

Enhancing Fish Processing Skills Through Steam-Based Smart Technology: a Capacity-Building Model for Small-Scale Tongkol (*Euthynnus Affinis*) Processors in Rural Indonesia

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Abstract

Small-scale fish processing in Indonesia's coastal regions continues to face major challenges, including inconsistent product quality, limited technical skills, and minimal utilization of appropriate processing technologies. These conditions contribute to the low added value and weak competitiveness of micro-scale tuna processing enterprises. This program aims to enhance technical capacity, product quality, and overall productivity of MSMEs through the implementation of Smart Fish Processing technology grounded in STEAM principles and facilitated using a Participatory Action Research (PAR) approach. A total of 25 MSME members participated in awareness sessions, technology diffusion activities, hands-on training, demonstrations, and intensive mentoring over a two-month period. The results indicate a significant improvement in participants' knowledge of hygiene, sanitation, and modern processing techniques based on pre-post test scores. Technical skill enhancement was reflected in their ability to operate the smart steaming unit, standardize processing parameters, and produce three value-added products: steamed tuna, tuna floss, and tuna broth concentrate. During the program, production capacity increased to a cumulative total of 1,498 kg of steamed fish, 419 kg of tuna floss, and 548 kg of shredded tuna, yielding total sales of IDR 153.44 million and a net profit of IDR 45.9 million. Qualitative findings from interviews and FGDs show increased participant confidence, more structured production collaboration, and emerging digital marketing initiatives through WhatsApp and Facebook. Overall, the integration of controlled processing technology with participatory learning effectively improved product quality, productivity, and business capacity among coastal fish processors. The Smart Fish Processing model demonstrates strong potential for replication among fisheries-based MSMEs in other regions with similar characteristics.

Keywords: Smart Fish Processing; STEAM; tongkol processing; MSME empowerment; Participatory Action Research.

INTRODUCTION

Fish processing is a vital livelihood activity for coastal communities in Indonesia, particularly for micro- and small-scale enterprises that rely on marine resources to sustain household economies. Commodities such as bullet tuna or small tuna (*Euthynnus affinis*) are abundantly available and hold substantial value-added potential; however, processing practices in many rural areas remain dominated by traditional techniques such as salting, steaming, smoking, and sun drying (Retnawati & Retnaningsih, 2021; Saliman et al., 2024; Taiwo et al., 2024). These methods often result in inconsistent product quality, short shelf life, and unstable sensory characteristics. Such conditions reduce the competitiveness of fish-based products, including those produced by MSMEs, thereby limiting their contribution to local economic development. Previous

studies have shown that traditional methods cannot ensure long-term stability in nutritional content, texture, and food safety, whereas modern science- and engineering-based processing approaches provide more consistent product quality (Gassem, 2019; I Gde Suranaya Pandit et al., 2024; Indriati et al., 2023; Nadya, 2022).

Although steaming-based processing technologies have been designed and introduced, the greatest challenge lies in the capacity of MSME operators to utilize them effectively. This challenge is evident in Wonosari Village, Demak Regency, one of the major fish-processing centers in Central Java (Buchori et al., 2023). Demand for processed fish products, including steamed fish, floss, and shredded tuna, continues to increase, yet most processors still rely on inherited, non-standardized practices (Dewi et al., 2023). Field observations in the village show that although modern STEAM-based steaming equipment is accessible, limited knowledge of temperature–pressure settings, fish handling techniques, sanitation, raw material arrangement, and product formulation leads to fluctuating quality. The gap between available technology and operator competence results in inconsistent texture, color, and flavor, particularly in tuna-based products that are highly sensitive to improper thermal treatment.

This competency gap is reinforced by findings from empowerment programs in other coastal regions, which highlight that training in hygiene, modern processing techniques, and product diversification can significantly enhance technical skills among fish processors (Ismail et al., 2025; Shoimah et al., 2013). However, the implementation of scientific and technology-based approaches among small-scale tuna processing groups remains limited, unsystematic, and fragmented. Strengthening human resource capacity is therefore essential to ensure that available technologies can be optimally utilized and effectively contribute to increasing product value.

Given these conditions, the present study delivers training and mentoring to enhance tuna-processing competencies using STEAM-based technology through a participatory community empowerment approach. Involving micro-enterprise members in Wonosari Village, this study focuses on training the production of tuna-based products by integrating modern processing equipment, hygiene practices, process standardization, and product diversification such as tuna floss and shredded fish. A Participatory Action Research framework was employed to ensure that the learning process remained collaborative and aligned with the actual needs of MSME actors. The primary aim of this study is to demonstrate that MSMEs can improve their capacity to produce high-quality processed tuna products, utilize STEAM-based technology effectively, and contribute to strengthening local economic development. The study contributes to the literature on community-based technological innovation and supports broader agendas for sustainable fisheries-based economic empowerment in coastal regions.

METHODS

This study employed a Participatory Action Research (PAR) approach, which emphasizes active collaboration between researchers and MSME fish processors in identifying problems, understanding technology, conducting production practices, and continuously reflecting on the outcomes (Küsel & Markic, 2024; Puri, 2023). This approach was selected because it directly supports the goals of enhancing knowledge, technical skills, and the socio-economic capacity of MSME actors, as demonstrated by the results of this study. The program was carried out from June to August 2025.

A total of 25 MSME processors of *Euthynnus affinis* (bullet tuna) in Wonosari Village participated fully in all stages of the program, including awareness sessions, technology diffusion, training, mentoring, and evaluation. To obtain in-depth qualitative data, eight key informants were selected using a criterion-based selection strategy (Wallerstein & Duran, 2010), focusing on individuals with strategic roles in production activities and technology adoption. These informants were coded IK-01 to IK-08, as shown in Table 1, representing the group leader, senior processor, STEAM operator, novice processor, new operator, sanitation supervisor, and specialists in shredded and floss tuna production. The diversity of roles aligns with the variation of findings in the results section, such as increased confidence, improved collaboration, and strengthened digital marketing initiatives.

Table 1. Training Participants Involved in Interviews

Code	Age (years)	Experience (years)	Role in MSME	Description
IK-01	48	15	Group Leader	Decision-maker and production coordinator
IK-02	52	20	Senior Processor	Expert in traditional steaming
IK-03	45	12	STEAM Operator	Responsible for temperature and pressure control
IK-04	38	7	Novice Processor	Sorting and fish arrangement
IK-05	32	3	New Operator	Early adopter of Smart Fish Processing
IK-06	40	10	Sanitation Supervisor	Oversees equipment and workspace hygiene
IK-07	50	18	Shredded/Floss Processor	Specialist in product diversification
IK-08	44	6	Village Official	Coordination and facilitation support

The PAR framework consisted of five key activities, each contributing directly to the documented improvements in knowledge, skills, product quality, and socio-economic outcomes: 1) Community Education

The initial stage involved awareness sessions on hygiene, sanitation, raw material handling, food safety, and basic STEAM principles. This stage formed the basis for the pre–post test, the results of which are presented in the knowledge improvement table. 2) Technology Diffusion

Participants were introduced to Smart Fish Processing technology, including the operation of temperature and pressure control systems. This activity was strongly associated with improved technological understanding, as reflected in pre–post test results and interview statements regarding ease of use. 3) Training and Demonstration

Participants practiced producing three main products: standard steamed tuna, tuna floss, and shredded tuna. Technical skills were assessed using a 1–5 rubric that evaluated equipment operation, process standardization, hygiene and sanitation practices, and product output. These findings were confirmed through field observations and increased skill scores. 4) Mediation

The research team facilitated communication between MSMEs, village authorities, and equipment providers to address technical constraints and tailor procedures to local conditions. This process contributed to improved collaboration and more structured production task distribution. 5) Advocacy and Mentoring

Intensive mentoring ensured consistent application of skills, including refinement of formulas, cleanliness practices, process standardization, and basic digital marketing. This stage resulted in increased use of WhatsApp, Facebook, and Instagram for product promotion and expanded sales opportunities for tuna floss and shredded fish.

Participant competency was assessed comprehensively across two main dimensions: knowledge and technical skills. Knowledge was measured through pre–post tests covering food safety, equipment sanitation, tuna handling, and fundamental STEAM principles. Significant improvements across these indicators demonstrated the effectiveness of the awareness and technology diffusion activities, as documented in the knowledge improvement table. Technical skills were evaluated through direct observation using a 1–5 rubric that assessed the ability to operate Smart Fish Processing equipment, standardize production processes, implement hygiene and sanitation, and produce the three value-added products. Increases across all categories aligned with field findings on product texture consistency, optimal doneness, and participant proficiency in temperature and pressure–controlled processing. Qualitative data from interviews and FGDs reinforced these findings, revealing improved confidence, clearer division of labor, and emerging digital marketing initiatives via WhatsApp, Facebook, and Instagram. Competency development extended beyond technical aspects to include behavioral and collaborative improvements that support sustainable adoption of Smart Fish Processing technology in daily MSME operations.

Data were collected using a combination of quantitative and qualitative approaches. Knowledge improvement was captured through pre–post tests, while technical performance was assessed through rubric-based observations. To explore participant experiences, in-depth interviews were conducted with eight key informants (IK-01 to IK-08), alongside FGDs to examine changes in teamwork dynamics and group behavior. Photographic documentation was also used to record training processes and product outcomes. This mixed-methods approach

ensured that findings were valid, consistent, and aligned with the results. The supporting interview questions included:

What was your experience using the Smart Fish Processing equipment?

Do you feel more confident in processing fish products after the training?

Have there been changes in how you collaborate with group members?

Have you begun promoting products online?

How have consumers responded to the tuna floss and shredded fish products?

Data analysis integrated quantitative and qualitative techniques. Quantitative data from the pre–post tests were analyzed by comparing scores before and after training to identify improvements in hygiene, sanitation, tuna handling, and STEAM-related knowledge (Lucchetti et al., 2023). Technical skill gains were analyzed through rubric scores to assess changes in equipment operation, process standardization, hygiene maintenance, and product outcomes.

For qualitative data, analysis was conducted through data reduction, data display, and conclusion drawing. Interview and FGD transcripts were reviewed repeatedly to identify key themes, including confidence, collaboration, ease of technology use, digital promotion, and market opportunities. These themes were triangulated with quantitative findings to provide a comprehensive understanding of competency improvements. Methodological triangulation ensured consistency and validity, confirming that the results represented real gains in knowledge and skills.

RESULTS AND DISCUSSION

Program Outcomes

The implementation of the Smart Fish Processing program resulted in significant improvements in knowledge, skills, and product quality among the 25 participating MSME members. These outcomes were obtained through pre–post assessments, direct observations, and field documentation conducted throughout the program.

Improvement in Knowledge and Understanding

The pre–post test results presented in Table 2 indicate substantial gains in participants' knowledge of food safety, hygienic processing techniques, and basic understanding of STEAM-based technology.

Table 2. Improvement in Participants' Knowledge After Training and Extension Activities

Assessed Aspect	Before (%)	After (%)	Improvement (%)
Knowledge of hygiene and sanitation	48	88	+40
Understanding of smart steaming technology	30	82	+52
Knowledge of product diversification	35	80	+45
Knowledge of packaging and storage	42	86	+44

These improvements demonstrate that community education and technology diffusion activities were effective in significantly enhancing participants' cognitive capacity.

Improvement of Processing Skills

Skill evaluation was conducted through direct observation during the practical sessions of producing the three processed products: standard steamed tuna, tuna floss, and shredded tuna, as shown in Figure 1.





Figure 1. Training and Demonstration Process of the Smart Fish Processing Program

Participants demonstrated several newly acquired skills, as summarized in Table 3. These included: (1) operating the steaming equipment with temperature and pressure control; (2) producing products with more consistent doneness and texture; (3) applying hygiene procedures before, during, and after processing; and (4) producing all three products using standardized formulas. Skill levels were assessed using a five-point scale.

Table 3. Improvement in Product Processing Skills

Skill Category	Before	After	Remarks
Equipment operation	1.8	4.3	Able to operate independently
Process standardization	2.1	4.1	More consistent processing
Hygiene and sanitation	2.4	4.5	Improved compliance
Product diversification ability	1.9	4.0	Mastery of three main products

Processed Products Developed



Figure 2. Three Tuna-Based Processed Products Generated Through the Smart Fish Processing Program

This program resulted in the development of three processed products utilizing modern technology: (1) Standard steamed tuna, characterized by uniform doneness and more stable color; (2) Tuna floss, produced with a fine texture and controlled moisture content; and (3) Shredded tuna, generated through a controlled extraction technique, as illustrated in Figure 2. Participants reported that the product quality improved and became easier to market because the texture, aroma, and cleanliness were more consistent compared to those produced using traditional processing methods.

Social and Economic Impacts

Data kualitatif diperoleh dari wawancara mendalam dan diskusi kelompok dengan 8 anggota UMKM. Temuan menunjukkan perubahan signifikan pada aspek psikologis, sosial, dan potensi ekonomi peserta setelah mengikuti rangkaian pelatihan yang disajikan pada Tabel 4.

Melalui diskusi kelompok dan wawancara, peserta melaporkan: (1) Meningkatnya kepercayaan diri dalam mengolah produk secara mandiri. (2) Meningkatnya kemampuan melakukan promosi digital sederhana. (3) Semakin kuatnya kerja sama antarpeserta dalam berbagi tugas produksi. Dan (4) Terbukanya peluang pemasaran untuk produk abon dan konsentrat kaldu.

Qualitative data obtained from in-depth interviews and focus group discussions with eight MSME members revealed significant changes in psychological, social, and economic aspects following the training program. As summarized in Table 4, participants reported notable improvements in four main areas: (1) increased confidence in independently processing fish products, (2) enhanced ability to conduct basic digital promotion, (3) strengthened teamwork and clearer division of labor in production activities, and (4) expanded market opportunities for tuna floss and Shredded tuna. These findings demonstrate that the integration of technological training with participatory learning not only contributes to technical capacity building but also fosters meaningful social transformation and economic empowerment within the community.

Table 4. Social and Economic Impacts of the Training Program

Theme	Summary of Findings	Example Interview Quotes
Increased Confidence	Participants felt more assured in processing products independently.	<i>"Now I am no longer afraid of making mistakes. This equipment is easy to use."</i> (IK-03) <i>"Previously, I doubted whether I could produce high-quality products, but now I feel more confident."</i> (IK-01) <i>"I feel more encouraged to try new variations after the training."</i> (IK-06) <i>"The quality of the steamed fish is consistent every time."</i> (IK-04)
Ease of Technology Use	Participants stated that temperature and pressure control technology made their work easier.	<i>"Adjusting the sorting and processing tasks is now more organized."</i> (IK-04) <i>"We often discuss the workflow before starting production to avoid overlap."</i> (IK-08)
Improved Teamwork	Roles became clearer, coordination strengthened, and production became more efficient.	<i>"Work becomes faster now that we have divided responsibilities."</i> (FGD1) <i>"I now focus on sorting, while others handle processing and packaging, making it more structured."</i> (IK-04) <i>"We frequently coordinate before production, which helps avoid mistakes."</i> (IK-08)
Adoption of Digital Promotion	Participants began using platforms such as WhatsApp and Facebook for marketing.	<i>"After I posted on Facebook, many people started asking about the product."</i> (IK-07) <i>"I have started sending product photos to our customer WhatsApp group."</i> (IK-03) <i>"Online promotion helps a lot, especially for tuna floss."</i> (IK-06)
Emerging Market Opportunities	Tuna floss and broth concentrate started gaining demand from local food stalls and community consumers.	<i>"The food stall regularly requests tuna floss now."</i> (IK-05) <i>"Women in the neighborhood order tuna broth every week for cooking."</i> (IK-01) <i>"After selling it to a nearby stall, it quickly sold out."</i> (IK-02)

Production and Sales Evaluation

Summary data indicate that all three products, steamed fish, tuna floss, and shredded tuna—experienced stable increases in production and sales over the two-month period after participants mastered the Smart Fish Processing technology, as presented in Table 5. Steamed fish recorded the highest volume, averaging 30 kg per day or 1,498 kg over two months, with total sales reaching 1,430 kg. Although its selling price per kilogram is relatively low, the large production volume generated a total revenue of IDR 40,040,000. Tuna floss had the smallest production volume, averaging 7–8 kg per day or 419 kg over two months, but it produced the highest revenue (IDR 64,000,000) due to its significantly higher selling price (IDR 160,000 per kg). This product became the largest source of profit despite its lower volume. Shredded tuna ranked in the middle in terms of both production and revenue. With daily production of 9–11 kg and a total of 548 kg in two months, combined with sales of 520 kg, this product generated IDR 49,400,000. Shredded tuna

was particularly favored by food stalls and catering businesses due to its convenience and versatility.

Table 5. Profit per Product Over a Two-Month Period

Product	Selling Price/kg	Production Cost/kg	Margin/kg	Total Sold (kg)	Total Profit (2 Months)
Steamed Fish	IDR 28,000	IDR 18,000	IDR 10,000	1,430 kg	IDR 14,300,000
Tuna Floss	IDR 160,000	IDR 120,000	IDR 40,000	400 kg	IDR 16,000,000
Shredded Tuna	IDR 95,000	IDR 65,000	IDR 30,000	520 kg	IDR 15,600,000

Production and sales data indicate that the implementation of Smart Fish Processing technology not only increased production capacity but also expanded the profit potential of MSMEs. Tuna floss generated the highest profit margin, while steamed fish ensured business continuity due to its stable daily demand. Improvements in product quality after the training also facilitated the expansion of marketing channels through digital platforms such as WhatsApp, Facebook, and Instagram, and strengthened opportunities for collaboration with food stalls, local shops, and catering services.

The findings demonstrate that integrating STEAM-based fish processing technology with a participatory approach successfully enhanced knowledge, technical skills, and product quality among the 25 MSME tuna processors in Wonosari Village. The improvement in participants' understanding of hygiene, sanitation, and modern processing techniques was evident in the significant gains observed in pre–post test scores and in their ability to consistently produce three value-added products: steamed tuna, tuna floss, and shredded tuna. These improvements align with previous studies emphasizing that temperature and pressure control are critical factors in maintaining texture stability, microbiological safety, and sensory acceptability in fish products (Buchori et al., 2023; Suryaningrum et al., 2013). Controlled thermal processing has been shown to minimize quality inconsistencies commonly associated with traditional methods, resulting in more stable color, texture, and sensory characteristics.

From a capacity-building perspective, the PAR approach effectively promoted active participation, hands-on learning, and a sense of ownership over the technology. Participants were involved from process design and trial implementation to outcome evaluation, enabling them to tailor the technology to their local work environment. In-depth interviews revealed increased confidence in independently operating the technology, which supports earlier findings suggesting that direct engagement in the learning process enhances self-efficacy and accelerates innovation adoption. Additionally, group coordination improved noticeably, as evidenced by more structured task allocation across sorting, processing, and packaging teams (Kristianto et al., 2017; Ningsih et al., 2022). This enhancement of collaboration and social capital is a key indicator of sustainable technology adoption at the community level.

In terms of production outcomes, Smart Fish Processing technology enhanced both product quality and production capacity at daily and weekly scales. Over two months, participants produced a total of 1,498 kg of steamed fish, 419 kg of tuna floss, and 548 kg of shredded tuna. Weekly production increased gradually as technical skills and equipment efficiency improved. This trend reinforces evidence that process standardization and temperature–pressure control can directly enhance productivity in small-scale fisheries-based MSMEs. In the final weeks, participants were able to sustain production autonomously, indicating sufficient mastery of the technology without relying heavily on the mentoring team.

These gains in production capacity directly contributed to increased sales. During the same period, total sales reached 1,430 kg of steamed fish, 400 kg of tuna floss, and 520 kg of shredded tuna, generating total revenue of IDR 153,440,000 and an estimated net profit of IDR 45,900,000. Notably, although tuna floss had the lowest production volume, it produced the highest profit due to its superior profit margin. This finding supports MSME development literature, which states that diversification into high–value products can elevate income even when production volume is relatively small. Meanwhile, steamed fish contributed consistently to daily cash flow due to stable demand in the local market.

Marketing outcomes also showed positive developments. Basic digital marketing training encouraged participants to promote their products through WhatsApp, Facebook, and Instagram. Market responses to tuna floss and broth concentrate were notably strong, as evidenced by recurring orders from local food stalls and consumer interest through social media platforms (Kholifah et al., 2025; Rojek, 2021; Senali et al., 2022). Increased product visibility through digital channels aligns with previous studies reporting that online marketing can open new market opportunities for MSMEs, provided that product quality and supply continuity are maintained (Li et al., 2018; Rozmi et al., 2021). These findings underscore that technical improvements in processing must be complemented by strengthened marketing strategies to achieve business sustainability.

Overall, this discussion highlights that structured, STEAM-based technological interventions, when combined with participatory social approaches such as PAR, can produce multi-dimensional impacts on technical, social, and economic aspects. Knowledge and production skills improved, product quality became more stable, production and sales increased significantly, and marketing opportunities expanded. These findings confirm the effectiveness of appropriate technology in small-scale fisheries contexts and extend the literature by demonstrating that STEAM integration can be realistically implemented within rural MSME environments. The Smart Fish Processing model developed in this study holds strong potential for replication in other coastal communities with similar characteristics, provided that local adaptation, continuous mentoring, and strengthened marketing networks are included as integral components of implementation.

CONCLUSION

The Smart Fish Processing program, implemented through a participatory approach, successfully enhanced the technical and socio-economic capacity of MSME tuna processors in Wonosari Village. The integration of STEAM-based processing technology, which enables more precise temperature and pressure control, proved effective in producing three value-added products with more consistent, hygienic, and standardized quality compared to traditional practices. These improvements were supported by substantial increases in participants' knowledge of hygiene, product diversification techniques, and thermal processing, as well as strengthened skills in independently operating the equipment. Positive social impacts were also evident, including increased confidence, strengthened production teamwork, and improved ability to utilize digital media for product promotion. These results indicate that combining technological innovation with hands-on training and continuous mentoring can reinforce the resilience of small-scale fish processing enterprises while expanding local market opportunities. Thus, the Smart Fish Processing model can serve as an effective and adaptive approach for enhancing the value of fishery products and empowering coastal communities sustainably.

RECOMMENDATIONS

This study has several limitations, particularly regarding sample size, the duration of mentoring, and the scope of product quality testing. Future research is therefore recommended to expand the number and diversity of MSME groups to allow comparisons across different regions. More comprehensive technical assessments, such as microbiological stability, shelf-life evaluation, and the effects of varying temperature and pressure settings on sensory quality, are also needed to develop more robust operational standards. In addition, long-term studies that examine the sustainability of technology use, its impact on income, and the behavioral patterns of technology adoption among MSME actors will provide stronger insights into the effectiveness of the Smart Fish Processing model within the context of coastal community empowerment.

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