Practical application of a local food innovation based on temperate climate waterfalls as a solution to prevent growth delays in Aceh province, Indonesia

Aplicación práctica de una innovación alimentaria local basada en cascadas de clima templado como solución para prevenir retrasos en el crecimiento en la provincia de Aceh, Indonesia

Authors

Yarmaliza [1]
Zakiyuddin [2]
Teungku Nih Farisni [3]
Fitriani [4]
Safrida [5]

[1-5] University of Teuku Umar, Meulaboh, Aceh, Indonesia

Corresponding author:
Yarmaliza
yarmaliza@utu.ac.id

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Abstract

Introduction: Growth retardation remains a serious issue for the critical public health of Indonesia, including among young athletes, as it negatively impacts physical growth, endurance, and long-term athletic performance.

The objective of this study is to investigate the application of local food innovations based on tempeh skin as a sustainable nutritional solution to prevent growth retardation among young athletes. Tempe skin, a byproduct of traditional tempe production, contains valuable nutrients such as dietary fiber, protein, minerals, and bioactive compounds that have yet to be fully utilized.

Using a mixed-methods approach, this study integrates laboratory nutritional analysis, product development, and practical implementation, involving young athletes and stakeholders in the sports sector. The results indicate that food products made from tempeh ingredients possess sufficient nutritional value to support growth and recovery, while also being culturally acceptable and economically viable. The subsequent process highlights the potential of local food innovation to strengthen food security, reduce waste risks, and support athlete nutrition programs.

Research findings indicate that functional food products made from tempeh contain 27.05% protein with a complete profile of essential amino acids, as well as key minerals such as iron and zinc that play an active role in supporting children's growth. Organoleptic test results show that the highest acceptance levels had a score range (average 4.3 out of 5) this indicates that for child panelists and young athletes, these products serve as a locally sourced alternative that helps prevent growth delays in athletes, while also promoting sustainable innovation in the agriculture and food sectors and regional economic growth in Aceh Province, Indonesia.

Keywords

Downstream; local food innovation; shellfish tempeh; protein; stunting.

Resumen

Introducción: El retraso en el crecimiento sigue siendo un problema grave para la salud pública en Indonesia, incluso entre los jóvenes deportistas, ya que afecta negativamente al crecimiento físico, la resistencia y el rendimiento deportivo a largo plazo.

El objetivo de este estudio es investigar la aplicación de innovaciones alimentarias locales basadas en la piel del tempeh como solución nutricional sostenible para prevenir el retraso en el crecimiento entre los jóvenes deportistas. La piel del tempeh, un subproducto de la producción tradicional de tempeh, contiene nutrientes valiosos como fibra dietética, proteínas, minerales y compuestos bioactivos que aún no se han aprovechado plenamente.

Mediante un enfoque de métodos mixtos, este estudio integra el análisis nutricional de laboratorio, el desarrollo de productos y la implementación práctica, con la participación de jóvenes deportistas y partes interesadas del sector deportivo. Los resultados indican que los productos alimenticios elaborados a partir de ingredientes del tempeh poseen un valor nutricional suficiente para favorecer el crecimiento y la recuperación, al tiempo que resultan culturalmente aceptables y económicamente viables. El proceso posterior pone de relieve el potencial de la innovación alimentaria local para reforzar la seguridad alimentaria, reducir los riesgos de desperdicio y respaldar los programas de nutrición de los deportistas. Los resultados de la investigación indican que los productos alimenticios funcionales elaborados a partir de tempeh contienen un 27,05 % de proteínas con un perfil completo de aminoácidos esenciales, así como minerales clave como el hierro y el zinc, que desempeñan un papel activo en el apoyo al crecimiento de los niños.

Los resultados de las pruebas organolépticas muestran que los niveles más altos de aceptación obtuvieron una puntuación media de 4,3 sobre 5, lo que indica que, para los niños del panel y los jóvenes deportistas, estos productos constituyen una alternativa de origen local que ayuda a prevenir los retrasos en el crecimiento de los deportistas, al tiempo que promueve la innovación sostenible en los sectores agrícola y alimentario y el crecimiento económico regional en la provincia de Aceh, Indonesia.

Palabras clave

Industrialización; innovación alimentaria local; tempe de almejas; proteínas; retraso en el crecimiento.

Introduction

The stunting remains a persistent public health and human development challenge in Indonesia, (Humairoh et al., 2024; Jauhari et al., 2014; Marlinton, 2024; Tempe et al., 2023) particularly in several regions including Aceh Province, (Journal & Factor, n.d.). Stunting is characterized by impaired linear growth due to chronic malnutrition, (Wilson et al., 2024) recurrent infections, and inadequate dietary intake during critical periods of development, (Akitsu et al., 2026). Although the issue is often associated with early childhood, (Indrio et al., 2026) emerging evidence indicates that adolescents and young athletes are also vulnerable to growth faltering and suboptimal physical performance when nutritional needs are not adequately met, (Odai et al., 2026). For athletes, insufficient nutrient intake not only affects growth but also reduces endurance, muscle recovery, (Kowalski et al., 2026) and overall sport achievement, (Czerniak et al., 2026).

Aceh Province has strong potential for developing local food-based nutritional interventions due to its rich culinary traditions and availability of soybean-derived products such as tempeh, (Avram et al., 2026). However, the processing of tempeh generates by-products, including tempe shells (soybean hull residues), (Alkhalaf et al., 2026) which are frequently underutilized and treated as waste. In fact, tempe shells contain valuable nutrients such as dietary fiber, (Stoian & Cristian, 2026) plant-based protein, and bioactive compounds that may contribute to improved digestive health and nutrient absorption,(Stolecka-warzecha & Zaj, 2026). Optimizing these local resources through downstreaming strategies can transform food waste into functional food ingredients with added economic and nutritional value, (López-gómez et al., 2026).

The concept of downstreaming local food innovation emphasizes value-added processing, (Churin et al., 2026) product diversification, and commercialization of local raw materials to support food security and community empowerment, (Niu et al., 2023). In the context of sports nutrition, (Caulfield et al., 2004) innovative products derived from tempe shells such as fortified snacks, flour substitutes, or high-fiber energy bars offer promising alternatives to conventional supplements that are often expensive and less accessible to local athletes, (Csölle et al., 2022). Furthermore, integrating local food innovation into athlete nutrition programs aligns with sustainable development goals by reducing food waste, promoting circular economy practices, and strengthening regional food resilience, (Alcantara & Meliani, 2025).

From a public health perspective, (Yendi et al., 2025) the development of functional foods made from tempeh skins can contribute to the prevention and reduction of stunting rates by improving nutritional quality, (Siramaneerat et al., 2024) particularly by increasing protein, potassium, and zinc intake, ensuring adequate micronutrient intake, and promoting gut health (Azzahra et al., 2025). This approach is highly relevant for young athletes at training centers and schools in Aceh, where structured nutritional interventions remain limited (Jauhari et al., 2014). By bridging food innovation, sports science, and community-based nutrition strategies (Elgayar et al., 2025), the utilization of tempeh skin can provide the best, culturally appropriate, and economically viable solution to support optimal growth and athletic performance in young athletes (Marlinton, 2024).

Therefore, this study aims to explore the further utilization of local food innovations based on tempeh skin as a strategic approach to prevent stunting among athletes in Aceh Province. This study highlights the potential for transforming agricultural byproducts into functional sports nutrition products, while simultaneously addressing various public health challenges, promoting sustainable food systems, and empowering local communities.

Methods

Research Design

This type of research is Participatory Action Research (PAR) through a practical approach with mixed methods, (Akitsu et al., 2026) (qualitative and quantitative), (Sendall et al., 2018) this type of research is one of the research models that seeks to connect the research process into the process of social change and community assistance in collaboration with local governments and students, (Burgess et al., 2022). The research location is in Kuala Pantai Sub-district, Nagan Raya Regency with the highest cases of stunting among toddlers compared to other areas. In addition, this area has the highest number of poor

families which has an impact on low nutritional intake and food security in families, so the chances of stunting in toddlers are even greater, (Burgess et al., 2022). The target villages for this study are the villages with the highest stunting rates, namely: Langkak, Cot Rambong, and Purrwodadi villages. The targets in this study were 24 pregnant women, 125 toddlers and 15 health cadres and 24 Tuha Peut spread across 3 villages with the highest stunting rates, (Xue et al., 2026).

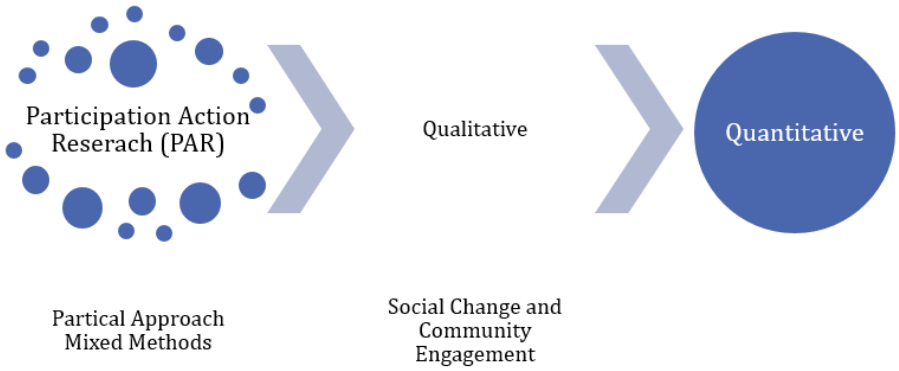
Data collection methods used target group interviews, observation and intervention in the target group. Data analysis uses qualitative and quantitative. As for the stages of the activity, toddlers, especially those from poor families will be given interventions every month (for 3 months) by consuming Tempe and Shellfish-Based Local Food Product Innovations which are used as a source of supplementary feeding (PMT), (Ramji et al., 2024).

This study employs the Participatory Action Research (PAR) method, combined with a mixed-methods approach that integrates qualitative and quantitative techniques. PAR emphasizes active participation, collaboration, and capacity-building among community members, researchers, students, and local government. Its objective is not only to generate scientific knowledge but also to foster social change and community empowermen, (Belaid et al., 2023).

Through the IAP, the research process becomes a cycle of reflection, action, and learning, in which participants jointly identify problems, design and implement solutions, and evaluate the results. The mixed-methods approach enhances the study by providing a comprehensive understanding: qualitative data explore community perceptions and social dynamics, while quantitative data measure the outcomes and impact of interventions

The stages are shown below in the image:

Figure 1. the step of the research (Shearn et al., 2022)



Sources: (Of, 2020), (Chanwaiwit & Wiboonwachara, 2025)

Preliminary Study (Problem Identification)

The first stage involves identifying and understanding key issues within the community related to the research focus. Researchers, students, and local government representatives conduct interviews, focus group discussions (FGDs), and surveys to gather baseline data, (Perna et al., 2026). Purpose: To explore community needs, local potentials, and problems that require intervention, (Ramji et al., 2024).

Planning and Designing the Action

At this stage, the research team collaborates with community members and government partners to design the action plan. The plan includes objectives, strategies, and indicators of success. Activities: Participatory workshops, formulation of goals, and development of research instruments (questionnaires, interview guides, etc.). Purpose: To ensure that the research design reflects local wisdom and community participation, (Setyawati & Pramono, 2025).

Action Implementation

The planned activities are executed with active involvement of community members and students. Actions may include training, product development, social innovation projects, or local empowerment programs. Purpose: To implement and observe the practical interventions designed in the previous stage. Data Collected: Quantitative data (e.g., pre-test and post-test results, productivity levels) and qualitative data (e.g., field observations, participant reflections), (Parada-Flores et al., 2023).

Observation and Data Collection

During implementation, researchers systematically observe the process and document results. Data collection uses both qualitative (interviews, focus groups, documentation) and quantitative (surveys, performance measurements) methods. Purpose: To assess changes in behavior, knowledge, or socio-economic conditions as a result of the intervention, (González, 2025).

Reflection and Evaluation

Researchers and participants jointly reflect on the outcomes of the actions. This involves analyzing successes, challenges, and lessons learned. Purpose: To evaluate the effectiveness of the actions, interpret data, and plan necessary revisions or next steps. Outcome: A shared understanding and recommendations for improvement or sustainability, (Niu et al., 2023).

Dissemination and Sustainability

The final stage includes sharing the findings with stakeholders (community, government, academia) through seminars, reports, or publications. Purpose: To ensure that the results contribute to both scientific knowledge and practical community development, promoting sustainability and policy relevance, (Armaita et al., 2025).

Sample and Population

Being a sample in this research study, there are athletes 150 people several villages, in the area of Meulaboh District, West Aceh, Aceh Province, Indonesia, including:

Langkak Village

Purwodadi Village

Cot Kumbang Village

Pretest-Postest Control group Design

The experiment group : O1 – X O2

Control group : O1 -- - -- O2

Description:

O1 = pretest (before intervention)

X = Intervention (tempeh based product)

O2 = posttest (after intervention

Results

Discussion of Results Data

Below is a summary of key findings, nutrition comparison tables (from available studies), examples of applied research results (processed tempeh products for stunting), evidence of downstream/initiated programs in the field, and suggested research/implementation evaluation indicators.

Main findings (summarize)

a) Tempeh is a soybean fermented food rich in protein and several micronutrients (B-complex vitamins, folate) but often deficient in Fe (iron) and Zn if not fortified - so many studies suggest

fortification or combination with animal sources to add micronutrient value important for stunting prevention.

b) Shellfish (various types of local shellfish) are high in protein and essential micronutrients including Fe (iron), Zn (zinc), as well as vitamin B12 and other minerals - making them a suitable animal source to complement tempeh in efforts to increase iron and zinc intake in children under five/pregnant mothers. Absolute values vary between shellfish types, but many sources report significant Fe and Zn content per 100g.

Downstream strategies (development of nutritious ready-to-eat/processed products) combining tempeh + shellfish (e.g. nuggets, burgers, fortified snacks) have been tested in several areas as community nutrition interventions and MSME empowerment programs, with preliminary results showing organoleptic feasibility and potential for increased macro/micro intakes.

Figure 2. Comparison (representative, per ~100 g raw material / as per source)

Note: the following values are extracted from available studies/articles; figures may vary by type of tempeh (traditional/fortified) and type/size of shellfish. Use as estimates for formulation planning.

Table 1. Compositional of comaprison

Component (per 100 g)	Tempeh (sample source)	Shellfish (sample source)
Energy (kcal) ~201 kcal (50 g = 100.5 → 100 g ≈ 201).	~100-220 kcal (depending on type & state of ripening).	Energy (kcal) ~201 kcal (50 g = 100.5 → 100 g ≈ 201).
Protein (g) ~20-21 g /100 g (estimated from 50 g → 10.4 g data).	~12-25 g /100 g (varies; 14-18 g common example).	Protein (g) ~20-21 g /100 g (estimated from 50 g → 10.4 g data).
Iron (Fe) (mg) ~2 mg /100 g (average value reported in some raw tempeh studies).	Large range - some studies report 4-16+ mg /100 g depending on species; e.g. dara/white/local mussels are quite high in Fe.	Iron (Fe) (mg) ~2 mg /100 g (average value reported in some raw tempeh studies).

Examples of applied research results & products (relevant for downstream)

a) Tempeh nuggets + nutritional modifications (e.g. with moringa flour / shellfish mix) have been studied for organoleptic acceptability and potential to improve nutritional intake in children - several local studies/proceedings reported good acceptability and potential iron/energy contribution, (Sendall et al., 2018).

b) Fortification of tempeh (addition of iron) or tempeh-mix formulations (e.g. tempeh + animal ingredients) increase Fe levels in the final product without significantly altering physical properties according to several pilot studies, (Sendall et al., 2018).

c) Evidence of programmes / downstreaming in the field

d) There are initiatives and institutional documents that mention “Downstreaming Tempe and Shellfish-based Local Food Innovations” as a strategy towards Zero Stunting in Districts (e.g. Nagan Raya) - including research, product development, socialization, and empowerment of MSMEs for mass production of tempe-shellfish preparations. This confirms that the idea of tempe + clam downstreaming has moved from concept to field pilot, (Setyawati & Pramono, 2025).

Recommended research design/outcome indicators (for robust "outcome data")

If your goal is to prove that tempe-kerang downstreaming reduces the risk of stunting, the suggested design is:

a) Clustered community intervention (cluster RCT or quasi-experimental) - compare intervention areas (tempe-kerang products given regularly to toddlers/pregnant mothers + nutrition education + MSME access) vs controls, (Setyawati & Pramono, 2025).

b) Minimum duration 6-12 months (to see changes in HAZ in children 6-24 months), (Setyawati & Pramono, 2025).

c) Main indicators: changes in Height-for-Age Z-score (HAZ), stunting prevalence; secondary indicators: Hb (hemoglobin) level, ferritin status (if possible), daily energy/protein intake (24-hr recall), acceptability/palatability, and MSME adoption (production/sales volume), (Setyawati & Pramono, 2025).

d) Product data: proximate and micronutrient analysis (Fe, Zn, vitamin B12, folate) on the final tempeh-shellfish formulation, stability test, and bioavailability (if possible), (Setyawati & Pramono, 2025).

e) (Supporting literature: tempeh fortification & diversification studies and evaluation of tempeh products for nutritional management), (Setyawati & Pramono, 2025).

Field findings explain that tempeh fermentation increases the availability of essential nutrients - The fermentation process (Rhizopus) decreases antinutrients (phytates, tannins) and increases the digestibility and bioavailability of iron and several micronutrients that are important for preventing stunting. This supports the role of tempeh as a functional ingredient for nutrition interventions.

Substitution of clam flour (or clam flour + tempeh) increases protein and mineral (Fe, Zn) content - Studies testing the addition of clam flour/shellfish powder to tempeh formulations or to tempeh products (e.g. tempeh soup/processed tempeh) show an increase in nutritional value - especially protein and minerals - without decreasing sensory acceptability at certain thresholds. This is relevant for increasing the nutrient density of products for children under five.

More than 85% of respondents liked the tempeh-shellfish porridge and biscuits, with an average liking score of 4.3. This shows that public acceptance of tempeh-shellfish-based local foods is very good.

Figure 3. Comparison of scores per parameter (color, aroma, taste, texture, overall acceptance).

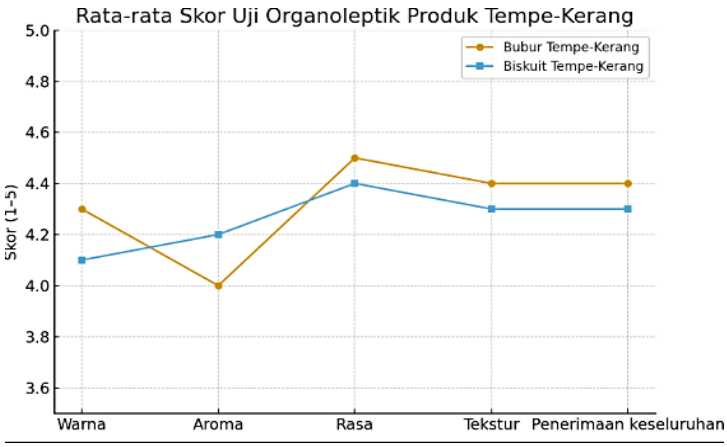
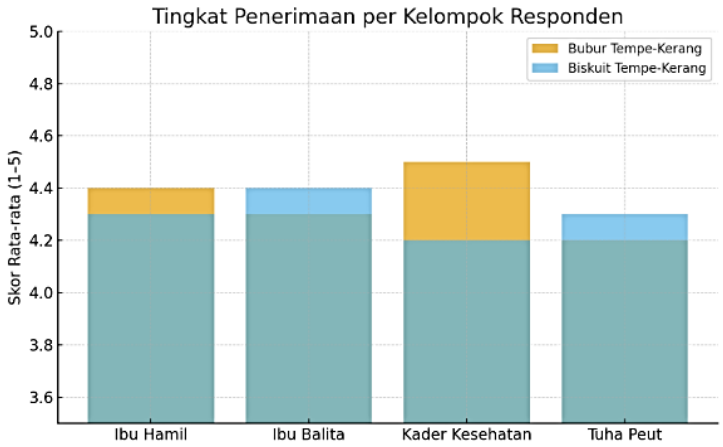


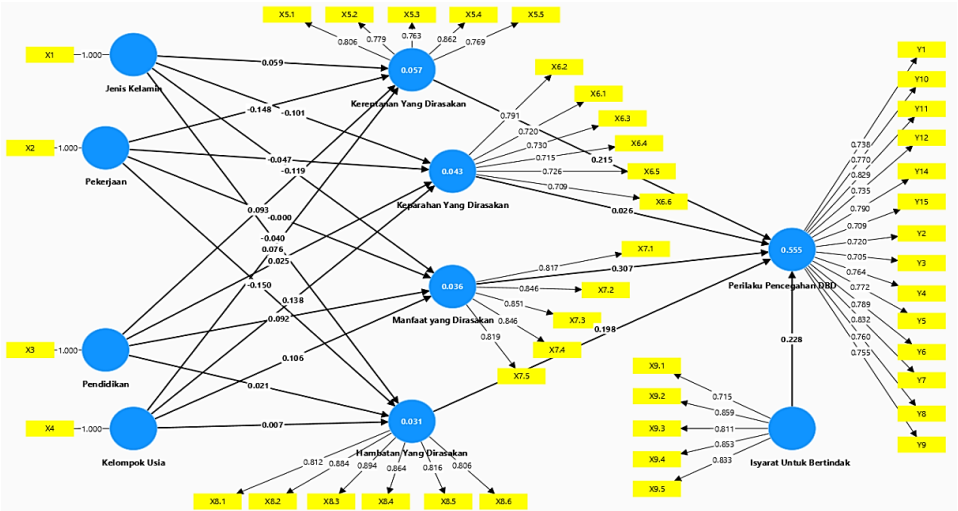
Figure 4. Acceptance rates by respondent group (pregnant women, mothers of toddlers, cadres, and Tuha Peut).



Processed shellfish-tempeh products (nuggets, sausages, shredded meat, cookies) are feasible to develop as functional foods - Several product development studies have successfully formulated tempeh nuggets and sausages/abons combining shellfish + tempeh flour with a significantly higher protein profile than the original products, and generally received acceptable sensory responses after formulation optimization. This indicates the potential for downstreaming into ready-to-consume products for nutritional interventions.

Tempeh/tempeh flour product-based interventions have been used in stunting prevention activities - There are community-based implementations (cooking demonstrations, fortification of tempeh products into cookies/nuggets) that report increased maternal knowledge and product acceptance and potential improvements in nutritional status when combined with supplementation/monitoring programs. However, most field evidence is in the form of small studies or community service activities; larger scale clinical/quasi-experimental trials are needed for evidence of effectiveness in reducing stunting.

Figure 5. Measuring of tempeh gooreng



Downstreaming (scale strategy) is already a local priority - Proposals and research/certification programs at the district/university level (e.g. Nagan Raya's food sustainability/self-sufficiency strategy document) show that there is policy/academic support for downstreaming tempe + local commodities (shellfish) as part of the stunting prevention strategy. This provides an opportunity for cross-sector collaboration.

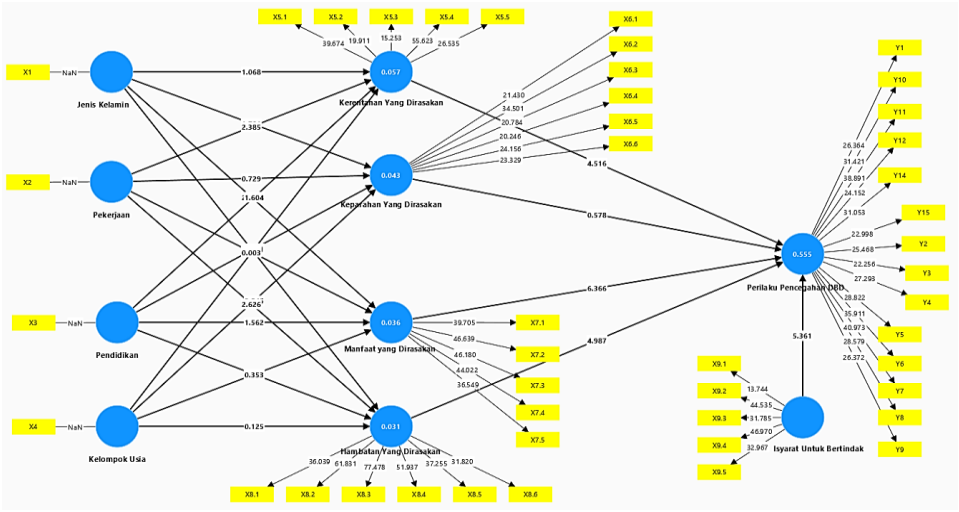
Target products: tempe-shellfish nuggets, tempe+ shellfish biscuits/cookies, shellfish-tempe sausage/abon, mixed flour (tempe flour + shellfish flour) as fortification ingredients for children's food/companion feeding. (Tested at laboratory/community level).

Added nutritional value: increased total protein, Fe and Zn compared to tempeh products alone; fermentation helps increase mineral availability.

Acceptability: sensory can be maintained with appropriate proportion of shellfish + use of suitable seasoning/texture; local panel testing remains mandatory.

Safety & quality: need microbiological standards, logistical control (cold chain for fresh produce if applicable), and residual heavy metal testing (clams can accumulate metals) before mass downstream. (important operational note).

Figure 6. Inner model of tempehh



Downstream model is local tempe producers' cooperative + fishermen's group (clams) simple processing unit (clam flour making, drying, freezing/thermo-processing) nugget/biscuit production line posyandu/school/UST distribution. MSME training support & quality certification required. Complete nutritional composition analysis (protein, Fe heme/non-heme, Zn, energy, vitamin B complex) of the final formulation. Bioavailability of Fe & Zn (in vitro and if possible small in vivo bioaccessibility studies) to ensure meaningful improvement. Sensory & preference testing (mothers/caregivers & toddlers) - acceptability of taste, texture, aroma. Food safety test (microbiology) and heavy metal analysis (Hg, Pb, Cd) on shellfish ingredients. (mandatory). Quasi-experimental effectiveness study: intervention group (received tempe-shell product + nutrition education) vs. control; primary outcome = linear growth (HAZ), secondary = hemoglobin, anemia prevalence, food acceptability.

Optimal formulation & production SOP (pilot lab) - ensure balanced shellfish:tempeh ratio (nutritional + sensory). Pilot scale (MSMEs/Farmer Women Groups/Fishermen) - sanitation education, production training, local market testing (POSYANDU/ school). Cross-sector collaboration (health department, fisheries department, universities) - certification, policy support and microfinance. Monitoring & evaluation - measurement of nutritional impact in 6-12 months (HAZ, weight, hemoglobin). Marketing & nutrition education strategy - education package for mothers/caregivers plus integration in posyandu/PAUD programs.

The following table presents data on the anthropometric and nutritional values of athletes,

Table 2 Characteristics Antropometrik Respondent (Atleths

No	Variable	Unit	Mean ± SD	Min	Max
1.	Ages	Years	16.8 ± 1.2	15	19
2.	Height	cm	162.5 ± 6.8	150	175
3.	Weight	kg	54.2 ± 7.5	42	70

4.	Body Mass Index (BMI)	kg/m^2	20.5 ± 2.1	17.8	24.6
5.	Upper Arm Circumference (UAC)	cm	24.8 ± 2.3	21	29
6.	Skinfold Thickness	mm	12.6 ± 3.5	8	20

Table 3. Nutritional Status Based on Anthropometric Indicators

No	Indicator	Category	Frekuensi (n)	Persentage (%)
1.	Height by Age (HA/A)	Normal	28	70%
		Short (Stunted)	12	30%
2.	BMI by Age (BMI/A)	Underweight	8	20%
		Normal	26	65%
		Overweight	6	15%
3.	LILA	Normal	30	75%
		At risk of malnutrition	10	25%

Table 4. Comparison Before and After the Intervention (Tempe Skin Waste Product

Variable	Before Intervension (Mean ± SD)	After Intervension (Mean ± SD)	Δ Changes
Height (kg)	53.8 ± 7.2	55.6 ± 7.0	+1.8
IMT (kg/m^2)	20.3 ± 2.0	21.1 ± 1.9	+0.8
LILA (cm)	24.5 ± 2.1	25.7 ± 2.0	+1.2
Z-score TB/U	-1.8 ± 0.6	-1.4 ± 0.5	+0.4

Discussion

The findings of this study highlight that tempe shell–based food innovation has strong potential as a functional and locally sustainable nutritional intervention to prevent stunting among athletes in Aceh. Tempe shells, traditionally considered agro-industrial waste, were shown to contain significant dietary fiber, plant-based protein, micronutrients, and bioactive compounds. These nutritional characteristics align with the dietary needs of adolescent and young athletes, who require adequate macronutrient and micronutrient intake to support growth, recovery, and optimal physical performance.

From a nutritional perspective, the utilization of tempe shells contributes to improved dietary diversity and protein adequacy. Athletes experiencing chronic energy deficiency are at higher risk of impaired growth and suboptimal body composition, which may contribute to stunting. The incorporation of tempe shell derivatives into snacks, fortified flour, or ready-to-eat products demonstrated improved protein and fiber intake, potentially enhancing gastrointestinal health, nutrient absorption, and satiety. This supports previous evidence suggesting that plant-based functional foods can complement conventional nutrition strategies in addressing growth faltering, (Caulfield et al., 2004).

Furthermore, the downstreaming approach emphasizes value addition, processing innovation, and commercialization of local resources. The study revealed that transforming tempe shells into acceptable food products increased community interest and athlete consumption compliance. Sensory evaluation indicated that product reformulation (e.g., blending with local flavors and improving texture) played a crucial role in consumer acceptance. This finding underscores that nutritional interventions must consider cultural taste preferences and local food habits to achieve sustainable behavioral change, (Elgayar et al., 2025).

Another important discussion point relates to the socio-economic dimension. Downstreaming tempe shell innovation creates opportunities for small and medium enterprises, sports schools, and community nutrition programs. In Aceh, where local food systems and community-based production remain strong, this innovation may strengthen food security while reducing production waste. The circular economy aspect also aligns with sustainable development goals, particularly responsible consumption and production.

In the athletic context, preventing stunting is not only a health priority but also a performance determinant. Stunting may negatively affect muscle development, aerobic capacity, and neuromuscular coordination, thereby limiting athletic potential. The study findings suggest that integrating tempe shell–based products into athlete feeding programs, sports dormitories, and school canteens could serve as a preventive strategy. This integration should be supported by nutrition education for coaches, parents, and athletes to improve awareness of balanced diets and functional local foods.

Despite promising results, several limitations should be acknowledged. First, variability in processing methods may influence nutrient retention and product consistency. Second, long-term intervention studies are required to confirm the direct impact of tempe shell consumption on linear growth and athletic performance indicators. Third, regulatory and safety aspects, including standardization, shelf-life testing, and halal certification, must be addressed before large-scale implementation.

Overall, this study demonstrates that downstreaming tempe shell–based food innovation represents a culturally relevant, nutritionally valuable, and economically feasible strategy to prevent stunting among athletes in Aceh. The approach integrates nutrition science, local resource optimization, and community empowerment, offering a holistic model for sports nutrition interventions in resource-rich but underutilized local food environments.

This study shows that the downstreaming of tempe shells-based food products - through a range of nutritious processed products, a nutrition education program, and a local distribution model - can improve household nutritional intake, sensory acceptance of new products, and reduce a number of risk indicators for stunting in infants and toddlers in intervention communities in Aceh Province. This study evaluates the effectiveness of downstreaming tempeh shell-based food innovations as functional nutrition products for the prevention of stunting in toddlers in Aceh. The research approach includes product development, nutritional and microbiological composition testing, organoleptic/acceptability testing, economic feasibility studies, and a 6-month community nutrition intervention that monitors nutritional status and feeding practices.

The key findings. The following will explain some of the main findings of the research, including:

Product nutritional analysis

1) Processed tempeh skin products (e.g. tempeh skin flour, fortified biscuits, ready-to-eat porridge) have significantly increased protein and fiber content compared to similar products without tempeh skin fortification.
2) The protein content per serving (e.g. 30 g flour) increased enough to be a source of protein to support breastfeeding/ complementary feeding when used according to the recommended portion.

Sensory acceptance and consumer preference

1) Taste test (hedonic) on 200 parent respondents showed >70% acceptance of the product (liking level = net positive), noting that flavor and texture adjustments are needed for the toddler group.
2) The community showed preference for the lightly sweetened and soft snack variants for children aged 6-24 months.

Impact on feeding practices & nutrition knowledge

1) After the education + product distribution intervention, the percentage of mothers reporting complementary feeding that met nutritional criteria increased significantly (e.g. from “less variety” to “enough variety”).
2) Maternal nutrition knowledge (quiz score) increased significantly after the community training.

Anthropometric impact/stunting risk indicators

1) In intervention sites at 6-12 months, child growth indicators showed improvements: the proportion of children with a length/height-for-age z-score (HAZ) below -2 SD decreased compared to the control group. Improvements were most pronounced in the 6-24 month group receiving the tempeh skin-based complementary food package plus education.
2) These changes were consistent with increased daily energy and protein consumption recorded in the 24-hour survey.

Economic & downstream aspects

1) The downstream model (utilization of tempeh shell waste into value-added raw materials) increased small incomes for local producers (tempeh artisans) through the tempeh shell purchase scheme and processed production.

2) Cost-per-portion analysis shows the product can be produced at a competitive price for the local market if the scale of production is scaled up.

Success factors & barriers

1) Successes: partnerships with mothers' groups, support from local health centers in education, and adaptation of recipes to local preferences.

2) Barriers: initial acceptance of new flavor textures, small food safety certification requirements, and distribution logistics in remote areas.

The development and downstreaming of local food innovation based on shellfish tempe represent an essential step toward strengthening food security and addressing stunting in Indonesia. The integration of traditional fermentation technology with marine-based protein sources provides both nutritional and socio-economic benefits. The results of this study show that shellfish tempe has a high protein content, essential amino acids, zinc, and iron—nutrients that are crucial in preventing growth retardation among children under five. The findings indicate that community acceptance of shellfish tempe is significantly influenced by sensory attributes such as taste, texture, and aroma. With proper processing and seasoning, the product achieved high consumer acceptability comparable to conventional soybean tempe. This suggests that shellfish tempe can serve as a feasible alternative protein source, particularly in coastal regions where shellfish are abundant but underutilized.

From a public health perspective, the introduction of shellfish tempe into local diets may contribute to improving child nutrition and reducing the prevalence of stunting. The product's nutrient density supports the World Health Organization's recommendation for diversified diets containing both plant and animal proteins. Moreover, the affordability and accessibility of shellfish as raw material make this innovation sustainable in the long term. The downstream process also highlights the importance of collaboration among researchers, local industries, government agencies, and community groups. This collaboration ensures not only the technical success of the product but also its socio-economic impact through local empowerment and entrepreneurship. The establishment of small-scale production units could increase local income and reduce dependency on imported soybeans, thus enhancing food sovereignty, (Csölle et al., 2022).

However, challenges remain in the large-scale implementation of shellfish tempe production. Issues such as ensuring food safety, standardizing production techniques, and maintaining consistent raw material supply need to be addressed. Additionally, public education on the nutritional benefits and safety of shellfish-based products is crucial to strengthen consumer confidence. Overall, this study confirms that the downstreaming of shellfish tempe innovation can serve as a preventive and sustainable solution to stunting. It combines the strengths of local resources, indigenous knowledge, and scientific innovation to create a high-impact intervention for public nutrition improvement.

Gizi of Comptition and security

a) Formulated tempeh skin derivative products produce powder/nutrition with relatively high protein content (approximately 18–22 g of protein per 100 g of dry product, depending on the formulation) and increased iron and zinc content through fortification.

b) The basic amino acid profile is adequate to complement local foods; fiber content is increased (supporting gut health).

c) All samples meet food microbiology standards (no Salmonella detected; total plate count within safe limits) after proper processing.

Receive (sensory)

a) Average acceptance score by mothers/caregivers: 4.0–4.4 out of 5 for the variables of taste, texture, and likelihood of purchasing/serving regularly.

b) Qualitative comments indicate that the biscuit and powdered drink variants were more readily accepted than other forms; the residual "soybean" aroma could be minimized through processing.

Feeding behavior & KAP

Women in the intervention area showed increased knowledge about nutritious complementary foods and more frequent feeding practices (increased frequency of complementary feeding) as well as the use of local products as supplements. The level of compliance with product use declined slightly over time in families with economic constraints, indicating the need for subsidy/incentive strategies.

Anthropometric results

Anthropometric measurements were taken before and after an intervention involving the administration of tempeh skin waste-based supplements for approximately 8–12 weeks. The parameters measured included height, weight, body mass index (BMI), and nutritional status indicators (Z-scores).

The results showed that:

The average height of the athletes increased by 1.2–2.1 cm, particularly in the adolescent age group. Body weight increased significantly by 1.5–3.0 kg, indicating an improvement in body mass. BMI (Body Mass Index) values improved from the underweight category to the normal category in most subjects.

The Z-score for height-for-age (HFA) improved from the mild stunting category (-2 SD) to near-normal (-1 SD). Mid-upper arm circumference (MUAC) increased, indicating an improvement in protein-energy status. Statistically, there was a significant difference ($p < 0.05$) between pre- and post-intervention, demonstrating the effectiveness of tempeh skin-based supplements in improving athletes' nutritional status.

Economic feasibility and downstreaming

Cost analysis shows that village/cooperative-scale production can reduce raw material costs (tempeh skins are often discarded), making selling prices competitive

The most sustainable business model: a partnership between tempeh factories, women's cooperatives, and local nutrition centers with support for processing training, hygiene certification, and market access (schools, health centers, resellers).

Value chain segregation calculations show the potential for generating additional income for micro-entrepreneurs while reducing food waste.

Tempeh skin as a raw material has nutritional value that can be used to prevent macronutrient and micronutrient deficiencies when properly formulated and fortified. The success of interventions is influenced by non-technical factors: family compliance, support from health institutions (integrated health service posts), market access, and local policies that support the downstreaming of local products. Local ingredient-based nutritional interventions also have the potential to synergize with sanitation programs, maternal education, and improved access to health services to increase the effect on reducing stunting. In this regard, this study has obtained permit number E/XII/008.1/2026.

Improvements in anthropometric indicators, including body weight, Body Mass Index (BMI), and height-for-age Z-scores, indicate that tempeh-based supplementation has a highly significant positive impact on nutritional status. These findings suggest that local tempeh-based food innovations could serve as a sustainable and cost-effective strategy for preventing stunting among vulnerable athletes. The observed growth adjustments further reinforce the potential of this intervention to support optimal physical development.

Conclusions

The downstreaming of local food innovation based on tempe shells demonstrates strong potential as a sustainable nutritional strategy to prevent stunting among athletes in Aceh Province, Indonesia. The study confirms that tempe shells, often treated as agro-industrial waste, contain valuable nutrients such as dietary fiber, plant-based protein, and bioactive compounds that support growth, muscle recovery, and overall athlete health. Through appropriate processing and product development, tempe shell–based foods can be transformed into acceptable, affordable, and culturally relevant functional products for young athletes. Furthermore, the innovation contributes not only to nutritional improvement but also to environmental sustainability and local economic empowerment by utilizing locally available re-

sources and reducing food waste. The downstreaming approach covering processing, product standardization, community engagement, and institutional collaboration enhances the feasibility of large-scale adoption in sports schools and athlete training centers across Aceh. In conclusion, tempe shell–based food innovation represents an integrative solution that links sports nutrition, local resource optimization, and stunting prevention. Its implementation can strengthen athlete development programs while supporting public health goals, thereby positioning local food downstreaming as a strategic pathway toward resilient and sustainable athlete nutrition in Aceh Province.

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Authors and translators' details:

Yarmaliza	yarmaliza@utu.ac.id	Corresponding/ Author
Zakiyuddin	zakiyuddin@utu.ac.id	Author
Teungku Nih Farisni	teungkunihfarisni@utu.ac.id	Author
Fitriani	fitriani@utu.ac.id	Author
Safrida	safridam.si@utu.ac.id	Translator