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Nutritional Contribution of Patin (*Pangasius*) Bone Flour and Snakehead Fish Flour Fortification to Food Products for Children: A Narrative Literature Review

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Abstract

Background: Stunting is a chronic nutritional problem affecting physical growth, cognitive development, and long-term productivity in children. Local, protein- and mineral-rich food-based interventions support nutrition improvement during the First 1000 Days of Life. Fish flour, including bone flour, from patin and snakehead fish is rich in protein, calcium, phosphorus, and energy, and has potential as a fortification ingredient in products such as biscuits, cookies, and dimsum. **Objective:** To review the contribution of patin bone flour and snakehead fish flour fortification to the nutritional composition and organoleptic acceptability of food products, and its relevance to stunting-prevention strategies. **Method:** This narrative review searched Scopus, PubMed, ScienceDirect, and Google Scholar for English and Indonesian language articles published between 2020 and 2025 using a PICO framework for screening. Seventeen articles were assessed for eligibility; six meetings of the inclusion criteria were analyzed. **Result:** Six included studies, three used patin (*Pangasius hypophthalmus*) bone flour and three used snakehead fish (*Channa striata*) flour, incorporated into biscuits, cookies, or dimsum at 10–75% concentrations. Where control values were reported, fortification increased protein and calcium content relative to unfortified controls, with increases in phosphorus and energy reported in individual studies, though higher concentrations reduced organoleptic acceptability; none of the studies measured anthropometric or stunting-related outcomes directly. **Conclusion:** Patin bone and snakehead fish flour fortification shows potential to increase the nutrient density of food products for children, supporting broader stunting-prevention strategies. However, evidence remains limited to a few heterogeneous formulation studies without anthropometric endpoints, quality appraisal, or safety data, indicating nutritional potential rather than proven effectiveness.

Keywords: Fish flour, Fortification, Stunting

Review Article

INTRODUCTION

Stunting is a growth and development disorder in children caused by chronic malnutrition and repeated infections, characterized by a height or length below the standard set by the ministry responsible for government health affairs (Badan Kependudukan dan Keluarga Berencana Nasional,

2021; Kementerian Kesehatan Republik Indonesia, 2022). Stunted children not only have a height below the standard for their age but also face a range of subsequent impacts, including delayed growth and development, decreased intelligence and productivity, and greater susceptibility to infectious and non-communicable diseases (Lestari et al., 2022). Stunting can also hinder fine and gross motor development and, in the long term, increases the risk of metabolic syndrome such as obesity, type 2 diabetes, and cardiovascular disease due to early-life changes in metabolism (Grillo & Gigante, 2019; Widjaja et al., 2025).

The impact of stunting also extends to socioeconomic aspects. Children who grow up with cognitive and physical impairments tend to have lower productivity in adulthood, which implies reduced educational, employment, and income opportunities and perpetuates a cycle of poverty (Firdaus et al., 2024; Musheiguza et al., 2021). Stunting is also shaped by environmental determinants such as access to sanitation infrastructure (Fitri et al., 2025), which underlines the need to combine such multisectoral measures with nutrition-specific interventions. These impacts may also be transmitted across generations through epigenetic mechanisms that alter genes related to growth and metabolism, so that the cycle of malnutrition and susceptibility to stunting can be repeated from mother to child (Gu et al., 2024).

In Indonesia, stunting prevalence remains a serious public health problem despite a downward trend over the past decade: from 37.2% in 2013, based on the 2013 Basic Health Research (Riskesdas 2013) (Kementerian Kesehatan Republik Indonesia, 2013), to 19.8% in 2024, according to the 2024 Indonesian Nutritional Status Survey (Survei Status Gizi Indonesia/SSGI 2024) (Kementerian Kesehatan Republik Indonesia, 2024). This figure still falls short of the 2020-2024 National Medium-Term Development Plan (RPJMN) target of below 14% (Bappenas, 2020), leaving a gap of around 5-6 percentage points that must be closed in a relatively short time. Because most linear-growth faltering occurs during the First 1000 Days of Life (Kementerian Kesehatan, 2023), adequate protein and micronutrient intake during this critical window - particularly from affordable animal-protein sources such as fish - is central to prevention efforts (Setiawati et al., 2023).

Local fish that are rich in protein and minerals include patin (*Pangasius hypophthalmus*) and snakehead fish (*Channa striata*). Patin bone, a by-product of patin fillet processing, is a concentrated source of calcium and phosphorus: adding patin bone flour to biscuits raised calcium content from 1.3% in the unfortified control to 5.39-5.95% (Siagian et al., 2020), and adding it to dimsum significantly increased calcium, phosphorus, and ash content (Yolahumaroh et al., 2025). Because published proximate data for patin bone flour itself are scarce, the flesh composition of a related Siluriform fish, the African catfish (*Clarias gariepinus*), is cited here only as an indicative reference for this fish order: on a wet-weight basis it contains approximately 17.7% protein, 4.8% fat, 1.2% minerals, and 76% water (Primawestri et al., 2023). These catfish data do not describe patin bone flour and are not part of the evidence synthesized in this review. Snakehead fish flour has been reported to contain 75.52% water, 77.69% protein, 4.18% fat, 14.77% ash, and 3.36% carbohydrate (Prastari et al., 2024); because these values sum to well over 100%, the protein and other proximate figures were most likely determined on a dry-matter basis while moisture was reported on a wet-weight basis. As the primary source does not explicitly state the analytical basis used, these figures are reported here as published and should be interpreted with caution until verified against the original methodology. To maximize their use in nutrition interventions, fish such as patin and snakehead fish - including their bones - can be processed into flour, making them more practical, shelf-stable, and easier to incorporate into food products.

Previous studies have explored the use of patin (*Pangasius hypophthalmus*) bone flour and snakehead fish (*Channa striata*) flour in food formulations intended to support child nutrition, generally reporting that fortification increases the protein, mineral, and energy content of biscuits, cookies, and dimsum, and that products remain organoleptically acceptable within certain concentration ranges (Siagian et al., 2020; Misnati et al., 2023; Yolahumaroh et al., 2025). However, none of these studies directly measured anthropometric indicators (e.g., height-for-age) or stunting status, so the link between consuming these fortified products and stunting prevention remains

inferential rather than demonstrated. In addition, the terminology used for fish species and flour type (bone flour versus flesh flour) is inconsistent across studies, which complicates comparison between them. This review addresses that gap by compiling and critically appraising the nutritional-composition and organoleptic evidence for fish-flour fortification, clarifying the specific species and flour types actually studied, and explicitly identifying what further evidence would be required to translate these formulation-level findings into support for stunting prevention. Efforts to utilize local animal-protein sources such as fish flour are aligned with Sustainable Development Goal (SDG) 2 (Zero Hunger) and SDG 3 (Good Health and Well-being), which respectively target the elimination of malnutrition among children under five and the reduction of preventable child mortality (Rajagukguk et al., 2021; Liu et al., 2022). Accordingly, this article aims to review the nutritional and organoleptic contribution of incorporating patin bone flour and snakehead fish flour into food formulations for children, and to discuss the implications and evidence gaps relevant to local food-based nutrition strategies aligned with SDGs 2 and 3.

METHODS

This study is a narrative literature review; it was not conducted as a full systematic review and was not registered in PROSPERO. Eligibility was assessed by the authors without a validated critical-appraisal instrument (e.g., JBI, CASP), and no formal risk-of-bias or certainty-of-evidence assessment (e.g., GRADE) was performed. These methodological limitations, and their implications for the strength of the conclusions drawn, are discussed further in the Discussion (Advantages and Limitations).

The PICO framework used to guide the search and eligibility of this review was revised from the authors' original framework to accurately reflect the outcomes actually reported in the eligible studies (nutritional composition and organoleptic acceptability), rather than stunting status or anthropometric outcomes, which none of the eligible studies measured directly:

- Population: Fish-flour-based food products intended for children
 - Intervention: Fortification with patin and/or snakehead fish flour (including fish bone flour)
 - Comparison: Food products without fish-flour fortification
 - Outcome: Nutritional content (protein, energy, minerals) and product organoleptic acceptability
- Literature was searched in Scopus, PubMed, ScienceDirect, and Google Scholar, which are recognized scientific databases; Mendeley was additionally used to compile and manage candidate records but is a reference manager rather than a primary scientific database, and records retrieved through it were cross-checked against the four primary databases for duplication. Searches covered publications from 2020 to 2025, a range applied consistently throughout the Abstract, Methods, and Results of this review - in English and Indonesian. Table 1 reports the exact Boolean search string used for each database, including the Indonesian-language terms needed to retrieve the Indonesian-language articles ultimately included, together with the last search date and the number of records retrieved per database, so that the search can be reproduced.

Table 1. Search keyword databases

Database	Search string	Last search date	Records retrieved
Scopus	("catfish flour" OR "patin flour" OR "fish bone flour" OR "tepung tulang ikan" OR "tepung ikan lele") AND ("snakehead fish flour" OR "tepung ikan gabus") AND (prevent OR prevention OR "pencegahan stunting") AND stunting	6 September 2025	15
PubMed	(catfish OR patin OR "snakehead fish" OR "Channa striata" OR "Pangasius") AND (flour OR meal) AND stunting	7 September 2025	1

Database	Search string	Last search date	Records retrieved
ScienceDirect	("fish flour" OR "fish bone flour") AND ("catfish" OR "patin" OR "snakehead fish") AND stunting AND prevention	7 September 2025	7
Mendeley (reference manager)	"tepung ikan lele" OR "tepung ikan gabus" OR "tepung tulang ikan" OR "pencegahan stunting" (cross-checked against the databases above)	6 September 2025	20
Google Scholar	"tepung ikan lele" OR "tepung ikan gabus" OR "tepung tulang ikan" AND "pencegahan stunting"; catfish flour AND snakehead fish flour AND prevent OR prevention AND stunting	8 September 2025	69

Studies were eligible for inclusion if they (1) were original research articles (experimental or product-formulation studies); (2) evaluated food products fortified with patin (*Pangasius*) bone flour and/or snakehead fish (*Channa striata*) flour intended for children; (3) reported nutritional composition (protein, energy, or minerals) and/or organoleptic acceptability, compared with an unfortified control or across fortification levels; (4) were published between 2020 and 2025 in English or Indonesian; and (5) were available in full text. Studies were excluded if they were reviews, editorials, or conference abstracts without full text; used fish species other than patin or snakehead fish; addressed non-food or animal-feed applications; or did not report extractable nutritional or organoleptic data.

The database searches yielded 112 records (Table 1). After removal of 46 duplicate records, the titles and abstracts of 66 records were screened, and 17 full-text articles were assessed for eligibility. Eleven articles were excluded at the full-text stage because they lacked a control group ($n = 3$), did not use fortification ($n = 3$), or did not target food products intended for children ($n = 5$), leaving six studies for analysis. Screening and data extraction were performed independently by both authors (FNA and FDD), and disagreements were resolved through discussion until consensus was reached. The extracted data comprised study, fish species and flour type, food product, formulations, outcomes measured, and key findings (Table 2), together with the quantitative nutrient values reported for each formulation (Table 3).

RESULTS

Table 2. Summary of included studies

Study	Fish species / flour type	Food product	Formulations (control & test)	Outcome measured	Key finding
Siagian et al., 2020	Patin (<i>Pangasius hypophthalmus</i>) bone flour	Biscuits	Control: 0%; F1: 25%; F2: 50% bone flour	Protein, calcium content	Bone-flour addition increased calcium and protein content, indicating potential nutritional benefit. Increasing bone-flour proportion increased
Sidoretno et al., 2023	Patin (<i>Pangasius hypophthalmus</i>) bone flour	Biscuits	Control: 0%; F1: 25%; F2: 50% bone flour	Protein, carbohydrate, fat content	protein and carbohydrate content; fat did not increase linearly; all formulations remained within quality standards.

Study	Fish species / flour type	Food product	Formulations (control & test)	Outcome measured	Key finding
Yolahumaro h et al., 2025	<i>Patin (Pangasius hypophthalmus) bone flour</i>	Dimsum (hakau)	Control: 0%; F1: 50%; F2: 75% bone flour	Calcium, phosphorus, ash, protein content	Significantly increased calcium, phosphorus, ash, and protein content, highest in the F2 (75%) formulation.
Febry et al., 2024	<i>Snakehead fish (Channa striata) flour</i>	Cookies	Control: 0%; F1: 20% fish flour	Protein, fat, energy, ash content	High protein, fat, and energy content meeting standards, with increased mineral (ash) content.
Helmizar et al., 2021	<i>Snakehead fish (Channa striata) flour</i>	Cookies	Control: 0%; F1: 10%; F2: 20%; F3: 30% fish flour	Protein, fat content; organoleptic acceptance	F2 (20%) was most acceptable overall (protein 12.51%, fat 24.78%), meeting consumption standards.
Misnati et al., 2023	<i>Snakehead fish (Channa striata) flour</i>	Biscuits	Control: 0%; F1: 10%; F2: 20%; F3: 30% fish flour	Protein, fat, mineral, carbohydrate content	Significant increases in protein, fat, and minerals; carbohydrate remained the dominant energy source.

Table 3. Quantitative nutrient content by study and formulation (F0 = control)

Study	Formulation	Protein (%)	Calcium (%)	Carbohydrate (%)	Fat (%)
<i>Siagian et al., 2020</i>	F0	2.59	1.3	-	-
	F1	4.74	5.39	-	-
	F2	4.71	5.95	-	-
<i>Sidoretno et al., 2023</i>	F0	11.75	-	70.81	-
	F1	13.05	-	82.05	-
	F2	14.30	-	85.54	-
<i>Yolahumaroh et al., 2025</i>	F0	-	-	-	-
	F1	6.70	4.58	29.75	3.45
	F2	8.84	18.64	22.22	4.54
<i>Febry et al., 2024</i>	F0	7.33	-	-	-
	F1	15.44	-	-	-
<i>Helmizar et al., 2021</i>	F0	-	-	-	-
	F1	-	-	-	-
	F2	12.51	-	54.55	24.78
	F3	-	-	-	-
<i>Misnati et al., 2023</i>	F0	-	-	-	-
	F1	9.96	-	51.33	38.67
	F2	-	-	-	-
	F3	-	-	-	-

Note: F0 = unfortified control; "-" = not reported or not extractable from the primary study. Values are reproduced as reported in the primary studies (% by weight); the analytical basis (wet or dry weight) was not stated in most studies. Control (F0) values were not reported by Yolahumaroh et al. (2025), Helmizar et al. (2021), or Misnati et al. (2023). Phosphorus and energy values were reported narratively or in non-comparable units and are therefore not tabulated.

Table 2 summarizes six studies evaluating patin bone flour and snakehead fish flour fortification in biscuits, cookies, and dimsum at concentrations ranging from 10% to 75%. In the three studies that reported control (F0) values, fortification increased protein content relative to unfortified controls - from 2.59% to 4.71-4.74% in Siagian et al. (2020), from 11.75% to 13.05-14.30% in Sidoretno et al.

(2023), and from 7.33% to 15.44% in Febry et al. (2024) - and calcium increased from 1.3% to 5.39-5.95% in Siagian et al. (2020) (Table 3). Yolahumaroh et al. (2025), Helmizar et al. (2021), and Misnati et al. (2023) did not report extractable control values; for these studies, the increase relative to unfortified controls cannot be verified from Table 3 and rests on the comparisons reported by the original authors. Increases in phosphorus (Yolahumaroh et al., 2025) and energy (Febry et al., 2024; Helmizar et al., 2021) were reported narratively in individual studies and are therefore not tabulated. Patin bone flour contributed most notably to calcium and phosphorus content, consistent with its origin in fish bone rather than flesh, whereas snakehead fish flour derived primarily from fish flesh contributed more strongly to protein and fat content. This distinction between bone-derived and flesh-derived fish flour is an important source of variation in the nutrient profiles observed across the studies included. All nutrient values in Table 2 and Table 3 are reported as percentage by weight (%) as presented in the original studies; because the analytical basis (wet or dry weight) was not stated in most studies, cross-study comparisons of absolute values should be made with caution.

DISCUSSION

Organoleptic Characteristics

The addition of fish flour from both patin bone and snakehead fish flesh has been shown to significantly affect the organoleptic quality of various processed food products. A related study found that snakehead-fish meatballs, particularly when combined with pumpkin flour, provided high protein content and were well accepted by children, suggesting a favorable role in improving nutritional status (Mahmudiono et al., 2020). In biscuits made from patin bone flour, increasing the flour concentration produced a darker, slightly yellowish color; although the product's nutritional content increased, panelists' acceptance of color and texture tended to decline, especially at higher bone-flour concentrations, and a fishy aroma and taste became more apparent as the flour percentage increased (Siagian et al., 2020). A similar pattern occurred in cookies fortified with snakehead fish flour, where fish addition darkened the product and affected texture and aroma (Helmizar et al., 2021).

In dimsum products made from patin bone flour, the sensory impact was more pronounced in taste and texture. Fish-flour addition produced a tougher dimsum skin and a strong fishy aftertaste; panelists reported that increasing the flour proportion made the product less preferable than the unfortified formulation, and a paler, less transparent color also affected visual perception (Yolahumaroh et al., 2025). This suggests that wet, high-moisture products are more sensitive to the addition of fish-derived components than dry products such as cookies and biscuits. Overall, these studies indicate that the main sensory challenge in fish-flour fortification lies in changes to color, flavor, and texture. Optimizing organoleptic properties is therefore key to ensuring consumer acceptance of fish-flour-based products without compromising their nutritional value.

Optimal Product Formulation

For biscuits, patin bone flour at 25% of total flour increased protein and calcium relative to the control while still meeting biscuit quality standards; because the increase in fat content was non-linear, increasing the formulation to 50% offered little further benefit and this lower level provided increased nutrition without the risk of the quality changes that often occur with high-level fortification (Sidoretno et al., 2023). For cookies fortified with snakehead fish flour, approximately 10-20% fish flour met the protein, fat, and water-content standards set by the Ministry of Health, although ash content slightly exceeded the limit, reflecting the added mineral content from the fish flour. This range also tended to have the highest acceptance scores for color, taste, aroma, and crispness (Helmizar et al., 2021). For hakau dimsum using patin bone flour, no single formulation was clearly optimal: the 50% formulation had lower nutritional value than the 75% formulation, but the 75% formulation produced a tougher, fishier skin that panelists found less acceptable, despite its higher nutrient content. A further, better-balanced formulation appears to be needed to secure adequate nutritional content without the sensory drawbacks reported at higher fortification levels (Yolahumaroh et al., 2025).

Quantitative Nutrient Gains and Benchmarking Against Toddler Nutrient Requirements

Fortification with patin bone flour and snakehead fish flour has been reported to increase the nutrient content of food products such as biscuits, cookies, and dimsum. Supporting evidence from outside the included studies shows a similar pattern: incorporating Nile tilapia (*Oreochromis niloticus*) into biscuits increased their protein, mineral, and energy content (Settapramote et al., 2024). In cookies, a single 20% snakehead fish flour formulation increased protein content from 7.33% to 15.44%, meeting the protein standard of the Minister of Health Regulation (Febry et al., 2024). Formulations containing snakehead fish flour provided reported energy values of up to 400 kcal per 100 g, with protein content reaching 12-24% (Helmizar et al., 2021). However, these figures describe nutrient density per 100 g of product, not the amount a child consumes. Using the Indonesian Recommended Dietary Allowance (Angka Kecukupan Gizi/AKG, Peraturan Menteri Kesehatan No. 28/2019) of 20 g protein/day and 1,350 kcal/day for children aged 1-3 years, and 25 g protein/day and 1,400 kcal/day for children aged 4-6 years, a realistic single serving of fortified biscuits or cookies (approximately 20-30 g, i.e., two to three pieces) containing 10-15% protein by weight would supply roughly 2-4.5 g protein, or approximately 10-22% of a toddler's daily protein requirement a meaningful but partial contribution that would need to be combined with other protein sources. Reported energy contributions of up to 400 kcal/100 g are more substantial relative to the 1,350-1,400 kcal/day energy AKG for this age group but again depend on the portion consumed. Because none of the included studies reported the serving size given to or consumed by toddlers, these calculations are illustrative estimates rather than figures derived directly from the primary studies and should be confirmed with product-specific consumption data before nutritional claims are finalized.

Bioavailability, Digestibility, and Safety Considerations

The nutrient-content values discussed above are laboratory-analyzed values, which do not necessarily equate to the nutrients' bioavailability or digestibility once consumed. None of the six included studies assessed protein digestibility (e.g., in-vitro protein digestibility-corrected amino acid score) or mineral bioavailability (e.g., calcium or phosphorus absorption, which can be reduced by phytate or fiber content in composite flours). Likewise, food-safety parameters relevant to fish-based ingredients - heavy-metal contamination (e.g., mercury, cadmium, lead), microbial quality, and the shelf-life stability of fish-flour-fortified products - were not reported in any of the included studies. These are essential considerations before fish-flour fortification that can be recommended for routine use in complementary feeding for young children and represent priority areas for future research.

Potential Relevance of Fish-Flour Fortification to National Stunting-Prevention Strategy

The use of patin bone flour and snakehead fish flour as food fortificants has potentially strategic relevance to national nutrition policy and stunting-reduction efforts. Their protein, calcium, and energy content suggests possible value for integration into supplementary feeding programs for toddlers through Posyandu, schools, or local food-based initiatives, in line with Peraturan Presiden Nomor 72 Tahun 2021, Peraturan Menteri Kesehatan Nomor 51 Tahun 2016, and the Beragam, Bergizi, Seimbang, dan Aman (BS2A) guideline (Kementerian Kesehatan Republik Indonesia, 2016; Presiden Republik Indonesia, 2021). Related work has shown that fish-based complementary feeding can improve nutrient intake and hemoglobin levels in toddlers (Bustami et al., 2023), which lends indirect support to this rationale. However, because the studies reviewed here report only nutritional-composition and organoleptic outcomes - not height-for-age or other stunting-related indicators - this relevance remains a plausible hypothesis rather than a demonstrated effect and claims about this approach's contribution to stunting prevention should be limited to its nutritional potential pending direct evidence.

Feasibility for Population-Scale Implementation

Beyond nutrient content, integrating fish-flour-fortified products into Posyandu supplementary feeding, school programs, or micro-enterprises require evidence on cost per serving, production scalability, shelf-life logistics, and community acceptability outside a controlled sensory-panel setting. None of the included studies reported these parameters. This is an important evidence gap: even a

nutritionally promising formulation cannot be implemented at population scale without data on affordability for target households, the production capacity of small and micro food enterprises, and whether acceptability observed among trained or convenience panels translates into everyday consumption by toddlers and caregivers. Future studies should report these implementation-relevant outcomes alongside nutrient composition.

Comparison with Established Supplementary-Feeding Interventions

None of the included studies positioned patin bone flour or snakehead fish flour fortification against existing supplementary-feeding options such as egg-, milk-, or legume-based Pemberian Makanan Tambahan (PMT), or standard Ready-to-Use Therapeutic Food (RUTF). Without this comparison, the relative nutritional, economic, or logistic advantage of fish-flour fortification cannot be established; egg- and milk-based PMT, for example, already have established production and distribution pathways within national supplementary-feeding programs, so fish-flour products would need to demonstrate a comparable or superior cost-nutrient profile to justify adoption alongside or in place of these options. Future research directly comparing fish-flour-fortified products with established interventions on nutrient density, cost, and acceptability would help clarify their added value within the broader landscape of stunting-prevention interventions.

Advantages and Limitations

Within the six included studies, fortification with patin bone flour and snakehead fish flour showed nutritional potential: protein and calcium content was higher than in unfortified controls where these were measured and increases in phosphorus and energy were reported in individual studies. Supporting literature outside the included evidence base, on catfish-flour-enriched arrowroot biscuits and cod-protein-enriched bread, points in the same direction (Afiah & Kusumaningrum, 2025; Desai et al., 2021); these two studies are cited only as contextual evidence and were not part of the reviewed evidence base. Most fortified formulations met the national quality parameters for protein, fat, and moisture, although ash content exceeded the limit in snakehead fish flour cookies, reflecting their higher mineral content (Helmizar et al., 2021). Formulations containing approximately 10-25% fish flour were generally organoleptically acceptable in terms of color, taste, aroma, and texture. These features are relevant to government programs addressing malnutrition, but they indicate nutritional potential rather than proven effectiveness for stunting prevention.

The overall strength of evidence supporting these conclusions is limited. The evidence base comprises only six small-scale Indonesian formulation studies, several published in lower-indexed local journals, and organoleptic differences between formulations are generally reported descriptively rather than with formal statistical testing. No formal risk-of-bias or certainty-of-evidence appraisal (e.g., JBI, GRADE) was performed as part of this narrative review, and the primary studies themselves did not report such appraisals; sample sizes and sensory-panel sizes were also often not reported (Table 2). These factors substantially limit the generalizability and strength of the conclusions drawn here and should be borne in mind when interpreting the nutritional-potential claims made throughout this review.

Additional limitations relate to sensory, formulation, and safety aspects. Fish-flour addition can change taste, texture, aroma, and color in ways that are not always desirable to consumers, especially at high concentrations, owing to a fishy odor, dark color, or tough texture. Long-term evaluation of product safety and stability, and of the impact of regular consumption, is also lacking across the reviewed studies. Therefore, despite its nutritional potential, formulation optimization, reduction of undesirable sensory attributes, and further feasibility and safety testing are essential before wide-scale implementation is considered.

CONCLUSION

Based on the six studies reviewed, fortifying food products with patin bone flour and snakehead fish flour increased protein and calcium content compared with unfortified controls where control values were reported, with increases in phosphorus and energy reported in individual studies, indicating

potential nutritional value for products intended for children. However, the current evidence base is small, heterogeneous, and limited to nutritional-composition and organoleptic outcomes: none of the included studies measured anthropometric or stunting-related outcomes, formal quality or risk-of-bias appraisal was not performed, and safety, bioavailability, cost, and feasibility data are lacking. Fish-flour fortification with patin and snakehead fish should therefore be regarded as potentially supportive as part of integrated stunting-prevention strategies, rather than as a proven effective intervention for stunting prevention. Further studies incorporating growth outcomes, digestibility and safety testing, larger and more rigorous formulation trials, and implementation-feasibility data are needed before wider application can be recommended.

CONFLICT OF INTEREST

The authors declare no conflict of interest

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