key quality and safety requirements due to limited or no formal hygiene specifications, poor infrastructure, and insufficient staff training [11]. The results, therefore, highlight the critical need for structured technology transfer through extension programs to facilitate improvements in compliance. The GMP assessment of BAICE at the case level highlights persistent structural deficiencies in sanitation and maintenance within small community-based food enterprises, aligning with broader sectoral findings. These shortcomings reflect systemic issues rather than isolated cases. The analysis, framed by theories such as prerequisite-program theory and innovation-diffusion, underscores the necessity and theoretical basis for targeted interventions. The baseline scores serve as diagnostic tools to guide theory-driven improvements in the pla-duk-ra production system rather than as final measures of organizational effectiveness.

3.1.1 GMP assessment by categories

The facility faced major structural issues, including poor zoning, unsealed ceilings, pest infestations, and uneven flooring, which increased the risk of contamination (Figure 3). These inadequacies are consistent with emerging evidence from studies of small- and medium-scale enterprise (SME) food processors in Southeast Asia, where inadequate infrastructure and site layout were identified as critical factors in contamination and pest infestation within facilities [12]. Before the renovation, the production building was an open, common space without any separation, where the supply of processed products and packages was made at the same location for drying (Figure 3). The remodeling of the pla-duk-ra processing layout balances modernization with traditional rural culture, promoting hygienic and safe production. This reflects the broader challenge in Southeast Asia of integrating Good Manufacturing Practices (GMP) with longstanding methods. Small community-based producers often face constraints in equipment hygiene and operational efficiency. Suggested improvements, such as better tools, hygienic zoning, and clear Standard Operating Procedures (SOPs), aim to enhance safety and efficiency without compromising cultural values. Major process issues, such as reckless water use, poor storage of raw materials, and inadequate procedures, pose contamination risks in rural fermentation [13]. Planned improvements to water filtration and record-keeping enhance safety and traceability. Research in Thailand confirms that capacity-building in rural enterprises reduces contamination and boosts compliance [14].

The facility faced major non-compliance issues, including pest control, open containers, and poor hand-washing facilities, threatening pla-duk-ra hygiene. Traditional open-air processing highlights the

challenge of balancing cultural norms with modern safety measures to prevent contamination. Similar challenges in fish processing show that GMP integration improves quality and safety [15]. Key weaknesses included a lack of sanitation protocols and improper storage of chemicals. Recommended improvements focus on cleaning schedules, secure chemical storage, and ongoing staff training to sustain a strong food safety culture.

The six GMP non-compliance categories at BAICE reveal a rural food enterprise that is structurally underdeveloped yet culturally rich and behaviorally unique. Each issue aligns with established food safety literature on sanitation, knowledge transfer, and microbial hazard control [16]. This assessment offers a theory-based framework for targeted improvements, demonstrating that traditional production can be systematically enhanced under GMP without losing its cultural identity, making the approach especially effective for pla-duk-ra.



Figure 2. The BAICE production facility that produced pla-duk-ra before the improvement project. Front area (a), Inner area (b)

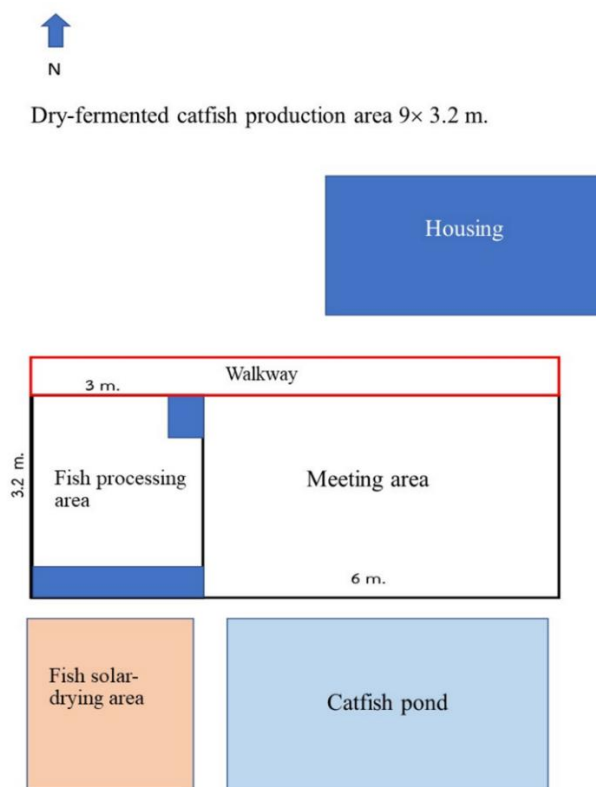


Figure 3. Diagram of the pla-duk-ra product processing facility before the Primary GMP audit and improvement

Table 1. Assessment of food production processes of Pla-duk-ra

Aspects	Score (%)	Issues detected	Recommendations
1. Locations and production buildings	31.58	-Unused items or items that weren't related to production are in the production area. -Failure to proportionally separate production areas. -Some areas do not have insect screens to prevent contamination, especially at doors and windows. -The arrangement of the production area does not follow the production line sequence. -The division of the production area is not proportional. -The lack of standard drainage pipes. -The rough building floors with corners collecting dust and pathogens. -The absence of a ceiling. -The lack of light bulb covers in some places.	-Clear the production area of unused items. -Divide work and packaging space with separate rooms. -Add more insect screens in places with no protection. -Make sure the ceiling is installed correctly in the packaging area. -Maximize production line sequence. -Independent packing spaces prevent cross-contamination. -Upgrading the drainage pipes to meet standards. -Making the floors of the building smooth and free of dust and germs. -Putting covers on all the light bulbs. -Making additional improvements as appropriate.
2. Production equipment and utensils	31.55	-Not enough tools and equipment. -Not enough space for storing items. -Cabinets used for tool storage that were not in the right place. -No instructions for how to use tools.	-Changing the layout of machinery and equipment to make cleaning easier. -Getting more equipment that is needed for the production process. -Getting shelves and cabinets to store different types of equipment. -Making signs and documents that explain how to use tools. -To build shelves and change the way raw materials are stored. -To build a whole new production line system. -To install water filtration systems used in production to meet standards. -To make quality analysis inspection data files. -To keep written records for at least two years.
3. Process control	35.00	-Not having enough space to store raw materials. -Moving raw materials, ingredients, and packaging containers during production in a way that could contaminate them. -Water systems coming into contact with food during production that didn't meet standards and didn't have quality analysis inspections.	-Making signs and documents that explain how to use tools. -To build shelves and change the way raw materials are stored. -To build a whole new production line system. -To install water filtration systems used in production to meet standards. -To make quality analysis inspection data files. -To keep written records for at least two years.

Table 1. Assessment of food production processes of Pla-duk-ra (continue)

Aspects	Score (%)	Issues detected	Recommendations
4. Sanitation	30.71	-Not enough covered trash cans in the right places. -Not enough toilets for workers. -Not enough soap or disinfectant and hand-drying equipment at all positions. -No measures to keep bugs away and get rid of them in the GMP production area.	-Changing open trash cans to covered ones. -Setting up hand-washing stations. -Getting enough soap for hand-washing at those stations.
5. Maintenance and cleaning	30.10	-No set procedures for cleaning tools and machines. -No clear place to store cleaning supplies. -No labels showing names and safe storage of cleaning chemicals or other chemicals used for sanitation maintenance. -No regular cleaning methods and measures for tools, machines, and production equipment.	-To wash tools and equipment before and after use. -Store cleaning chemicals in the right amounts. -Make clear signs showing where to store chemicals for cleaning. -Make plans for cleaning tools, machines, and equipment.
6. Personnel	41.91	-No health screening of employees. -Absence of rules on the handling of shoes used in production areas. -Staff allowed to wear jewelry, such as rings, necklaces, and bracelets. -Absence of protocols for washing hands and disinfection before starting work. -Employees not adhering to the cap and hairnet rule. -Lack of training for employees regarding employee hygiene, with some employees not understanding procedures.	-Holding meetings with employees to talk about sanitation.

3.1.2 Participatory extension–driven transformation

Participatory extension redefined BAICE and enabled public health officers, extension specialists, and communities to collaboratively examine GMP issues and development strategies. The community gained hands-on experience, a better understanding of regulation, and shared responsibility for compliance—the ingredients needed to make long-term rural food safety sustainable ultimately. This is through an intervention that simultaneously addresses the technical, organizational, and cultural dimensions by reframing extension as co-production rather than a top-down transfer; enabling an institution-wide helix arrangement; and embedding learning in a social context. The results confirm that how capacity is built can be as significant as what is taught.



Figure 4. On-site inspection and assessment of pla-duk-ra product production facilities by the public health officers in Phatthalung province

3.1.3 Layout improvement and compliance achievement

Following the GMP assessment, BAICE redesigned its production layout to support a hygienic workflow (Figure 5), with distinct rooms for changing, raw material handling, processing, and packaging/storage (Figure 6). These improvements enhanced hazard control, met Primary GMP standards, and preserved pla-duk-ra's traditional character. BAICE earned SB.1 registration from the Ministry of Public Health, demonstrating its effective capacity-building. This case exemplifies how culturally grounded, participatory modernization can transform rural food enterprises into safe, competitive businesses without sacrificing cultural identity.

3.1.4 Apply for food production facility licensing

After the GMP assessment, BAICE reorganized its production facility to meet food safety standards, creating distinct areas including a changing room, a wet zone for raw material reception and cleaning, a dry processing zone with shelves and preparation tables, and a packaging and finished product storage area. This layout met the requirements for a food production facility license. In Thailand, small-scale facilities with fewer than 50 employees and machinery under 50 horsepower apply via Form SB.1, while larger factories use Form O.1. With seven workers and machinery below 20 horsepower, BAICE qualified under Group 1 (non-factory) and applied accordingly. The application to the Provincial Consumer Protection Unit included verification documents, business registrations, premises evidence, and technical materials such as layout maps, flowcharts, machinery lists, sanitation, and water quality plans. Although not classified as a factory, BAICE complied with Ministry of Public Health Notification No. 342 (B.E. 2555/2012). After review and inspection, BAICE obtained an eight-digit food production registration number, enabling legal operation and market

distribution. This success reflects the integration of facility design, food safety science, regulatory compliance, and small enterprise development, demonstrating that GMP adherence can drive microenterprise upgrading and competitive positioning rather than serve as a regulatory burden.

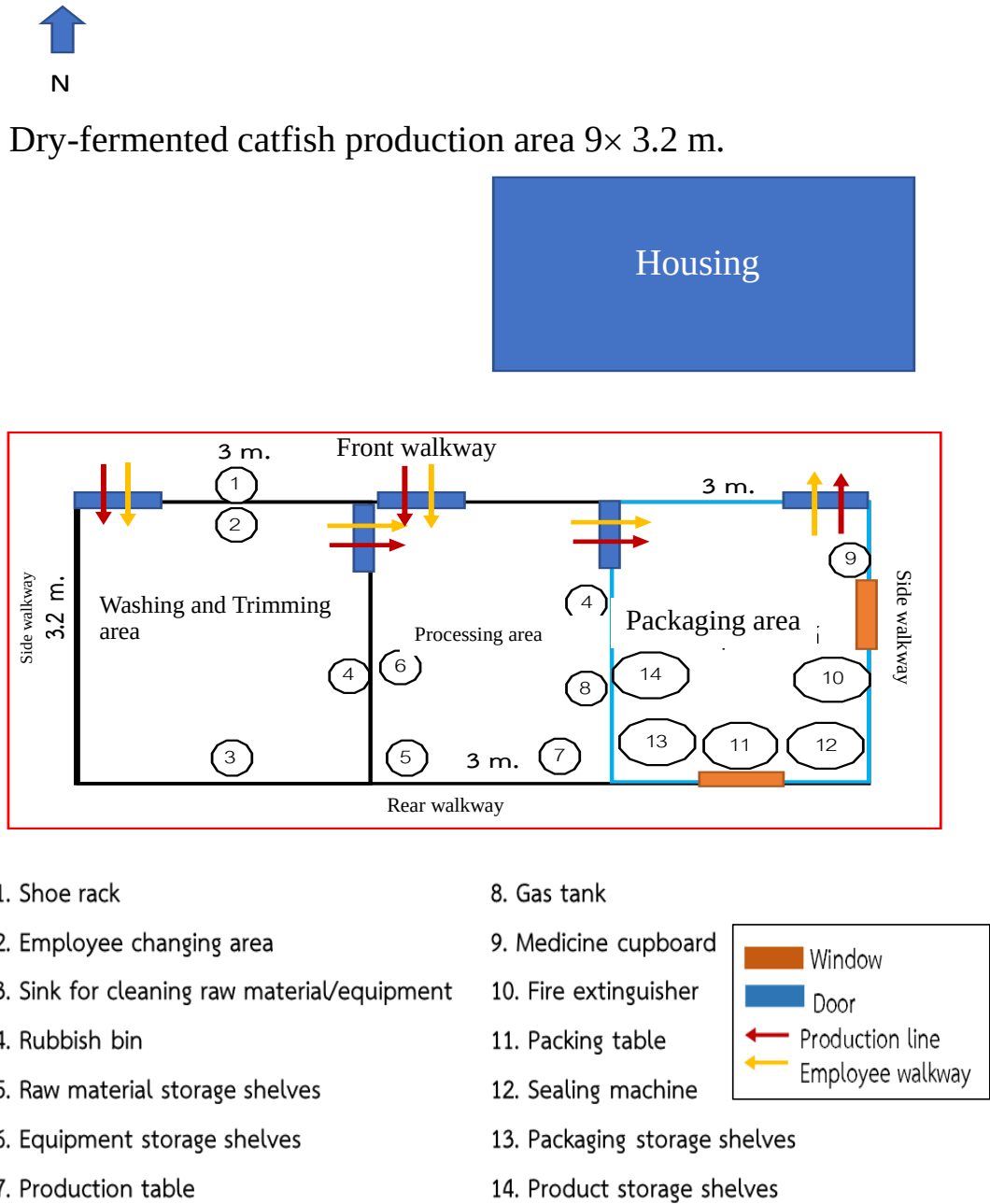


Figure 5. Diagram of the pla-duk-ra product processing facility after Primary GMP audit and improvement



Figure 6. The BAICE production facility that produced pla-duk-ra after the improvement project. Front area (a), Side area (b), Employee changing area (c), Raw material washing and preparation area (d), Mixing area (e), Packing area (f)

3.2. Quality evaluation of pla-duk-ra products

The chemical and biological properties of pla-duk-ra products are presented in Table 2. Quality parameters were compared before and after GMP implementation using the Thai Community Product Standards as the reference criteria. The results showed that water activity (a_w) decreased significantly after GMP implementation ($p < 0.05$), from 0.85 before implementation to 0.71 after implementation. The post-intervention value was below the Thai Community Product Standard limit of 0.80 [10]. This reduction is important for product safety and shelf-life extension, as lower water activity can inhibit the growth of pathogenic and spoilage microorganisms. The improvement may be associated with better control of fermentation and drying practices following GMP-based training and process standardization. This finding is consistent with previous studies on fermented fish products, which have emphasized the importance of controlling water activity in producing safer intermediate-moisture foods with extended shelf life [2]. A substantial reduction in yeast contamination was also observed, with counts decreasing from 1.2×10^4 CFU/g before implementation to 1.0×10^2 CFU/g after implementation. The post-intervention value was well below the Thai standard limit of 1.0×10^4 CFU/g. This approximately two-log reduction indicates improved sanitation,

handling practices, and process control. Similar improvements have been reported in fish products when strict hygiene practices, clean water, and controlled drying conditions were applied [15].

Lower yeast counts may also reflect better environmental control, improved equipment cleaning, and more hygienic handling during production [16]. Mold counts were low both before and after GMP implementation, at 13 and 10 CFU/g, respectively, well below the Thai standard limit of 500 CFU/g. The low mold counts may be partly related to the natural antimicrobial effects of salt and fermentation. The slight reduction after implementation may also be associated with improved facility conditions, better ventilation, reduced environmental contamination, and improved humidity control. Appropriate facility design and good airflow are important factors in reducing mold growth in fermented fish products. The most critical safety concern was observed in the pathogenic bacterial indicators. Before GMP implementation, *E. coli* was detected at 30 MPN/g, exceeding the Thai standard limit of 10 MPN/g. After GMP implementation, *E. coli* decreased to less than 3.0 MPN/g, meeting the standard requirement. This reduction indicates improved hygiene control, especially in raw material handling, water quality, equipment sanitation, and the prevention of fecal contamination. Similarly, *S. aureus* decreased from 150 MPN/g before implementation to less than 3.0 MPN/g after implementation. Importantly, the pre-intervention value of 150 MPN/g exceeded the Thai standard limit of 100 MPN/g, indicating a genuine public health concern before the intervention. The presence of *S. aureus* above the standard may reflect inadequate personal hygiene, improper handling, insufficient sanitation of equipment and production areas, or lack of systematic health and hygiene practices among workers. Since *S. aureus* is commonly associated with human handling and can produce heat-stable enterotoxins under favorable conditions, its detection above the regulatory limit highlights the need for strict hygiene management in traditional fermented fish processing. After GMP implementation, the reduction of *S. aureus* to less than 3.0 MPN/g suggests that improved management practices were effective in reducing contamination risks. These practices included worker hygiene training, hand-washing procedures, use of protective clothing, improved sanitation of production areas, better cleaning of equipment and utensils, and stronger process control.

Therefore, the microbiological results demonstrate not only product quality improvement but also a meaningful reduction in public health risk. Fundamentally, controlling intrinsic parameters such as water activity, in conjunction with minimizing initial contamination through hygienic practices, is the primary mechanism for inhibiting specific spoilage organisms and extending the shelf life of fish products [17]. Overall, the reductions in water activity, yeasts, *E. coli*, and *S. aureus* indicate that GMP-based upgrading contributed to improved safety and quality of pla-duk-ra. These findings support the participatory action research approach used in this study, which combined community participation and expert guidance to achieve measurable improvements in production practices. Although the post-intervention results met the relevant Thai Community Product Standards, continued monitoring is still necessary to ensure that product safety and quality are consistently maintained over time.

Table 2. Chemical and biological properties of pla-duk-ra product from BAICE

Chemical and biological properties	Before the project implementation	After the project implementation	Thai Community Product Standards
Water activity (aw)	0.85±0.02	0.71±0.04	0.80±0.06
Yeasts (CFU/ g sample)	1.2×10 ⁴	1.0×10 ²	1×10 ⁴
Molds (CFU/g sample)	13	10	500
<i>E. coli</i> (MPN/g sample)	30	<3.0	10
<i>S. aureus</i> (MPN/g sample)	150	<3.0	100

Note: Values of water activity are expressed as mean ± standard deviation. Microbiological values are reported as CFU/g or MPN/g sample, as appropriate.

Sensory evaluation was conducted before and after project implementation by the same five trained assessors who had experience in evaluating pla-duk-ra (Table 3). Employing a trained sensory panel is critical for minimizing individual psychological biases and obtaining objective, reproducible analytical data on

specific product attributes [18]. The study concludes that GMP implementation improves all sensory attributes, indicating that this type of quality improvement is not only related to food safety and legal aspects but also to sensory attributes important for consumer appeal and market value. The appearance stringency was increased by 18.1%, and the appearance scores were expectedly elevated from an average of 3.20 to 3.78, verifying that a standardized manufacturing process protocol, performed in compliance with GMP, can indeed be successfully established. This improvement is probably due to better selection of raw materials, consistent processing procedures, and superior quality assurance practices. Sensory parameters indicate that the size is uniform, the skin is intact, and the product is not over-dried. Further, the higher post-implementation scores indicate that the GMP training and SOPs were successful in training workers to consistently produce products that are appealing.

The color scores fared the best, with a 5.9% gain from 3.70 to 3.92, very close to "excellent". Quality standards demand that commodities have a natural color of pla-duk-ra. The relatively high initial product suggests that the traditional recipe already provided good color development, and the GMP modification improved stability more fundamentally, even though this property changed significantly. Fermented fish product color development is mediated by a number of complex biochemical mechanisms, including Maillard reactions, lipid oxidation, and enzymatic browning, which are better regulated under GMP conditions.

The flavor had the largest improvement, increasing by 26.8% from 3.10 to 3.93. This development is particularly noteworthy because flavor perception extends beyond mere physical taste; it is a profound psychological determinant that significantly influences consumer food choice, overall acceptance, and eventual repurchase behavior [19]. According to quality standards, fermented catfish should have a natural taste without off-flavors such as mustiness, rancidity, or bitterness. The large decrease was associated with a significant reduction in microbial load, especially *E. coli* and *S. aureus*. Since the survival and proliferation of these pathogens during fermentation pose significant safety risks and can lead to the production of metabolites that alter characteristic flavor profiles, controlling them through systematic hygiene is crucial [20]. Furthermore, GMP for cleaning food-grade materials and equipment prevents chemical contamination that might alter taste.

Texture scores for pla-duk-ra rose by 18.8%, from 3.20 to 3.80, meeting quality standards of softness and tenderness without undesirable sensations. This improvement resulted from better control of the fermentation-drying cycle using standardized methods, which lowered water activity from 0.85 to 0.71, limiting microbial growth and enhancing product stability. All sensory attributes showed statistically significant improvements ($p < 0.05$) post-GMP implementation, with ratings near or above the "excellent" category (≥ 3.80). This demonstrates that GMP enhances both safety and consumer-relevant quality, aligning with Codex guidelines on hygiene supporting safe, suitable food production [21]. Unlike conventional methods, BAICE maintained original sensory characteristics while improving quality, addressing concerns about authenticity loss through standardization. These sensory gains have important business implications, as product quality influences consumer satisfaction, repeat purchases, and willingness to pay premium prices. Sensory evaluation is crucial to understanding consumer perceptions and acceptance. The improved appearance and taste reinforce pla-duk-ra's status as a Southern Thai specialty, supporting efforts to promote traditional foods that enhance nutritional value and commercial potential while preserving cultural identity.

In this study, the objective of the sensory evaluation was therefore not to quantify direct consumer preference or purchase behavior, but rather to evaluate the quality attributes of pla-duk-ra in line with established product-specific criteria with intermediate moisture foods [22]. Therefore, the sensory score increases seen in the present study should be interpreted as increased product quality from a trained sensory panel perspective rather than consumer acceptance [23]. Enhancements are likely due to improved control of raw catfish, salting, drying, sanitation, and overall process management under GMP. However, further consumer-focused sensory studies, including acceptance and purchase intent, are needed to confirm if these quality improvements meaningfully influence consumer preferences and purchasing behavior in the market.

Table 3. Sensory property of pla-duk-ra from BAICE

Sensory property	Before the project implementation	After the project implementation
Appearance	3.20 ± 0.43	3.78 ± 0.32
Color	3.70 ± 0.23	3.92 ± 0.44
Flavor	3.10 ± 0.33	3.93 ± 0.39
Texture	3.20 ± 0.38	3.80 ± 0.39

Note: Values are expressed as mean ± standard deviation. Different letters within the same row (horizontally) indicate statistically significant differences ($p < 0.05$).

Sensory/quality criteria

General appearance: Must be fairly dry; units within the same container should be similar in size; skin must be intact (no tears).

Color: Should exhibit a good, natural color characteristic of fermented catfish (pla duk ra).

Aroma & taste: Should have a good, natural aroma and taste characteristic of fermented catfish; free from undesirable off-odors/off-flavors such as musty, rancid, or bitter notes.

Texture: Should be soft; neither mushy nor overly hard/tough.

Scale: 4 = Excellent; 3 = Good; 2 = Fair (acceptable); 1 = Needs improvement.

3.3 Packaging and Thai FDA certification

To enhance pla-duk-ra's market competitiveness, continued focus on packaging and label design is essential. Good packaging not only improves product appeal and security but also preserves quality and extends shelf life, facilitating market expansion. According to the Ministry of Public Health Notification B.E. 2557 (2014), retail packaging must comply with specified volume limits and include clear labels detailing product name, ingredients, nutrition facts, usage instructions, and necessary warnings to meet regulatory requirements and consumer expectations. Good packaging helps protect food products, maintain quality and safety, and extend shelf life during storage and distribution [24]. For retail packaging, the declared net quantity should comply with the Ministry of Commerce regulation on prepackaged goods. Labeling of pla-duk-ra products should follow the Ministry of Public Health Notification No. 450 B.E. 2567 on labeling of prepackaged foods, which replaced earlier labeling notifications, including Notification No. 367 B.E. 2557 [25]. Product labels for pla-duk-ra must be clear, readable, and easy for consumers to understand. Labels should include production or expiry dates, proper storage instructions, and a detailed list of main ingredients. This aligns with Ministry of Public Health Notification No. 450 B.E. 2567 (2024), which mandates that prepackaged food labels be legible, accurate, and informative, including food name, net quantity, allergen information, date marking, warnings, and usage instructions. The notification also clarifies expiration and consume-before dates based on food quality and storage conditions, emphasizing the importance of clear date marking and storage guidance [25].

Packaging and labels for BAICE products are presented in Figures 7 and 8. Packaging and labels influence consumer decisions by conveying quality, safety, and product identity. Appropriate packaging for pla-duk-ra adds value and sustainability by protecting food quality, controlling environmental contact, reducing waste, and extending shelf life when matched to preservation needs. Good packaging can also help slow quality deterioration by reducing exposure to factors that may cause oxidation, mold growth, microbial contamination, and other changes that affect product safety and shelf life [26]. Clear and well-designed label graphics can help build consumer confidence when the label is easy to read and contains complete, accurate, and non-misleading information. According to the Thai FDA labeling requirements, label text must be prominent, readable, and presented with appropriate contrast between the text and background [25]. Sustainable packaging preserves food quality, reduces waste, and offers economic and environmental benefits through eco-friendly materials and technologies [27].

The process of obtaining food registration numbers in Thailand demonstrates BAICE's success in securing Thai FDA certification for six traditional fermented fish products. This achievement is significant because traditional fermented foods must be rigorously controlled as they are developed from household or community-based production into standardized commercial products. Steinkraus [28] emphasized that the

industrialization of indigenous fermented foods should preserve traditional characteristics while improving hygiene, process control, consistency, and safety. In this context, BAICE's certification represents an important step toward transforming fermented fish products into regulated, market-ready foods. Food registration in Thailand requires submission of Form SB.7 through the Thai FDA E-submission system, which evaluates product formulations and ingredient compositions. BAICE's six FDA registration numbers indicate progress in quality standardization, Primary GMP implementation, and compliance with food safety regulations. This is especially important for fish-based products, which are vulnerable to quality deterioration and microbial contamination if raw materials, processing, drying, packaging, storage, and distribution are not properly controlled. Huss et al. [29] noted that seafood safety management must address hazards throughout the production chain. The dry-fermented catfish product, FDA No. 93-2-00567-6-0002, is classified as a general food under animal products and requires microbiological safety evaluation for pathogens such as *S. aureus*, *Salmonella* spp., and *Clostridium* spp. Overall, BAICE's certification reflects the integration of traditional fermentation knowledge with modern food safety standards [28], [29].

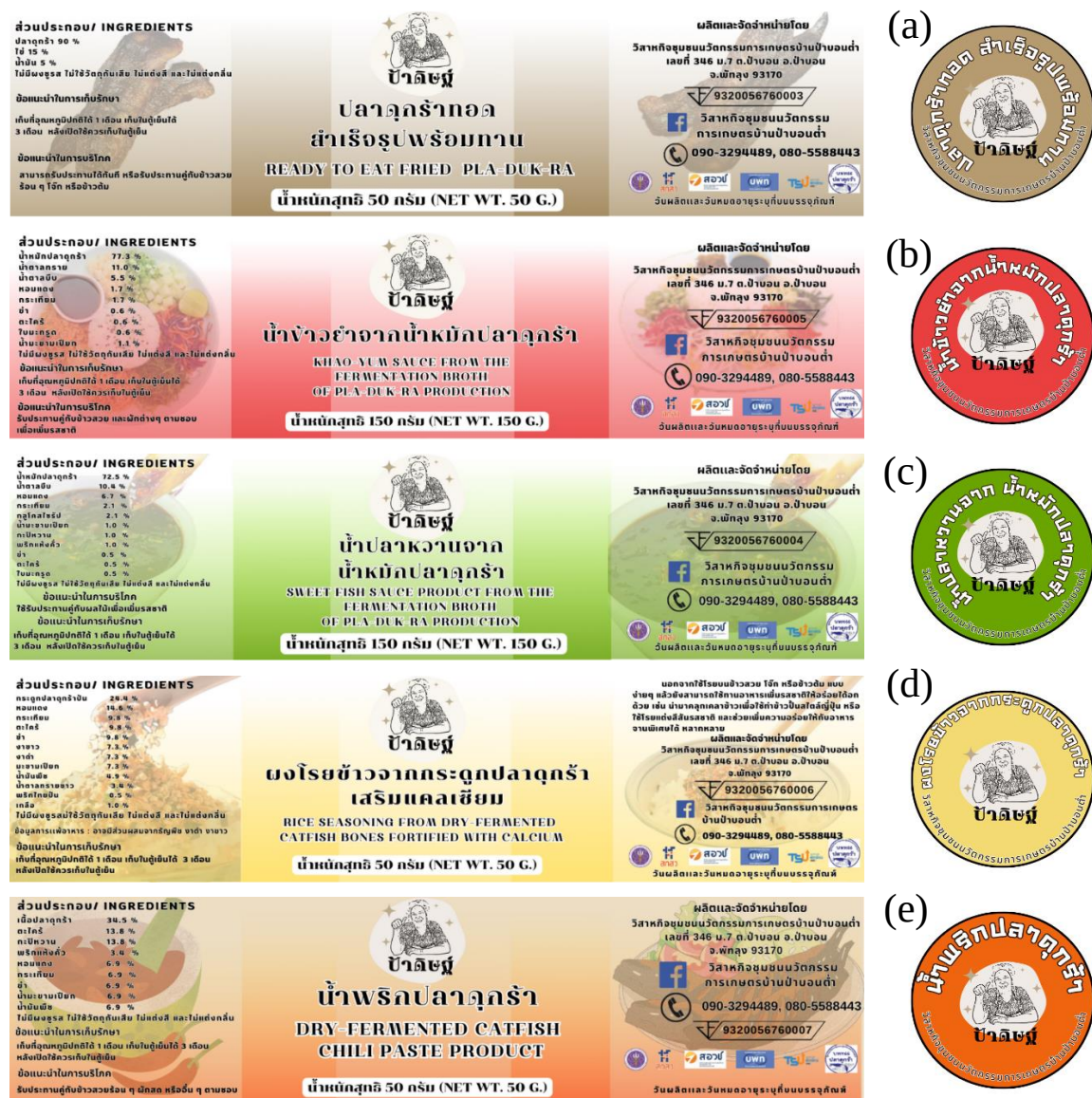


Figure 7. Labels of products from the PLA-duk-ra production process. Ready to eat fried pla-duk-ra (a), Khao-yum sauce (b), Sweet fish sauce (c), Rice seasoning (d), Dry-fermented catfish chili paste (e).

Most registered BAICE products are classified as ready-to-eat or ready-to-cook foods, including FDA Nos. 93-2-00567-6-0003, 93-2-00567-6-0004, 93-2-00567-6-0006, and 93-2-00567-6-0007. This classification shows how processing innovation can enhance the value chain of traditional fermented fish products by converting them into convenient forms that meet modern consumer needs. This development aligns with the Thailand 4.0 approach, which emphasizes innovation, product development, knowledge application, and quality management to improve the competitiveness of community enterprises [30]. The Khao-yum sauce product, FDA No. 93-2-00567-6-0005, also reflects product diversification by transforming traditional fermented fish knowledge into a value-added condiment. This helps preserve regional culinary identity while expanding market opportunities. Fermented fish products are culturally important in Asia, and their characteristics are influenced by raw materials, traditional processing, and microbial activity, as shown in studies of *ngari*, *hentak*, and *tungtap* [31]. Globally, fermented foods demonstrate how traditional knowledge can be developed into diverse products while maintaining cultural and sensory qualities [32]. Overall, BAICE's FDA certification reflects effective quality control, product standardization, and technical support. This achievement enhances market access, consumer confidence, product value, and sustainable rural livelihoods.



Figure 8. Packaging of pla-duk-ra product (a) and ready-to-eat products (b) from pla-duk-ra production process of BAICE

Table 4. Thai FDA certification for food products in the form of food registration numbers of BAICE

No.	FDA Registration code	Name of product	Type of product
1	93-2-00567-6-0002	Dry-fermented catfish	General foods, including animals and animal products that have passed evaluation and inspection
2	93-2-00567-6-0003	Ready to eat fried Pla-duk-ra	Ready-to-cook foods and ready-to-eat foods, including ready-to-eat food products
3	93-2-00567-6-0004	Sweet fish sauce	Ready-to-cook foods and ready-to-eat foods, including ready-to-eat food products
4	93-2-00567-6-0005	Khao-yum sauce	General foods, including seasonings that have passed evaluation and inspection
5	93-2-00567-6-0006	Rice seasoning	Ready-to-cook foods and ready-to-eat foods, including ready-to-eat food products
6	93-2-00567-6-0007	Dry-fermented catfish chili paste	Ready-to-cook foods and ready-to-eat foods, including ready-to-eat food products

3.4 The economic analysis

This economic investigation of BAICE after GMP implementation and Thai FDA approval demonstrates the financial feasibility of upgrading traditional fermented fish products. Based on August 2025 data, six FDA-approved products generated total monthly revenue of USD 2,821, with production costs of USD 1,383 and net income of USD 1,438. The overall profit margin was 51.0%, indicating that quality improvement, food safety certification, and product standardization can increase product value and strengthen market competitiveness. BAICE's performance is consistent with consumer behavior studies showing that consumers are willing to pay more for products perceived as safe, high quality, and produced under recognized standards. Thai FDA approval and GMP implementation may therefore enhance consumer confidence and support premium pricing for improved traditional fermented fish products [33]. Pla-duk-ra was the main revenue-generating product, contributing USD 2,480 (87.9% of total revenue) and USD 1,240 (86.2% of net income), with a 50.0% profit margin. This reflects strong market demand for traditional fermented fish. BAICE's success also underscores the importance of collective action in helping community enterprises improve quality, meet regulatory requirements, and access higher-value markets [34]. Overall, BAICE demonstrates how small-scale producers can adapt to changing agrifood markets through certification, quality management, and enterprise cooperation [35].

The five value-added derivative products contributed USD 341, or 12.1% of total monthly revenue, and USD 198, or 13.8% of total net income. These products showed profit margins ranging from 49.5% to 71.0%. The second-highest revenue was generated by ready-to-eat fried pla-duk-ra, with USD 155 in monthly revenue, USD 62 in production cost, USD 93 in net income, and a profit margin of 60.0%. Sweet fish sauce and Khao-yum sauce each generated USD 31 in monthly revenue, USD 9 in production cost, USD 22 in net income, and a profit margin of 71.0%. Rice seasoning generated USD 31 in monthly revenue, USD 16 in production cost, USD 15 in net income, and a profit margin of 48.4%. Dry-fermented catfish chili paste generated USD 93 in monthly revenue, USD 47 in production cost, USD 46 in net income, and a profit margin of 49.5%. These findings indicate that product diversification after GMP implementation and FDA certification helped BAICE generate additional income from value-added products. Such diversification may also strengthen market linkages by enabling producers to offer a broader product portfolio that responds to consumer demand and market opportunities. In addition, GMP implementation and FDA certification can enhance buyer confidence and trust in agribusiness supply chains, which are important factors supporting long-term market relationships and commercial sustainability.

Several factors explain BAICE's financial success after regulatory compliance. Certification and FDA registration strengthened the enterprise by improving access to formal retail markets, where certified products are often required and may command better prices [36], [37]. FDA approval also enhanced consumer trust, particularly among urban consumers who increasingly value food safety, health, and product quality [38], [39]. In addition, improved production management helped reduce losses from contamination, inconsistent quality, and batch failure. For fermented products, such control is especially important because quality depends on fermentation conditions and microbial activity [40]. BAICE's monthly net income of USD 1,438 is economically significant in rural Thailand, where household livelihoods are closely connected to local production and consumption systems. When distributed among community members, this income supports household welfare, food security, and local economic resilience. Product diversification also reduces dependence on a single product and reflects sound risk-management practice for smallholder food enterprises. The overall cost-to-revenue ratio of approximately 49.0% and profit margin of 51.0% indicate that quality improvement and regulatory compliance can be economically beneficial, not merely administrative obligations. BAICE demonstrates how traditional food wisdom can be integrated with modern quality standards to strengthen value-chain inclusion, support smallholders, and meet demand for safe products. This model may benefit other community enterprises and contribute to SDGs 1, 2, 8, and 12 [41].

Table 5. Cost analysis and returns of BAICE after the project implementation in August 2025

Product	Revenue (USD/Month)	Cost (USD /Month)	Net income (USD /Month)	Profit margin (%)
1. Dry-fermented catfish (pla-duk-ra)	2,480	1,240	1,240	50.0
2. Ready to eat fried Pla- duk-ra	155	62	93	60.0
3. Sweet fish sauce	31	9	22	71.0
4. Khao-yum sauce	31	9	22	71.0
5. Rice seasoning	31	16	15	48.4
6. Dry-fermented catfish chili paste	93	47	46	49.5
Total	2,821	1,383	1,438	51.0

Note: Calculation: Net income = Revenue - Cost, Profit margin (%) = (Net income ÷ Revenue) × 100

4. Conclusions

This study demonstrates that adopting GMP significantly improves food safety, product quality, and economic performance in community-based catfish production. Using an extension-by-participation approach, BAICE successfully reduced microbial contamination, improved sensory characteristics, and obtained Primary GMP and FDA validation, allowing it to enter the regulated marketplace. Economic analysis showed significant gains, with profit rates of 50%, reinforcing the possibility of improving ancient food systems. Results show that mid-tier rural enterprises can meet national standards through training and facility upgrades with a cultural foundation. This model provides a replicable platform to enhance sustainable rural food systems in Thailand.

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References

- [1] Swangdacharuk, P. Aquafeed Industry in Thailand: Current Status, Sustainability & Future Trends. *Int. Aquafeed Fish Farming Technol.* **2025**. Aquafeed Industry in Thailand: Current Status, Sustainability & Future Trends.
- [2] Thanonkaew, A.; Jantachote, T.; Ruangrat, W.; Aksornniem, A. Quality Changes of Fermented Catfish (Pla-Duk-Ra) Products during Storage at Room Temperature. *J. Natl. Res. Counc. Thailand Sci. Sect.* **2009**, *41*(2), 27–41. (In Thai).

- [3] Thanonkaew, A.; Klompong, V.; Mayachiew, P.; Luanunkarb, T.; Hoktha, P.; Intarat, N.; Phatcharasit, K.; Panomjan, N.; Kiriratnikom, S. Integrated Dry-Fermented Catfish Production to Promote Sustainable Livelihoods and Community-Based Economic Development: A Case Study of the Community Enterprise Group in Koh Tao Subdistrict, Pa Phayom District, Phatthalung Province, Thailand. *Area Based Dev. Res. J.* **2025**, *17*(3), 175–194. <https://doi.org/10.48048/abcj.2025.175> (In Thai).
- [4] Danudol, A.; Weerawatanakorn, M. Good Manufacturing Practice (GMP 420): The Easiest Practice for Food Safety. *J. Nutr. Assoc. Thailand* **2022**, *57*(2), 43–62. (In Thai).
- [5] Klompong, V.; Klomklao, S.; Mayachiew, P.; Luanunkarb, T.; Hoktha, P.; Thanonkaew, A. Quality Improvement and By-Product Utilization in Dry-Fermented Catfish Processing: A Case Study of Ban Chumphon Community Enterprise, Phatthalung Province, Thailand. *Area Based Dev. Res. J.* **2025**, *17*(1), 35–54. <https://doi.org/10.48048/abcj.2025.035> (In Thai).
- [6] Febri; Apriani, A.; Luger, L.; Siskawanti, F.; Kurniasari, M. Implementation of Good Manufacturing Practices (GMP) in the Small-Scale Fish Ball Food Industry. *J. Fish. Mar. Appl. Sci.* **2024**, *2*(3), 123–135. <https://doi.org/10.58184/jfmas.v2i3.376>
- [7] National Strategy Secretariat Office. *National Strategic Framework of Thailand 2018–2037*; Office of the National Economic and Social Development Board: Thailand, 2018. National Strategic Framework of Thailand 2018–2037.
- [8] Food and Drug Administration. *Inspection Manual of Food Production Facility According to Good Manufacturing Practice in Production That Is Enforced by Law (GMP 420)*; FDA: Thailand, 2020. (In Thai). Inspection Manual of Food Production Facility According to GMP 420.
- [9] U.S. Food and Drug Administration. *Bacteriological Analytical Manual (BAM): Microbiological Detection Methods*; FDA: Silver Spring, MD, 2001. Bacteriological Analytical Manual (BAM).
- [10] Office of Industrial Product Standards. *Community Product Standards No. 1029/2005*; Office of Industrial Product Standards: Thailand, 2005. Community Product Standards No. 1029/2005.
- [11] Purwantiningrum, I.; Widhyastuty, W.; Christian, J.; Sari, N. Assessment of Good Manufacturing Practice for Small-Scale Food Industry in Malang Region, East Java, Indonesia. *IOP Conf. Ser.: Earth Environ. Sci.* **2018**, *131*, 012028. <https://doi.org/10.1088/1755-1315/131/1/012028>
- [12] Anal, A. K.; Perpetuini, G.; Petchkongkaew, A.; Tan, R. P.; Avallone, S.; Tofalo, R.; Nguyen, H. V.; Chu-Ky, S.; Ho, P. H.; Phan, T. T.; Waché, Y. Food Safety Risks in Traditional Fermented Food from South-East Asia. *Food Control* **2020**, *109*, 106922. <https://doi.org/10.1016/j.foodcont.2019.106922>
- [13] Rodmanee, S.; Huang, W.-C. Hygiene and Manufacturing Practices, Interagency Collaboration, and a Proposal for Improvement: A Case Study of Community Food Enterprise in Thailand. *Int. J. Soc. Sci. Humanit.* **2013**, *3*(3), 284–289. <https://doi.org/10.7763/IJSSH.2013.V3.232>
- [14] Rujjanakul, P.; Suwannaporn, P.; Kulthamrongsri, N. Development of Pickled Fish (Pla Som) Facilities in Khon Kaen Province to Safety Standards According to GMP through Community Participation. *J. Food Saf. Health* **2023**, *9*(1), 78–92. (In Thai).
- [15] Geraldo, V.; Ampofo-Asiama, J.; Adinortey, C.A.; Okyere, I.; Tulashie, S.K.; Nuer, A.T.K.; Nkansah, S.B.; Omega, S.; Seidu-Larry, S.; Kizzie-Hayford, N. Implementation of Good Manufacturing Practices (GMP) to Improve the Quality of Smoked Fish (*Scomber colias*). *Heliyon* **2024**, *10*, e27401. <https://doi.org/10.1016/j.heliyon.2024.e27401>
- [16] Frazier, W. C.; Westhoff, D. C. *Food Microbiology*, 5th ed.; McGraw Hill Education: India, 2022.
- [17] Gram, L.; Huss, H. H. Microbiological Spoilage of Fish and Fish Products. *Int. J. Food Microbiol.* **1996**, *33*(1), 121–137. [https://doi.org/10.1016/0168-1605\(96\)01134-8](https://doi.org/10.1016/0168-1605(96)01134-8)
- [18] Lawless, H. T.; Heymann, H. *Sensory Evaluation of Food: Principles and Practices*, 2nd ed.; Springer: New York, 2010. <https://doi.org/10.1007/978-1-4419-6488-5>
- [19] Köster, E. P. Diversity in the Determinants of Food Choice: A Psychological Perspective. *Food Qual. Prefer.* **2009**, *20*(2), 70–82. <https://doi.org/10.1016/j.foodqual.2007.11.002>
- [20] Adams, M. R.; Mitchell, R. Fermentation and Pathogen Control: A Risk Assessment Approach. *Int. J. Food Microbiol.* **2002**, *79*(1–2), 75–83. [https://doi.org/10.1016/S0168-1605\(02\)00181-2](https://doi.org/10.1016/S0168-1605(02)00181-2)

- [21] Codex Alimentarius Commission. *General Principles of Food Hygiene: CXC 1-1969*; Food and Agriculture Organization of the United Nations/World Health Organization: Rome, Italy, 2023. General Principles of Food Hygiene: CXC 1-1969.
- [22] U.S. Food and Drug Administration. *Water Activity (aw) in Foods*; U.S. Food and Drug Administration: Silver Spring, MD, 2024. Water Activity (aw) in Foods.
- [23] Meilgaard, M. C.; Civille, G. V.; Carr, B. T. *Sensory Evaluation Techniques*, 5th ed.; CRC Press: Boca Raton, FL, 2016. <https://doi.org/10.1201/b19493>
- [24] Kohli, D.; Loushigam, G.; Richa, R.; Bajad, R. Recent Advances in Food Packaging for Shelf Life of Food. In *Food Production, Diversity, and Safety under Climate Change*; Springer, 2024; pp 273–284. https://doi.org/10.1007/978-3-031-51647-4_23
- [25] Food and Drug Administration, Ministry of Public Health. *Notification of the Ministry of Public Health (No. 450) B.E. 2567 (2024), Issued by Virtue of the Food Act B.E. 2522: Labeling of Prepackaged Foods*; FDA: Thailand, 2024. (In Thai). Notification of the Ministry of Public Health No. 450 (2024).
- [26] Fadiji, T.; Rashvand, M.; Daramola, M. O.; Iwarere, S. A. A Review on Antimicrobial Packaging for Extending the Shelf Life of Food. *Processes* **2023**, 11(2), 590. <https://doi.org/10.3390/pr11020590>
- [27] Guillard, V.; Gaucel, S.; Fornaciari, C.; Angellier-Coussy, H.; Buche, P.; Gontard, N. The Next Generation of Sustainable Food Packaging to Preserve Our Environment in a Circular Economy Context. *Front. Nutr.* **2018**, 5, 121. <https://doi.org/10.3389/fnut.2018.00121>
- [28] Steinkraus, K. H. *Industrialization of Indigenous Fermented Foods*, 2nd ed.; Marcel Dekker: New York, 2004. <https://doi.org/10.1201/9780203022047>
- [29] Huss, H. H.; Ababouch, L.; Gram, L. *Assessment and Management of Seafood Safety and Quality*; FAO Fisheries Technical Paper No. 444; FAO: Rome, Italy, 2000.
- [30] Mettathamrong, J.; Promket, C.; Vichasilp, K. How Community Enterprises of Thailand Managed to Become Thailand 4.0. *Int. J. Oper. Quant. Manag.* **2022**, 28(1), 121–133. <https://doi.org/10.46970/2022.28.1.7>
- [31] Thapa, N.; Pal, J.; Tamang, J. P. Microbial Diversity in Ngari, Hentak and Tungtap, Fermented Fish Products of North-East India. *World J. Microbiol. Biotechnol.* **2004**, 20, 599–607. <https://doi.org/10.1023/B:WIBI.0000043171.91027.7E>
- [32] Tamang, J. P.; Kailasapathy, K., Eds. *Fermented Foods and Beverages of the World*; CRC Press: Boca Raton, FL, 2010. <https://doi.org/10.1201/EBK1420094954>
- [33] Boccaletti, S.; Nardella, M. Consumer Willingness to Pay for Pesticide-Free Fresh Fruit and Vegetables in Italy. *Int. Food Agribus. Manag. Rev.* **2000**, 3(3), 297–310. [https://doi.org/10.1016/S1096-7508\(01\)00049-0](https://doi.org/10.1016/S1096-7508(01)00049-0)
- [34] Markelova, H.; Meinzen-Dick, R.; Hellin, J.; Dohrn, S. Collective Action for Smallholder Market Access. *Food Policy* **2009**, 34(1), 1–7. <https://doi.org/10.1016/j.foodpol.2008.10.001>
- [35] Reardon, T.; Barrett, C. B.; Berdegue, J. A.; Swinnen, J. F. M. Agrifood Industry Transformation and Small Farmers in Developing Countries. *World Dev.* **2009**, 37(11), 1717–1727. <https://doi.org/10.1016/j.worlddev.2008.08.023>
- [36] Henson, S.; Caswell, J. The Economic Implications of Using HACCP as a Food Safety Regulatory Standard. *Food Policy* **1999**, 24, 625–635. [https://doi.org/10.1016/S0306-9192\(99\)00074-3](https://doi.org/10.1016/S0306-9192(99)00074-3)
- [37] Unnevehr, L.; Jensen, H. H. The Economic Implications of Food Safety Regulations for Food Processors. *Food Policy* **1999**, 24, 667–683.
- [38] Grunert, K. G. Food Quality and Safety: Consumer Perception and Demand. *Eur. Rev. Agric. Econ.* **2005**, 32, 369–391. <https://doi.org/10.1093/eurrag/jbi011>
- [39] Reardon, T.; Timmer, C. P. The Economics of the Food System Revolution. *Annu. Rev. Resour. Econ.* **2012**, 4, 225–264. <https://doi.org/10.1146/annurev.resource.050708.144147>
- [40] Udomsil, N.; Rodtong, S.; Tanasupawat, S.; Yongsawatdigul, J. Proteinase-Producing Halophilic Lactic Acid Bacteria Isolated from Fish Sauce Fermentation. *Int. J. Food Microbiol.* **2011**, 141(3), 186–194. <https://doi.org/10.1016/j.ijfoodmicro.2010.05.016>
- [41] United Nations. *Sustainable Development Goals 2025: Progress and Recommendations*; United Nations: New York, 2025.