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Nutritional composition and organoleptic characteristics of Milkfish (*Chanos chanos*) (Forsskal) bone powder enriched pandesal as a calcium source: A review

Sanchez, Merry Beatrice ✉
Iloilo State University of Fisheries, Science, and Technology, Philippines (mbvsanchez2@gmail.com)

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Abstract

Calcium deficiency remains a critical public health challenge in the Philippines, affecting over 95% of the adult and elderly population. Concurrently, the booming milkfish (*Chanos chanos*) processing industry generates massive volumes of postharvest solid waste, with bones alone accounting for 9–15% of total fish volume. This review examines the dual utility of repurposing milkfish bone waste into a nutrient-dense powder for the fortification of *pandesal*, a ubiquitous Filipino breakfast bread. Synthesized data indicates that milkfish bone powder contains high concentrations of essential minerals, specifically calcium and phosphorus, which can significantly improve the micronutrient profile of baked goods. However, the integration of fishbone biowaste presents distinct sensory challenges, particularly regarding texture (grittiness) and aroma (fishiness). This paper reviews the balance between maximizing nutritional fortification and maintaining acceptable organoleptic characteristics to establish a viable, circular-economy solution to local micronutrient malnutrition.

Keywords: calcium, milkfish, pandesal, fortification, food

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1. Introduction

The milkfish (*Chanos chanos*), historically classified as a monotypic, pelagic gonorhynchiform, is broadly distributed throughout the tropical Indo-Pacific region, thriving near continental shelves, islands, and shallow coral reef zones with clear waters exceeding 20°C (Bagarinao, 1994; FAO, 1990; Ravago-Gotanco & Juinio-Meñez, 2004). Within the Philippines, *C. chanos* stands as an deeply rooted environmental and commercial fixture. It inhabits coastal and inland waterways, estuaries, and rivers, functioning as the single most critical national aquaculture commodity by comprising over 70% of total domestic aquaculture volume (Bureau of Fisheries and Aquatic Resources [BFAR], 2021). The National Milkfish Industry Roadmap 2021–2040 formally acknowledges its cultural and dietary supremacy as the national fish of the Philippines, noting its cultivation spans nearly every geographic territory save for the landlocked Cordillera Administrative Region.

Historically, over a quarter of a million tons of milkfish have been harvested annually from brackish water assets across Southeast Asia, representing more than 60% of regional aquaculture yields (FAO, 1990). By 2021, the Philippine Fisheries Profile documented a surging national output of 414,476.99 metric tons (MT), with Region I leading production at 31.18%, followed closely by Region VI (22.06%) and Region III (20.26%). However, the expansion of the marine capture and aquaculture sectors—which has maintained an average 22% growth rate in output over recent decades—has systematically exacerbated post-harvest management crises (Philippine Fisheries Profile, 2021; Samson, 1984).

As global per capita fish consumption climbed from 9.0 kg in 1961 to 20.5 kg in 2018, industrial processing lines encountered immense economic and environmental challenges stemming from solid waste generation (FAO, 2020). Modern processing plants rely primarily on milkfish meat and skin, leaving enormous volumes of non-edible fractions underutilized (Wulandari & Kusumasari, 2019). Anatomical breakdowns reveal that while the internal stomach contents encompass 9.9% of the yield, the solid fins comprise 1.6%, and structural bones with attached residual flesh comprise a substantial 11.3% of total body weight (Panggat, 2003). Discarding these dense matrices creates severe environmental bottlenecks, polluting coastal ecosystems and degrading sanitary conditions near processing hubs (Chen et al., 2018; Sayana & Sirajudheen, 2017).

Concurrently, public health data highlights a profound, systemic nutritional crisis within the Philippine population. Inadequate dietary intake of essential micronutrients is exceptionally widespread across the archipelago: iron deficiencies range from 97% to 99%, calcium deficiencies persist between 95% and 98%, and vitamin C deficiencies hover between 96% and 98% (Angeles-Agdeppa et al., 2019). Alarmingly, these nutritional deficits are not restricted to lower socioeconomic strata; more than 50% of individuals within the highest wealth quintiles fail to meet baseline requirements for calcium and foundational vitamins (Angeles-Agdeppa et al., 2019). The physiological repercussions of chronic calcium starvation are starkly apparent in the widespread incidence of osteoporosis, which disproportionately degrades bone mineral density in women during early menopausal stages due to declining estrogen synthesis (Afalla et al., 2008).

To bridge this dietary gap, food scientists are targeting innovative zero-waste pathways by transforming discarded bone fractions into mineral-dense flours (Mizuri et al., 2019). Utilizing milkfish bone powder as a functional fortificant within *pandesal*—the country's primary breakfast bread staple—constitutes an optimal vehicle for public health intervention. This paper reviews the underlying nutritional architecture of milkfish bone powder and evaluates its sensory (organoleptic) performance when integrated into carbohydrate-heavy baked goods.

Objectives

- To evaluate the ecological and nutritional viability of converting milkfish (*Chanos chanos*) processing byproducts, specifically solid bone waste, into a functional food-grade powder.
- To analyze the macro- and micro-nutrient profiles of milkfish bone powder, focusing on its effectiveness as a highly bioavailable, natural source of calcium and phosphorus to counteract national micronutrient deficiencies.
- To synthesize existing scientific evidence regarding the threshold limits of fishbone fortification in various food matrices, specifically assessing its rheological and organoleptic impacts on the color, texture, aroma, and consumer acceptability of baked goods like *pandesal*.

2. Nutritional Composition of Milkfish Bone Powder

Raw and processed fish bone matrices host exceptional concentrations of elemental ash and macrominerals. Untreated milkfish bone meal inherently exhibits a proximate distribution consisting of 35.22% crude protein, 23.06% crude fat, 30.47% inorganic ash, and 9.68% elemental calcium (Salitus et al., 2017, as cited in Eris et al., 2020). Even at small serving sizes, modest 2.9-gram distributions of refined bone meal deliver roughly 5.24% pure calcium and 2.36% phosphorus directly into food systems (Bakhtiar et al., 2019, as cited in Eris et al., 2020). Comparative biochemical reviews confirm that snack products integrated with milkfish bone powders possess significantly elevated quantities of essential ash, crude fiber, and carbohydrates relative to standard formulations made exclusively from shredded fish flesh (Karim et al., 2021). The isolation and refinement of these nutrients depend fundamentally on processing variables, as detailed below:

Extraction Dynamics and Thermal Pre-treatments - The mechanical and chemical transformation of bone waste into food-grade powder demands meticulous structural modification. Wulandari and Kusumasari (2019) demonstrated that utilizing either acidic or alkaline extraction pathways results in statistically significant variations in overall yield, protein retention, and ash concentrations. Both methodologies outperform basic water-extraction processes by completely breaking down organic matrix barriers to maximize mineral release. Advanced processing regimes often employ a **Bone-Embrittlementing Technique (BET)**, which pairs organic acids with extreme thermal pressure to alter physical properties. Wang (2020) observed that exposing bones to elevated temperatures and high pressures forces the dissolution and removal of volatile fats and unstable organic matter. Consequently, the moisture content is driven down, triggering a steep, relative surge in the remaining inorganic ash portion. Scanning Electron Microscopy (SEM) reinforces these findings, revealing that while the high-temperature, high-pressure environment exerts a dominant shear force that consolidates inorganic minerals, the concurrent introduction of an acetic acid solution strips away lipids and volatile compounds, effectively neutralizing the raw raw material's inherent fishy odor (Wang, 2020).

3. Physical & Rheological Impacts on Flour and Dough

Replacing standard wheat flour with non-glutenous marine bone powder drastically alters the physical behavior of baking composites. Data from analogue studies involving fish-flour substitutions in dough systems reveal that as the concentration of fish bone powder increases, the overall **bulk density** of the composite flour rises systematically, moving from 0.87 g/cm³ up to 0.92 g/cm³ (Akusu et al., 2023). Conversely, critical functional parameters like **swelling power** and **oil absorption capacity** decline sharply, dropping from baseline values of 10.60 to 8.67, and 2.74 to 1.47, respectively. These shifting properties directly impact the final structure of the baked goods. The substitution of wheat proteins with fishbone alternatives compromises the gluten matrix, leading to distinct physical alterations:

- **Gas Retention & Expansion:** The reduction of the cohesive gluten network curtails the dough's ability to trap gas during fermentation. This results in a notable reduction in loaf volume and specific volume

(Akusu et al., 2023).

- **Extensograph Parameters:** Incorporating fish protein powders limits the natural extensibility of dough strands while increasing resistance to extension, forcing structural cell changes that generate larger, more uneven air pockets within the final bread crumb (Shekarabi & Shahbazi, 2022).

4. Organoleptic Profiles and Consumer Acceptance

Carbohydrate-dense staple snacks derived from wheat or rice are often criticized for their unbalanced nutritional profiles, particularly their high glycemic indices and lack of essential amino acids and omega-3 fatty acids (Desai, 2019). While enriching these foods with marine ingredients restores nutritional balance, it introduces distinct sensory challenges across key organoleptic metrics:

***Color and Visual Distortion* -** The aesthetic profile of baked goods undergoes distinct color shifts upon fortification. In cookie formulations, a 10% substitution of milkfish powder yields a characteristically dull brown hue (Muzaki et al., 2021). This alignment toward darker, less reflective profiles is corroborated by bread evaluations showing a continuous drop in the Whiteness Index as marine protein percentages rise (Shekarabi & Shahbazi, 2022). Furthermore, the specific processing methods applied to the bones dictate the visual outcome; SEM data shows that as acetic acid concentrations scale up during the pre-treatment phase, the resultant bone powder shifts from yellow to a distinctly brownish-yellow shade (Wang, 2020).

***Texture, Crispness, and Hardness* -** The integration of bone particles yields highly contrasting structural outcomes depending on the moisture profile and internal starch arrangement of the food matrix:

- **Yeast Breads & Soft Cookies:** High fortification levels introduce a firm, dense, and noticeably dry crumb mouthfeel (Muzaki et al., 2021).
- **Dehydrated Starch Matrices (e.g., *Rengginang* rice crackers):** The addition of milkfish bone powder actually reduces hardness values. The inclusion of bone powder lowers the overall amylose content within the glutinous rice matrix, resulting in a softer, crispier, and more fragile cracker structure with linear expansion rates settling between 33.08% and 47.69% (Eris et al., 2020).

***Aroma and Flavor Thresholds* -** Managing marine volatile compounds is essential to securing long-term consumer satisfaction. In unrefined formulations, high inclusion levels trigger strong fishy notes that cause swift consumer rejection. However, when appropriate processing techniques or masking agents are employed, these profiles change significantly. For instance, cookie formulations fortified with milkfish bone powder successfully maintained high consumer acceptability scores through extended storage trials, with trained panels recording highly favorable odor ratings even 65 days post-packaging (Afalla et al., 2008). Similarly, controlled cookie trials at a 10% substitution level reported a pleasant, sweet profile characterized by a light vanilla aroma rather than distinct fish notes (Muzaki et al., 2021).

5. Synthesis of Fortification Limits across Food Matrices

A cross-examination of existing literature reveals distinct differences regarding how much fish bone powder can be successfully incorporated into various popular food items before quality degrades.

Food Matrix Product	Optimal Substitution Limit (%)	Primary Organoleptic and Nutritional Effects	Source
Donuts	2.0%	Retains excellent traditional appearance, aroma, taste, and texture metrics; higher doses cause sensory decline.	Nuraeni et al. (2020)
Wheat-based Bread	3.0%	Delays staling profiles by up to 48 hours; maintains standard crumb cell configurations without sensory drawbacks.	Shekarabi & Shahbazi (2022)

continued …

Egg Rolls	3.0%	Maximizes overall consumer acceptability; bone powder processed via acetic acid BET yields excellent brightness.	Wang (2020)
Traditional Rice Crackers	Up to 10.0%	Decreases product hardness while increasing crispness; balances structural amylose reduction.	Eris et al. (2020)
Composite Grain Breads	Up to 20.0%	Drastically elevates ash, fat, and protein levels; increases calcium and phosphorus values to 63.21 and 4.49 mg/100g, but significantly sacrifices loaf volume.	Akusu et al. (2023)

6. Conclusion and Future Directions for Fortified Pandesal

The repurposing of milkfish (*Chanos chanos*) processing waste into a functional, food-grade bone powder represents a powerful, dual-purpose strategy for the Philippine context. It offers an efficient solution for post-harvest aquaculture waste management while providing an affordable, bioavailable weapon against the country's chronic calcium deficiencies. When applying these findings specifically to *pandesal*, the literature indicates that an entry-level fortification threshold of **3.0% to 5.0%** is ideal for commercial, large-scale baking. This range significantly boosts calcium and phosphorus delivery without compromising the gluten network, altering the expected loaf volume, or introducing fishy aromas. To successfully scale this formulation, future research should prioritize:

- Standardizing nano-milling and pulverization metrics to completely eliminate internal crumb grittiness.
- Optimizing organic acid and thermal pressure pre-treatments to guarantee complete lipid extraction and odor neutralization.
- Conducting rigorous clinical trials to measure the long-term bioavailability of fish-derived hydroxyapatite within local vulnerable demographics, including schoolchildren and the elderly.

For Curriculum and Classroom Integration - The findings of this review carry meaningful implications beyond food science, extending into health and nutrition education at multiple school levels. Science and home economics teachers can use milkfish bone powder fortification as a real-world, locally relevant case study to illustrate core concepts in biochemistry, food technology, and public health nutrition. The measurable nutritional outcomes; particularly calcium and phosphorus enrichment which offer concrete, quantifiable examples ideal for laboratory exercises and data interpretation activities in senior high school and undergraduate courses.

For Students - Students living in regions with high milkfish production, such as Regions I, III, and VI, are positioned to engage with this topic not merely as academic content but as lived community experience. Exposure to zero-waste food science principles encourages systems thinking, connecting ecological sustainability, human health, and local industry in ways that standard textbook lessons rarely achieve. Nutrition-focused learning around pandesal; a food students consume daily, makes abstract micronutrient concepts immediately tangible and personally relevant, which research consistently links to deeper conceptual retention.

For Schools as Institutional Stakeholders - School canteens and feeding programs represent a direct, scalable channel for deploying calcium-enriched pandesal. Given that the Philippine government's supplementary feeding program targets undernourished pupils in public elementary schools, partnering with local bakeries or food technology programs to produce bone powder-fortified pandesal could operationalize the nutritional benefits documented in this review. Schools with Technical-Vocational-Livelihood (TVL) tracks in bread and pastry production are particularly well-positioned to pilot such formulations, simultaneously building student competencies while addressing documented micronutrient gaps in the student population.

For Teacher Professional Development - Teachers equipped with food science literacy can bridge nutrition education and community development in ways that align with the K–12 curriculum's emphasis on contextualized, locally embedded learning. Professional development programs that incorporate aquaculture by-product utilization as a teaching theme can help educators in coastal and island communities design project-based learning units that connect fishery industry realities with health advocacy. This interdisciplinary framing supports the DepEd's broader goals of developing functionally literate, socially responsive graduates.

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