

RESEARCH ARTICLE

Editorial Process: Submission:08/25/2025 Acceptance:02/21/2026 Published:03/05/2026

3Es-Based Program to Enhance Safety Behaviors Among Fermented Fish Producers in Northeast Thailand: Implications for Liver Fluke and Cholangiocarcinoma Prevention

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Abstract

Objective: Consumption of fermented freshwater fish is common in Northeast Thailand but increases the risk of *Opisthorchis viverrini* (OV) infection, nitrosamine exposure, and cholangiocarcinoma (CCA). This study evaluated a 3Es-based safety program designed to enhance knowledge, attitudes, behaviors, and to reduce ergonomic risks among informal fish processors. **Methods:** A quasi-experimental study was conducted with 100 participants from two fishing communities in Ubon Ratchathani Province. The experimental group (n = 50) received a 13-week safety program based on engineering, education, and enforcement (3Es), while the comparison group (n = 50) received routine health services. Data were collected through a structured questionnaire and an ergonomic assessment using the Rapid Upper Limb Assessment (RULA). Statistical analyses included t-tests and effect size estimation with Cohen's d. **Results:** Post-intervention, the experimental group demonstrated significantly greater improvements than the comparison group in knowledge (mean difference = 2.09, p < 0.001, d = 2.69, very large effect), attitudes (mean difference = 0.39, p < 0.001, d = 3.88, very large effect), and behaviors (mean difference = 0.25, p < 0.001, d = 1.06, large effect). RULA scores also improved markedly, with fish sorting, drying, and packaging risk levels reduced from high to low, and cleaning and gutting reduced from very high to medium risk. **Conclusion:** The 3Es-based program significantly improved safety-related knowledge, attitudes, behaviors, and reduced ergonomic risks. Large effect sizes confirm that these gains are both statistically and practically meaningful, supporting integration into community health services and local policies for sustainable OV and CCA prevention.

Keywords: *Opisthorchis viverrini*- cholangiocarcinoma- occupational health- ergonomics- safety program

Asian Pac J Cancer Prev, 27 (3), 1081-1090

Introduction

The processing and consumption of fermented freshwater fish products are deeply embedded in the cultural and economic fabric of rural communities in Northeast Thailand. However, traditional processing methods particularly those involving short fermentation periods and inadequate hygiene pose significant public health risks, notably from *Opisthorchis viverrini* (OV) infection and exposure to nitrosamines, which are known carcinogens. In Thailand, the working-age population (ages 15–59 years) totals approximately 42.4 million from a total population of 66.1 million [1]. In 2021, informal workers outnumbered formal workers, with 19.6 million informal workers (52%) out of a total of 37.7 million employed persons [2]. In Ubon Ratchathani Province, located in Northeast Thailand, 588,074 individuals (80.48%) are skilled agricultural and fishery workers [3].

Despite the prevalence of these occupations, informal laborers remain particularly vulnerable to occupational injuries and chronic disease due to limited access to safety education and structural interventions [4].

Sirindhorn District is widely recognized for producing fermented fish products such as Pla ra, chili paste with fermented fish, and pickled fish. While these products contribute to household incomes and food security [5], their improper preparation has been directly linked to OV transmission and increased risk of cholangiocarcinoma (CCA) [6]. Northeast Thailand shows the highest incidence of liver and CCA, with age-standardized rates of 85.4 and 34.2 per 100,000 in males and females, respectively, resulting in nearly 14,000 deaths annually [7]. OV infection is typically sustained through the ingestion of raw or underprocessed freshwater fish containing infective metacercariae. Simultaneously, nitrosamines formed during protein fermentation under

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unsanitary or suboptimal conditions further contribute to bile duct carcinogenesis.

In the Lower Mekong sub-basin, where this study was conducted, endemic OV infection remains a critical issue due to intertwined environmental and sociocultural factors. Contaminated freshwater ecosystems near human settlements such as irrigation canals and poorly drained ponds facilitate transmission by sustaining the parasite's intermediate host, the *Bithynia* snail [8]. In addition, fermented and raw fish dishes like *Pla ra* and *Koi pla* are consumed using traditional preparation methods that fail to eliminate OV metacercariae and may generate nitrosamines [9].

Recent evidence shows that informal fish-processing workers in endemic areas face combined risks from OV infection and ergonomic hazards, often without structured safety education or protection [10, 11]. The World Health Organization and International Labour Organization Joint Estimates highlight ergonomic risks as major contributors to global occupational disease burden [12]. Moreover, One Health-based programs such as the KALMeFS and Lawa models demonstrate the success of integrated interventions linking environmental management, food safety, and community behavior change [8, 13]. These findings underscore the urgent need for a community-centered 3Es-based program that integrates education, engineering, and enforcement to reduce infection and injury risks among informal fish processors.

CCA prevention requires integrated interventions targeting both biological and chemical risk factors. Strengthening occupational safety and food hygiene practices within fish-processing communities is essential for breaking the OV transmission cycle and reducing carcinogenic exposures. As chronic OV infection is a key driver of inflammation, periductal fibrosis, and epithelial dysplasia leading to CCA, upstream interventions focused on prevention are both cost-effective and sustainable [14].

The 3Es approach Education, Enforcement, and Engineering offers a promising framework for community-based interventions in informal work settings. Education raises awareness and builds knowledge; enforcement reinforces safe practices; and engineering modifies work tools and environments to reduce risk. This integrated model has been shown to improve health behaviors across diverse sectors, including parasitic disease prevention and occupational safety [10].

To address the dual burden of OV infection and nitrosamine exposure, this study implemented a structured safety intervention grounded in the 3Es approach. The program included training on food hygiene and safe fermentation, ergonomic tool design, and the creation of community safety manuals. By integrating culturally relevant strategies and emphasizing behavioral change, the intervention aimed to enhance safety knowledge, attitudes, and practices among informal fish processors in high-risk areas.

This study therefore aimed to assess the effectiveness of a 3Es-based safety program in improving occupational safety and public health outcomes. Specifically, the research examined whether this community-based intervention could enhance preventive behaviors, reduce

accident risks, and interrupt the transmission of OV and nitrosamines before these fish products reach consumers.

Materials and Methods

Study design

This quasi-experimental study aimed to evaluate the effectiveness of a safety promotion program for processing freshwater fish products in high-risk communities located along the Sirindhorn Dam in Ubon Ratchathani Province, Northeast Thailand. The study site, illustrated in blue areas (Figure 1), encompasses communities involved in producing, processing, and exporting freshwater fish products to markets throughout Northeast Thailand. The intervention was designed around the 3Es of safety—Education, Enforcement, and Engineering—and was delivered over 13 weeks between January and October 2022.

The experimental and comparison groups were selected from two distinct villages located within the same subdistrict in Sirindhorn District, Ubon Ratchathani Province. The villages are approximately 18 kilometers apart and share similar geographic and socioeconomic characteristics both are situated along the reservoir shoreline, where fishing and freshwater fish processing are the main occupations. This ensured comparable community contexts while preventing cross-contamination between intervention and comparison groups.

Population and samples

The sample size was calculated using G*Power software (version 3.1.9.4) for an independent t-test design. The effect size (Cohen's $d = 0.59$) was derived from the difference in mean preventive behavior scores between the experimental group (2.52 ± 0.51) and the comparison group (2.24 ± 0.43) reported by Panithanang et al. [15]. With a significance level ($\alpha = 0.05$) and a power ($1 - \beta = 0.80$), the required total sample size was 92 participants.

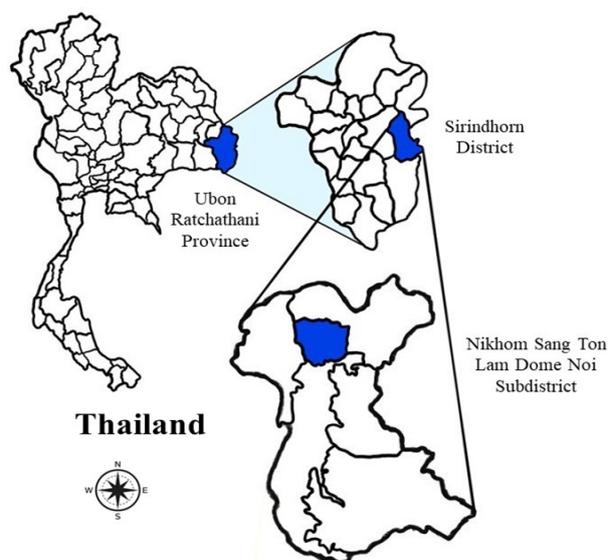


Figure 1. The Study Site Located in a Fishing Community along a Large Freshwater Dam in Ubon Ratchathani Province, Northeast Thailand.

To compensate for potential attrition (10%), the sample size was increased to 100 participants, equally divided into an experimental group ($n = 50$) and a comparison group ($n = 50$).

The study population comprised individuals engaged in the production and processing of freshwater fish products in communities surrounding the Sirindhorn Dam, a region known for high endemicity of OV and extensive aquaculture activity [16]. A total of 100 participants were purposively selected by the research team in collaboration with local community leaders and health officers to ensure representation of individuals actively involved in fish processing. Researchers conducted home and workplace visits to identify eligible individuals and explain the study purpose. Informed consent was obtained from all participants prior to enrollment. Fifty participants were assigned to the experimental group and 50 to the comparison group. Inclusion criteria were: 1) adults aged 30–60 years; 2) individuals currently engaged in the processing of freshwater fish products; 3) residents of the community for at least one year; and 4) those able to communicate in Thai and provide informed consent. Exclusion criteria were: 1) individuals with severe physical or mental health conditions that could affect participation; 2) those absent from more than 20% of intervention activities; and 3) individuals planning to relocate during the study period.

Research tools and quality assessment

This study employed three main research instruments to ensure a comprehensive and reliable evaluation.

1. The experimental tool (safety promotion program) was adapted and developed by the authors based on the safety-concept framework comprising the three basic Es Education, Engineering, and Enforcement [17]. The framework guided the program design, educational content, and implementation strategies. Content validity was verified by three experts in public health and occupational safety, with IOC values ranging from 0.80 to 1.00, confirming high validity.

2. Data collection instrument: The structured questionnaire used in this study was developed by the authors following standard methodological procedures to collect quantitative data. Its design was guided by the study framework, relevant literature, and previous research to ensure comprehensive coverage of key variables aligned with the study objectives. The questionnaire comprised four sections: (1) personal information (10 items), (2) knowledge of safe fish processing (15 multiple-choice and true/false questions), (3) attitudes toward workplace safety (3-point scale: Agree, Not Sure, Disagree), and (4) safety behaviors (3-point scale: Always, Sometimes, Never).

To ensure measurement quality, content validity was evaluated by three experts in parasitology, public health, and occupational safety, yielding a Content Validity Index (CVI) of 0.92. Reliability testing with 30 participants in a pilot study demonstrated strong internal consistency: the knowledge section achieved a Kuder–Richardson 20 (KR-20) coefficient of 0.78, while the attitude and behavior sections recorded Cronbach's alpha values of 0.74 and 0.79, respectively. For analysis, knowledge (10

items) was scored Yes = 1 and No = 0, with score ranges interpreted as high ($\geq 80\%$), moderate (60–79%), and low ($< 60\%$) based on Bloom's taxonomy [18]. Attitude and behavior (15 items) were rated on a 3-point scale: Agree/Always = 3, Unsure/Sometimes = 2, and Disagree/Never = 1. Scoring interpretation was defined as high (2.34–3.00), moderate (1.67–2.33), and low (1.00–1.66) [19].

3. Ergonomic risk assessment tool: The Rapid Upper Limb Assessment (RULA) was applied, along with observational analysis, to evaluate postural risks during various stages of fish processing (sorting, cleaning, gutting, drying, and packaging). RULA assesses upper-limb postural load and classifies ergonomic risks into four levels based on total scores: Level 1 (low risk; score 1–2), Level 2 (medium risk; score 3–4), Level 3 (high risk; score 5–6), and Level 4 (very high risk; score 7). These classifications follow the Workplace Ergonomics Guidelines of the National Institute for Occupational Safety and Health [20] and are consistent with the framework of Maurer-Grubinger et al. [21]. To ensure reliability, two trained occupational health assessors independently performed the evaluations, and inter-rater reliability testing yielded a Cohen's kappa coefficient of 0.82, indicating substantial agreement and confirming the robustness of the ergonomic risk data.

Data collection

Data collection was conducted from January to October 2022 using the Plan–Do–Check–Act (PDCA) framework to guide the implementation of the safety program. In the Plan phase, the research team organized community meetings to co-design the program, conducted risk assessments across five domains, and administered pre-tests to the experimental group.

The Do phase involved a structured 13-week safety program based on the 3Es of safety Engineering, Education, and Enforcement. Participants attended weekly 2-hour sessions led by the research team, village health volunteers, and local occupational health experts. The curriculum, aligned with Table 1, covered ergonomic workstation design, safe fermentation and heating techniques, and hygienic fish handling through hands-on demonstrations and real-time practice. Program implementation was monitored weekly by trained volunteers using structured checklists, while the research team conducted biweekly visits to provide feedback, verify progress, and address challenges.

In the Check phase, a post-test was administered to evaluate changes in knowledge, attitudes, and safety behaviors. The Act phase included data collection in the comparison group, which received routine health services. This phase also involved reflection and planning for future program integration. The PDCA framework ensured systematic execution, ongoing stakeholder involvement, and continuous quality improvement.

Statistical analysis

The statistical analysis was conducted using SPSS version 26.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics (frequency, percentage, mean, and standard deviation) were used to describe the general characteristics

of the study participants. Before conducting t-tests, key assumptions were assessed: the normality of score distributions was tested using the Shapiro–Wilk test, and the homogeneity of variances was evaluated using Levene’s test. All assumptions were met. To evaluate the effectiveness of the intervention, independent samples t-tests were used to compare between groups, while paired samples t-tests assessed within-group changes from pre- to post-intervention. In addition to p-values, Cohen’s d was calculated to determine the effect size and evaluate the magnitude of the program’s impact on knowledge, attitudes, and behaviors. All analyses were conducted at a significance level of $p < 0.05$.

Results

Table 1 shows that the experimental design was structured according to the PDCA framework. In the Plan phase, community meetings, surveys, and a pre-test were conducted to define objectives and assess baseline data. The Do phase included ergonomic workstation and tool redesign, training on food safety, hygienic processing, and ergonomics, together with the development of safety manuals based on the 3Es principle. The Check phase involved a post-test to evaluate changes, while the Act phase collected equivalent data from the comparison group and provided routine health services to ensure ethical balance.

Table 2 shows that the demographic and work-related characteristics of fermented fish processing workers in

the experimental and comparison groups were generally comparable, with no statistically significant differences ($p > 0.05$). Most participants were female, middle-aged (mean age 49.8 ± 7.28 vs. 47.6 ± 6.94 years), and primarily married. The majority had primary education, with income levels varying between groups, and all were engaged as fermented fish producers. Work-related pain, accidents, and illness histories were reported in both groups, confirming baseline similarity before the intervention. This similarity in demographic and occupational backgrounds supports the internal validity of the study, ensuring that observed post-intervention changes were attributable to the 3Es-based program rather than pre-existing group differences.

The changes in knowledge, attitude, and behavior (KAP) scores among participants in the experimental group before and after the safety program are presented in Table 3. Before the intervention, 28.00% of participants had high knowledge scores, which increased markedly to 98.00% after the program. Attitude scores also improved, with the proportion of participants in the high category rising from 70.00% to 96.00%. Similarly, behavioral scores demonstrated substantial improvement, increasing from 82.00% to 98.00% in the high category. These findings indicate that the safety program was effective in enhancing participants’ knowledge, attitudes, and behaviors regarding freshwater fish processing safety. The marked increase in KAP scores highlights not only knowledge acquisition but also successful translation into practical safety behaviors. The improvement in attitude

Table 1. Experimental Design of Program Activities based on the PDCA Framework in the Experimental Group

PDCA Phase	Program Code	Duration	Activities	Objectives	3Es Framework
Plan	D1	2 days	Organizing community meetings with academics, researchers, and community leaders	To clarify research objectives and jointly design the research	–
Plan	D2	2 days	Surveying basic information in the community	To survey the risk factors in 5 areas	–
Plan	P1	1 day	Administering pre-test in experimental group	To assess baseline knowledge, attitudes, and behaviors	–
Do	X1	2 weeks	Designing workstations according to ergonomic principles	E1 = Engineering (design to reduce musculoskeletal strain)	Engineering
Do	X2	2 weeks	Designing a spatula for mixing salt and fermenting fish according to ergonomic principles	E1 = Engineering (ergonomic equipment design)	Engineering
Do	X3	1 week	Training on reducing food processing risk factors that may cause CCA	E2 = Education (training on food safety and OV prevention)	Education
Do	X4	1 week	Training on work safety and hygienic fish processing procedures	E2 = Education (promoting hygienic and safe practices)	Education
Do	X5	1 week	Training on ergonomics in the workplace	E2 = Education (ergonomic awareness and safe posture)	Education
Do	X6	2 weeks	Preparing community safety manual and safety communication tools	E3 = Enforcement (establishing guidelines and safety promotion materials)	Enforcement
Check	P2	1 day	Administering post-test in experimental group	To assess changes in knowledge, attitudes, and behaviors post-intervention	–
Act	X7	2 weeks	Testing and data collection in the comparison group	To collect equivalent baseline and post-test data from non-intervention group	–
Act	P3, P4	2 days	Administering pre- and post-test in comparison group	To compare program effectiveness between experimental and comparison groups	–
Act	X0	1 week	Routine health services provided to comparison group	To maintain ethical parity and observe typical community health education effects	–

Table 2. Demographic and Work-Related Characteristics of Fermented Fish Processing Workers

Demographic and work-related characteristics	Experimental group (n=50)		Comparison group (n=50)		p-value
	Number	%	Number	%	
Gender					
Male	20	40.00	22	44.00	0.157
Female	30	60.00	28	56.00	
Age (years)					
30–40	9	18.00	7	14.00	0.199
41–50	22	44.00	23	46.00	
51–60	19	38.00	20	40.00	
Mean ± SD	49.8 ± 7.28		47.6 ± 6.94		
Status					
Married	49	98.00	35	70.00	0.157
Single	1	2.00	15	30.00	
Education levels					
No education	28	56.00	12	24.00	0.199
Primary education	18	36.00	34	68.00	
Secondary education	4	8.00	4	8.00	
Income (Baht)					
>5,000	2	4.00	5	10.00	0.199
5,001–10,000	17	34.00	38	76.00	
>10,000	31	62.00	7	14.00	
Mean ± SD	8,800 ± 2,873.17		7,850 ± 2,466.10		
Occupation					
(Fermented fish processing workers)	50	100.00	50	100.00	1.00
Work-related pain and discomfort					
Yes	17	34.00	12	24.00	0.157
No	33	66.00	38	76.00	
Accidents during fermented fish production					
Yes	32	64.00	30	60.00	0.157
No	18	36.00	20	40.00	
History of work-related illness					
Yes	36	72.00	29	58.00	0.157
No	14	28.00	21	42.00	

Table 3. Changes in Knowledge, Attitude, and Behavior (KAP) Scores before and after the 3Es-based Program in the Experimental Group (n = 50).

Factors	Before			After		
	Number	%	Inter-pretation	Number	%	Inter-pretation
Knowledge score ranges (points)						
0–6	8	16.00	Low	–	–	Low
7–10	16	56.00	Moderate	1	2.00	Moderate
11–15	14	28.00	High	49	98.00	High
Attitude mean score ranges						
1.00–1.66	–	–	Low	–	–	Low
1.67–2.33	15	30.00	Moderate	2	4.00	Moderate
2.34–3.00	35	70.00	High	48	96.00	High
Behavior mean score ranges						
1.00–1.66	–	–	Low	–	–	Low
1.67–2.33	9	18.00	Moderate	1	2.00	Moderate
2.34–3.00	41	82.00	High	49	98.00	High

Table 4. RULA Risk Levels and Evaluation Results before and after Workstation Improvements in the Experimental Group (n = 50)

Fermented fish production steps	Before workstation improvements		After workstation improvements	
	Levels*	Evaluation Results	Levels*	Evaluation Results
Fish sorting process	3	High risk	1	Low risk
Fish cleaning and gutting process	4	Very high risk	2	Medium risk
Fish drying process	3	High risk	1	Low risk
Packaging process	3	High risk	1	Low risk

*The risk level is divided into 4 levels: Level 1, low risk, Level 2, medium risk, Level 3, high risk, and Level 4, very high risk.

Table 5. Differences in Knowledge, Attitude, and Behavior (KAP) Scores before and after the 3Es-based Program between the Experimental and Comparison Groups

Factors	Mean scores		Mean Difference	95% Confidence Interval (CI)	p-value	Cohen's d (Effect size)
	Experimental group	Comparison group				
Knowledge						
Before	8.76	8.76	0.00	-0.42–0.42	1.000	2.69
After	10.85	8.76	2.09	1.88–2.31	<0.001*	(very large)
Attitude						
Before	2.45	2.46	-0.13	-0.31–0.05	0.159	3.88
After	2.84	2.29	0.39	0.28–0.50	<0.001*	(very large)
Behavior						
Before	2.61	2.61	0.04	-0.01–0.09	0.120	1.06
After	2.86	2.65	0.25	0.16–0.34	<0.001*	(large)

scores suggests that participants developed stronger perceptions of risk and responsibility toward hygienic and ergonomic practices. The concurrent gains across all three domains knowledge, attitude, and behavior demonstrate the effectiveness of integrating educational, engineering, and enforcement strategies under the 3Es framework to foster sustainable behavior change.

Table 4 presents the RULA evaluation of work-related postural risks before and after workstation improvements in the experimental group. Before the intervention, workers were classified as high risk in fish sorting, drying, and packaging processes, and very high risk in fish cleaning and gutting. After workstation improvements, risk levels decreased substantially, with fish sorting, drying, and packaging reduced to low risk, and fish cleaning and gutting reduced to medium risk. These results indicate that ergonomic modifications effectively minimized musculoskeletal risk across all processing steps. These reductions in RULA scores indicate that engineering solutions, such as redesigned workstations and ergonomic tools, directly alleviated postural strain. The improvements not only reduced physical discomfort but also enhanced productivity and safety awareness among workers, demonstrating the added value of engineering control within community-based interventions.

At baseline, no significant differences were observed between the experimental and comparison groups across knowledge, attitude, and behavior scores ($p > 0.05$). After the intervention, the experimental group demonstrated significantly greater improvements in knowledge (mean difference = 2.09, 95% CI = 1.88–2.31, $p < 0.001$, Cohen's $d = 2.69$, very large effect), attitude (mean difference = 0.39, 95% CI = 0.28–0.50, $p < 0.001$, $d = 3.88$, very large

effect), and behavior (mean difference = 0.25, 95% CI = 0.16–0.34, $p < 0.001$, $d = 1.06$, large effect) compared with the comparison group (Table 5). These effect sizes indicate that the 3Es-based safety program produced not only statistically significant but also practically meaningful improvements in participants' knowledge, attitudes, and safety behaviors regarding freshwater fish processing. The large and very large effect sizes confirm the robustness and practical significance of the intervention's impact. These quantitative findings underscore that the program achieved more than short-term awareness it facilitated behavioral transformation rooted in active participation and local relevance. The consistent patterns across KAP and ergonomic indicators collectively affirm that the 3Es-based model successfully integrated education, community empowerment, and workplace design to promote sustained occupational safety and health outcomes.

Discussion

This study examined the effectiveness of a 3Es-based safety program Engineering, Education, and Enforcement implemented among fermented fish processing workers in Ubon Ratchathani Province, Northeast Thailand. The results demonstrated that the program successfully improved occupational safety knowledge, attitudes, and behaviors, while also reducing ergonomic risk levels associated with fish processing tasks. Fish processing is the main occupation in communities along the waterfront, which often exposes workers to accidents and occupational injuries [22]. This is also in line with studies highlighting the prevalence of work-related diseases and injuries among agriculturists in Northeast

Thailand [23], and with research showing that insufficient or intermittent preventive behaviors are associated with higher OV infection risk [24]. In organizing the discussion, the interpretation of findings is presented in a sequence corresponding to the Results section, beginning with KAP, followed by ergonomic risk outcomes and effect size interpretation. This structure allows for a coherent reflection on how the 3Es-based intervention contributed to both behavioral and physical improvements among participants.

The present study found significant improvements in safety knowledge, attitudes, and behaviors after the intervention, with nearly all participants achieving high scores across these domains. Similar outcomes were reported in Ubon Ratchathani, where the “NONGBO NO-CCA Model” was developed through community-based action research to promote fruit and vegetable consumption. Active participation of leaders and villagers in planning and implementation led to significant gains in knowledge, attitudes, and preventive practices ($p < 0.001$) [25]. Together, these findings highlight how participatory programs can effectively modify health behaviors, reduce risky practices such as improper fermentation or unhygienic fish handling, and ultimately disrupt the OV transmission cycle, lowering the risk of chronic infection and CCA [26]. The present results are consistent with previous studies showing that experiential learning, peer engagement, and culturally relevant content enhance the effectiveness of community-based health interventions. However, unlike many prior liver fluke prevention programs focusing solely on education [15, 27, 28], the 3Es-based program combined education with engineering and enforcement strategies, leading to greater behavior change. This difference may explain the very large effect sizes observed in this study, as practical demonstrations and community monitoring reinforced behavioral compliance more effectively than education alone.

Notably, the intervention also addressed chemical hazards by reducing nitrosamine exposure, a carcinogenic byproduct of traditional fish fermentation practices. Training participants on safe fermentation methods and hygienic handling, alongside ergonomic tool design, not only improved workplace safety but also minimized exposure to carcinogens. This dual impact aligns with [14] and underscores the program’s potential for long-term CCA prevention at the population level. This multidimensional approach corresponds with the One Health perspective that recognizes the interconnectedness of occupational safety, food hygiene, and environmental protection. By improving hygienic processing, the program may indirectly reduce both human and environmental exposure to OV and nitrosamines, offering a preventive strategy that complements biomedical screening and treatment programs.

Beyond behavioral change, this study provides novel evidence of ergonomic benefits through RULA assessment [21]. Before workstation improvements, workers in fish sorting, drying, and packaging were classified as high risk, while fish cleaning and gutting were classified as very high risk. After ergonomic modifications, risk levels decreased to low or medium, confirming that engineering

interventions effectively reduced musculoskeletal strain. This is consistent with global evidence showing that ergonomic redesign and participatory interventions can lower musculoskeletal risk factors, particularly in informal labor sectors [10, 11]. By embedding ergonomic solutions within the 3Es framework, the program simultaneously improved knowledge, behaviors, and physical working conditions, thereby reinforcing its sustainability and relevance for occupational health promotion. Comparable studies in other manual labor industries, such as small-scale agriculture and food production, have reported similar reductions in musculoskeletal strain after ergonomic modifications [29]. The agreement across studies suggests that low-cost, participatory ergonomic redesign can be feasibly adopted in informal community settings. Differences may arise due to variation in task intensity and worker posture, but the consistent downward trend in RULA scores demonstrates the universality of ergonomic intervention benefits.

The large and very large effect sizes observed across KAP dimensions further validate the magnitude of program impact. Compared with previous quasi-experimental interventions for OV prevention that reported small to medium effects ($d = 0.5–0.8$) [15, 27, 28], the present study achieved substantially higher effect sizes ($d = 1.06–3.88$). This discrepancy likely reflects the combined use of educational and engineering components that addressed both cognitive and environmental determinants of safety behavior.

These findings also reinforce international evidence supporting integrated, community-driven strategies for OV and CCA prevention. Interventions based on the Health Belief Model have been shown to enhance preventive behaviors in multicultural areas [30], while combining social marketing with HBM has improved awareness and practices in endemic regions [31]. By incorporating occupational safety through the 3Es model, this study extends existing frameworks by showing how ergonomic workplace improvements and structured behavioral enforcement can complement health literacy interventions. This integration is consistent with the global evidence on occupational risk factors, which highlights the significant burden of disease and injury attributable to workplace exposures worldwide [12], and aligns with the WHO/ILO review that identified ergonomic hazards as major contributors to musculoskeletal disorders across industries [11]. The agreement between the current study and global evidence emphasizes that multidimensional, participatory frameworks are critical for achieving sustainable occupational health improvements. The inclusion of engineering controls in a behavioral program represents a contextual innovation that bridges the gap between health education and workplace safety policy.

Furthermore, the program reflects the One Health approach by addressing risks at the human–animal–environment interface [8, 13]. By improving sanitation and safer fish processing, the intervention not only reduced human OV infection risk but also minimized environmental contamination that sustains parasite transmission in aquatic hosts [32]. In doing so, the program contributes to Sustainable Development Goals

(SDGs), particularly good health and well-being (SDG 3), clean water and sanitation (SDG 6), and responsible consumption and production (SDG 12). This underscores its potential as a scalable model for sustainable public health and occupational safety promotion in other high-risk communities. Therefore, the findings have important implications for community health policy and local occupational safety promotion. Integrating the 3Es-based approach into public health service frameworks could enhance community self-reliance, strengthen cross-sector collaboration, and provide a practical model for other endemic regions in Thailand and the Mekong Basin.

Beyond statistical significance, the effect size analysis further underscores the program's practical impact. The very large effect sizes observed for knowledge ($d = 2.69$) and attitude ($d = 3.88$), together with the large effect size for behavior ($d = 1.06$), demonstrate that the improvements were not only statistically reliable but also substantial in magnitude. These findings indicate that the 3Es-based program had a strong and meaningful influence on participants' safety-related competencies, suggesting its potential for real-world application and scalability in similar high-risk communities. By reporting both p-values and effect sizes, this study highlights the robustness of the intervention's outcomes, ensuring that the observed benefits reflect genuine behavioral change rather than minimal differences detectable only through statistical testing. Future studies should examine the long-term sustainability of these behavioral and ergonomic improvements, including periodic reassessment and integration into local occupational safety regulations. Such efforts would help institutionalize community-based safety programs and strengthen the One Health system in endemic areas.

Strength and Limitations

Strengths of this study include its quasi-experimental design, use of validated tools, effect size analysis, and ergonomic assessment. The program yielded significant improvements in knowledge, attitudes, behaviors, and ergonomic risks, with effect sizes ranging from large to very large. However, the long-term sustainability of these gains remains uncertain. Reliance on self-reported data may have introduced bias, and the single-district setting limits generalizability. Future research should adopt longitudinal, multi-site designs with broader outcome measures to confirm the durability and wider applicability of these effects.

In conclusion, this study showed that a 3Es-based safety program improved knowledge, attitudes, behaviors, and reduced ergonomic risks among fish processors. The large to very large effect sizes confirm its substantial practical impact. By addressing parasitic, chemical, and musculoskeletal hazards, the program provides a scalable model for occupational and public health promotion. Integrating the 3Es within the One Health approach supports relevant SDGs and highlights its policy value for high-risk communities. Future efforts should emphasize sustainability and cultural adaptation.

Author Contribution Statement

All authors participated in the study design. CY, YP, JD, and NS conceived and designed the research. CY, and JD connected and coordinated the fieldwork. CY and YP collected the data. CY carried out the analyses. CY reviewed drafts of the paper. All authors contributed to the writing and revisions of the manuscript and approved the final version.

Acknowledgements

The authors would like to express their gratitude to the community enterprise group and the study participants for their cooperation and support throughout the research.

Funding statement

The authors received no financial support for the research, authorship, and/or publication of this article.

Ethical approval

The study was approved by the Ubon Ratchathani Rajabhat University Ethics Committee for Human Research, adhering to the Declaration of Helsinki and the ICH-GCP Guidelines (Reference Number: HE642022). All participants provided informed consent after being briefed on the study's objectives, design, potential risks, and benefits.

Availability of data (if apply to your research)

Data will be available upon request.

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Conflict of interest

The authors declare no competing interests.

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