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NUTRITIONAL COMPOSITION OF WILD AND FARMED TILAPIA IN ASUOGYAMAN DISTRICT, GHANA: MODELLED CONTRIBUTIONS TO IRON, ZINC, AND CALCIUM RECOMMENDED NUTRITIONAL INTAKES (RNIs)

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Abstract

This study investigates the nutritional composition of Nile tilapia (Oreochromis niloticus) from aquaculture systems (tanks, cages, and ponds) and wild sources in the Asuogyaman District of Ghana. The focus was on their contributions to the Recommended Nutritional Intakes (RNIs) for vulnerable groups, including children, pregnant and lactating women (PLW), and the elderly. A total of 40 Nile tilapia samples were analysed, comprising 10 from each culture system (tank, cage, and pond) with a common water source, and 10 from wild sources. The proximate composition—comprising moisture, protein, fat, carbohydrates, and ash—was consistent across systems, with protein content ranging from 15.9 to 17.3 g/100 g and lipid content ranging from 0.52 to 1.54 g/100 g. Energy values were highest in cage-cultured tilapia (87.93 kcal/100 g) and lowest in tank-cultured fish (79.88 kcal/100 g). Mineral analysis showed that farmed tilapia, especially those from pond systems, had more calcium, magnesium, iron, and zinc than wild tilapia. The iron contribution to RNIs was particularly significant from pond-cultured tilapia, reaching up to 30.1% of the RNI for adults and PLW. Wild tilapia, although nutritionally beneficial, provided lesser contributions to the RNIs, particularly for calcium and zinc. Furthermore, the sodium-to-potassium (Na/K) ratio varied across systems, with tank-cultured tilapia showing the most favourable balance for cardiovascular health (Na/K = 0.35). These findings emphasise the nutritional advantages of farmed tilapia, especially in improving mineral intake in vulnerable populations. The study provides important insights for aquaculture policy and consumer guidance, focusing on tilapia's potential to address micronutrient deficiencies in Ghana.

Keywords
Proximate, Nile Tilapia, Ghana, Vulnerable groups, Recommended Nutritional Intakes, Culture systems

Introduction

Fish provides about 20 per cent of the animal protein consumed by more than 3 billion people globally (Food and Agriculture Organization of the United Nations, 2020). In addition to being a dietary protein source, fish provides essential fatty acids and minerals that are difficult to obtain from plant-based foods (Bogard et al., 2015; Drewnowski et al., 2024). The role of fish in nutrition and food security is particularly important in sub-Saharan Africa, where dietary variety is often limited. Ghana serves as an example of such reliance: fish accounts for almost 60 per cent of animal protein consumption, as it is the most readily available and cost-effective source of high-quality food (Asiedu et al., 2023). The Nile tilapia (*Oreochromis niloticus*) is the dominant species in regional aquaculture and is prized for its flavour, availability, and versatility. The rising demand for tilapia and the mounting strain on wild fisheries have boosted the growth of aquaculture. Through this growth, food security is boosted, but significant concerns are also raised about the relative nutritional content of farmed and wild fish. This topic has not been sufficiently examined in Ghana.

It has been demonstrated that the proximate composition of fish, which includes fibre, protein, ash, fat, carbohydrates, and mineral content, depends on sex, season, species, size, and production environment (Jim et al., 2017; Matos et al., 2019; Usydus et al., 2011). Wild tilapia also show nutritional variations compared to those reared in controlled culture systems, which can be attributed to differences in diet, water quality, and activity. According to Islam et al. (2021), tilapia cultured in cages and ponds in Bangladesh had very high energy and fat levels compared to their wild counterparts. Calcium, zinc, and iron are important micronutrients for preventing anaemia, enhancing immune function, and promoting bone growth (Ullah et al., 2022). However, deficiencies in these micronutrients (particularly iron and zinc) remain a major public health concern in Ghana. Greffeuille et al. (2023) found that iron deficiency, which is a major cause of anaemia, is experienced by around 42 per cent of pregnant women and 66 percent of children under the age of five in Ghana, and zinc deficiency is a major health problem that affects 21 percent of children in rural areas in Ghana. Ayensu et al. (2020) also reported that calcium deficiency was more prevalent among pregnant women in Ghana.

Although tilapia is a major part of the Ghanaian diet, there is a lack of empirical studies on the contribution of fish produced in various aquaculture systems to the recommended nutritional intake (RNI) levels among susceptible populations. While consumers often claim that wild fish have better nutritional value, such claims are largely anecdotal in the Ghanaian context (Lingam et al., 2019).

Globally, many studies have compared the nutritional composition of wild and farmed fish; however, there is limited evidence on the proximate and mineral composition of tilapia in tanks, ponds, cages, and natural systems within Ghana. This limitation on data constrains understanding of how the diverse production systems influence the nutritional requirements of fish consumed by individual population groups, such as children, adults, and pregnant or lactating women (PLWs). This is a significant knowledge gap, since it is essential for informing consumer choices and designing aquaculture regulations to help address micronutrient shortages. Furthermore, the limited knowledge of mineral balances within cultural systems, especially the sodium-to-potassium ratio, and the possible impact of these changes on cardiovascular health in populations in which tilapia is a dietary supplement, needs to be addressed. Addressing these research gaps is therefore important for positioning aquaculture production with public health nutrition objectives and sustainable food system development in Ghana.

This work advances prior comparisons from Bangladesh (Bogard et al., 2015; Islam et al., 2021), Zimbabwe (Jim et al., 2017), and Poland (Usydus et al., 2011) by providing a Ghana-specific analysis. It explicitly models the potential RNI contributions of *O. niloticus* from diverse production systems: tanks, ponds, cages, and the wild to the RNI of key groups (children, adults, pregnant/lactating women). Using measured concentrations of Fe, Zn, and Ca on a wet-weight basis alongside Na/K profiling, this study provides a clear output of how each production system supports nutritional needs. By quantifying system-specific contributions to RNIs in Ghana, this study addresses a critical knowledge gap essential for informing nutrition-sensitive aquaculture policy and consumer guidance.

Materials and Methods

Sampling and sample preparation

Forty (40) Nile tilapia (*Oreochromis niloticus*) samples were collected from four sources (wild, cage, pond, and tank) in Asuogyaman, all sharing a common water source, with the assistance of local fish farmers. Ten (10) fish were sampled from each system (pond, tank, cage, and wild). In the wild (Lake Volta), tilapia were captured using artisanal fishing gear, primarily gill nets, operated in the early morning to coincide with peak fish activity. For cage systems, fish were collected directly from cages using hand nets, typically during routine farm operations in the morning. Pond and tank samples were obtained using a seine net after partial water drainage to facilitate capture. All sampled fish were handled carefully to minimise stress and physical damage. Following capture, samples were temporarily held in aerated containers with source water prior to measurement. Individual fish were then blotted dry to remove excess water and weighed using a calibrated digital balance. The weights of the samples from the tank, pond, cage, and wild systems ranged from 150–300 g, 200–300 g, 250–300 g, and 150–200 g, respectively. For each culture system and for samples collected from the wild in Lake Volta, a single pooled *O. niloticus* sample was obtained between April and June 2024. The samples were placed in zip-lock bags, stored in an insulated icebox, and transported to the Ecological Laboratory at the University of Ghana for further analyses.

Upon arrival, samples were categorised into four provenance groups (wild, tank, pond, and cage) and stored at –20 °C until analysis. Fish specimens were subsequently dissected, eviscerated, and filleted using a sterilised stainless-steel knife under hygienic conditions. The resulting fillets were homogenised using a laboratory blender to obtain a uniform sample matrix suitable for analysis. Following homogenization, the samples were re-packaged in labelled, sterilised polythene bags and stored at –20 °C pending further analyses. All analytical determinations were performed in triplicate to ensure accuracy, precision, and reproducibility.

Proximate analysis

Moisture was determined by forced-draft oven drying (AOAC 950.46); ash by muffle furnace incineration (AOAC 920.153); crude fat by solvent extraction (AOAC 991.36); and crude protein by Kjeldahl nitrogen (AOAC 981.10; N $\times$ 6.25). Energy (kcal/100 g, wet basis) was calculated using Atwater general factors: 4 $\times$ protein (g) + 9 $\times$ fat (g) + 4 $\times$ carbohydrate (g), where carbohydrate was computed by difference (AOAC International, 2019).

For crude fibre, given that fish skeletal muscle typically contains negligible dietary fibre and non-starch polysaccharides, any reported crude fibre values are considered to represent methodological residues rather than physiologically relevant fibre; accordingly, such values were excluded from energy calculations and interpreted with caution (Thilsted et al., 2016).

Mineral analysis

Calcium (Ca), iron (Fe), and zinc (Zn) were quantified by flame atomic absorption spectrophotometry (FAAS) using element-specific hollow cathode lamps at canonical analytical lines (Ca 422.7 nm; Fe 248.3 nm; Zn 213.9 nm), with background correction. Sodium (Na) and potassium (K) were measured either by FAAS (Na 589.0/589.6 nm; K 766.5 nm) or flame photometry with an internal standard (laboratory-standard procedure); instrument make/model and lamp currents are reported in the instrument log.

Calibration used multi-point external standards spanning expected sample concentrations; acceptance criteria were $R^2 \geq 0.995$ and residuals without systematic drift. Limits of detection (LOD) and quantification (LOQ) were estimated from the calibration residual SD (σ) and slope (S) as LOD = $3.3\sigma/S$ and LOQ = $10\sigma/S$. Quality control (per batch) included a

method blank, an independent check standard, and a certified reference material (CRM)—such as NIST SRM 1566b (Oyster Tissue) and NRC DORM-4 (fish protein)—processed alongside samples, with recoveries required within 80–120% of certified values; matrix spikes likewise targeted 80–120% recovery with ≤20% RPD across duplicates.
For dietary interpretation, Na:K was expressed as a mass ratio and contextualised against the WHO target (Na/K < 1).

RNI modelling

The contribution of tilapia derived from each system to the recommended nutrient intakes (RNIs) was evaluated for children aged 1–3 years and adults aged 8 years and above, in accordance with WHO/FAO guidelines (FAO/WHO, 2004). Adequate daily intake of fish provides sufficient amounts of protein, lipids, calcium, and micronutrients to meet human nutritional needs; the reference intake levels used were those recommended during the last quarter of pregnancy and the first 12 months of lactation for pregnant women. The possible role of fish in the recommended mineral intakes for specific population groups deemed at risk of mineral deficiency was determined using Equations 1 and 2, with the World Health Organisation (WHO) Recommended Nutrient Intake (RNI) as the reference (Table 1). This analysis utilised the possible contribution of fish to the intake of minerals in three vulnerable groups of pregnant and lactating women, children aged 1–3 years, and the elderly aged ≥8 years in accordance with WHO/FAO recommendations (FAO/WHO, 2004). In its report on Food Security and Nutrition (FAO High-Level Panel of Experts (HPLE), [HPLE Report 7, 2014]), it was determined that 150 grams of fish per day is sufficient to maintain the human nutritional needs. However, a standard portion of 50 g/day for adults, 50 g/day for PLW, and 25 g/day for infants, as employed by Bogard et al. (2015), was used in this study. Nutritionally beneficial tilapia were considered to be those that can provide ≥ 25% of the recommended daily intake (RNI) for pregnant and lactating women, adults, and infants, across three or more essential nutrients (Bogard et al., 2015; Kingsley et al., 2022) when consumed in portions of 50 g, 50 g, and 25 g, respectively.

$$N_{sp} = \frac{N_A \times S_p}{100} \tag{1}$$

$$\%RNI = \frac{N_{sp}}{RNI_i} \tag{2}$$

where N_A represents the nutritional value of the fish (g per gram of fish), S_p represents the measured standard intake of fish (g fish per day), N_{sp} is the amount of nutrient that is contained in a single standard portion (mg nutrient), RNI_i represents the Recommended Nutrient Intake of the given nutrient as envisaged in Table 1, and $\%RNI_i$ is the ratio of the daily RNI that is attributable to the assumed standard portion. This procedure for calculating fish's contribution to nutrient intake is based on previous research (Byrd et al., 2021; Kiczorowska et al., 2019; Kingsley et al., 2022; Magna et al., 2025).

Table 1. Daily RNI (mg) as Recommended by the Food and Nutrition Board

Average Daily RN	Segment of the Population		
	Children	**PLW**	**Adults**
Iron	10	18	16
Calcium	700	1200	1000
Zinc	2.4	6.0	3.6

Source: Kingsley et al. (2022); Magna et al. (2025)

Statistical analysis

All examined findings were reported as the mean ± standard deviation (SD). Statistical analyses were performed using SPSS version 21. Continuous variables were inspected for normality. Descriptive statistics (means ± standard deviation) and a test of statistical significance at p ≤ 0.05 were obtained using the software.

Results and Discussion

Comparison of Proximate Composition

Across production systems as shown in Table 2, filleted *Oreochromis niloticus* exhibited narrowly varying moisture (74.96–75.84 g/100 g), consistently high protein (15.90–17.34 g/100 g), low lipid (0.52–1.54 g/100 g), and stable ash (1.05–1.19 g/100 g), yielding energy densities of 79.88–87.93 kcal/100 g. Moisture was highest in wild fish (75.84 g/100 g). Protein peaked in tank-reared fish (17.34 g/100 g), suggesting efficient protein deposition under controlled conditions. Lipid—and consequently energy—were highest in cage-reared fish (1.54 g/100 g; 87.93 kcal/100 g), whereas tank systems produced the leanest fillets (0.52 g/100 g lipid; 79.88 kcal/100 g). Overall, all systems produced characteristically lean tilapia; however, variation was most evident in lipid and corresponding energy content, with cage systems at the upper range and tank systems at the lower range. When compared with similar studies, the findings were consistent with the broader classification of tilapia as a lean fish, while also revealing distinct system-level influences. In Bangladesh, Islam et al. (2021) reported moisture values ranging from 79.12 to 81.36 g/100 g, protein content between 14.93 and 16.03 g/100 g, lipid levels of 0.59 to 2.35 g/100 g, ash content ranging from 0.31 to 0.53 g/100 g, and energy values between 97.62 and 126.73 kcal/100 g across wild, pond, gher, and cage systems. Relative to these findings, the present protein values overlapped, lipid values fell within the lower–middle range, and moisture values were approximately 3–5 percentage points lower. Consequently, the calculated energy values were approximately 10–30 kcal/100 g lower. The most notable discrepancy was observed in ash content: these values (∼1.05–1.19 g/100 g), as shown in Table 2, exceeded the 0.31–0.53 g/100 g reported by Islam et al. (2021). This difference likely reflected variations in tissue selection (e.g., muscle-only

Table 2. Proximate composition (g/100g) and energy (kcal/100g) values in the wild, tank, pond and cage-cultured tilapia

System	Moisture	Ash	Protein	Fat	Carb.	Energy
Tank	75.11 ± 3.22^{a}	0.78 ± 0.02^{d}	16.80 ± 1.55^{c}	0.52 ± 0.02^{d}	3.08 ± 0.04^{a}	84^{d}
Cage	75.06 ± 1.82^{b}	0.59 ± 0.00^{a}	15.90 ± 3.15^{c}	1.54 ± 0.31^{a}	1.71 ± 0.12^{c}	84^{a}
Pond	74.74 ± 2.21^{d}	1.09 ± 0.31^{d}	17.30 ± 2.32^{a}	1.23 ± 0.22^{a}	2.10 ± 0.14^{b}	88^{c}
Wild	74.89 ± 2.05^{c}	1.31 ± 0.24^{b}	16.80 ± 1.31^{c}	0.67 ± 0.03^{c}	1.58 ± 0.00^{d}	79^{b}

Note: Carb. = carbohydrate; Values are mean ± SD. Values within the same rows with different superscripts are statistically significant.

versus skinned fillet), trimming procedures, and analytical methodologies for ash determination on a wet-weight basis.
Cross-regional comparisons in farmed freshwater species further supported these interpretations. Matos et al. (2019) profiled several South American freshwater fish, including Nile tilapia. They demonstrated that farming systems and feed composition influenced the development of lean muscle with relatively low and variable lipid content. Their findings supported the present observation that lipid and consequently energy varied with diet composition, activity levels, and environmental conditions, whereas protein remained comparatively stable. Furthermore, biological explanations for the observed system-based gradients were consistent with existing literature. Protein concentrations were highest in tank-reared fish, likely due to intensive management conditions characterised by controlled water quality, consistent feeding regimes, and reduced locomotor activity, all of which promoted protein deposition per unit wet mass. Studies incorporating modified culture practices, such as probiotics or functional feeds, reported only minor changes in muscle protein content, further supporting the stability observed in the present study (Biswas et al., 2018).
Conversely, cage-reared fish exhibited the highest lipid and energy values. Cage production systems often utilise energy-dense feeds and expose fish to moderate water currents, factors known to influence body composition; notably, feed lipid source and overall dietary energy are critical determinants (Matos et al., 2019). Wild fish exhibited slightly higher moisture content, consistent with ecological studies indicating that habitat conditions, dissolved oxygen levels, and environmental stressors influence proximate composition. For example, fish from well-oxygenated systems such as Lake Kariba demonstrated superior proximate quality compared with those from more polluted environments (Jim et al., 2017).
It is normal for proximate values to differ across studies.
Four practical explanations account for most of the spread:

1. **Feed and genetics.** Protein:energy ratios, lipid source, ration size, and strain genetics shift fillet lipid (and energy) content more readily than fillet protein content. Interventions such as probiotics have also nudged protein upward in cultured tilapia (Biswas et al., 2018; Matos et al., 2019).
2. **Habitat and water quality.** Temperature, oxygen, flow, and pollutant loads alter activity budgets and metabolism, leading to measurable compositional differences—even within the same species (Jim et al., 2017).
3. **Fish size and physiological stage.** Composition varies with size, age, and maturation. Studies that pool multiple size classes or harvest at later stages often report higher fillet lipid than studies focused on market-size fish (Islam et al., 2021).
4. **Post-harvest handling and analytical basis.** Skin-on vs skin-off fillets, trimming, chilling, drip loss, moisture correction, and the analytical method (e.g., AOAC protocols for ash and protein) all influence wet-weight proximate values and the energy calculations derived from them (Islam et al., 2021; Matos et al., 2019).

Mineral Composition

The micronutrient status of tilapia species under different aquaculture modalities, including tank systems, cage systems, pond systems, and wild capture, showed considerable variation in mineral levels, thereby highlighting the influence of husbandry practices and environmental conditions.
Calcium (Ca) was found to be highest in pond-cultured tilapia (18.42 mg/100 g), followed by cage-cultured tilapia (17.40 mg/100 g). Tank-cultured tilapia exhibited a lower calcium level (12.89 mg/100 g), while wild tilapia had the lowest concentration (9.52 mg/100 g), with all adjacent contrasts being statistically significant ($p < 0.01$). This trend implied that cultivated tilapia, particularly those reared in pond systems, accumulated higher calcium levels, likely due to regulated feeding regimes that incorporated nutrient supplementation. These findings were consistent with previous studies on cultured fish, which indicated that aquaculture practices often result in higher mineral concentrations than in wild specimens (Jim et al., 2017; Mogobe et al., 2023).
Magnesium (Mg) followed a similar pattern. Pond-cultured tilapia exhibited the highest concentration (12.82 mg/100 g), whereas wild tilapia had the lowest concentration (7.16 mg/100 g) (Table 3). These variations further underscored the positive impact of aquaculture practices on tilapia's mineral composition. Elevated magnesium levels in farmed fish were likely attributable to nutrient-enriched feed formulations designed to enhance growth and health (Raymond et al., 2020). The standardised feeding conditions in aquaculture systems likely contributed to greater uniformity in nutrient composition, whereas wild populations exhibited more variability due to fluctuations in natural food availability.
Significant variation was also observed in sodium (Na) content across farming systems. Cage-cultured tilapia recorded the

Table 3. Concentrations of minerals (mg/100g) in wild, tank-, pond- and cage-cultured tilapia

Minerals	Tank	Cage	Pond	Wild
Essential minerals (macro-nutrients)				
Ca	12.89 ± 0.21^a	17.40 ± 0.11^c	18.42 ± 0.61^b	9.52 ± 0.51^d
Mg	10.73 ± 0.62^b	8.19 ± 0.33^c	12.82 ± 0.83^a	7.16 ± 0.51^d
Na	8.60 ± 0.05^c	17.42 ± 0.82^d	31.99 ± 0.13^b	30.26 ± 0.46^b
K	24.56 ± 0.12^a	19.57 ± 3.32^d	24.42 ± 4.72^c	32.89 ± 8.16^b
Trace elements (micro-nutrients)				
Mn	1.28 ± 0.01^a	1.31 ± 0.41^a	1.99 ± 0.54^b	1.04 ± 0.33^d
Zn	0.92 ± 0.13^b	0.87 ± 0.21^d	0.98 ± 0.45^b	0.68 ± 0.12^c
Fe	4.22 ± 0.00^b	5.89 ± 0.00^b	9.62 ± 0.44^a	3.41 ± 0.15^c
Na/K	0.35	0.89	1.31	0.92

Note: Values are mean ± SD. Values within the same rows with different superscripts are statistically different at $p < 0.05$. Typically, a lower Na/K ratio (<1) is desirable for cardiovascular health.

highest sodium concentration (31.99 mg/100 g), possibly due to environmental conditions and water salinity. In contrast, wild tilapia exhibited a slightly lower sodium level (30.26 mg/100 g), suggesting a more natural and balanced mineral intake. These findings aligned with previous studies indicating that farmed tilapia, particularly those reared in cage systems, could accumulate higher levels of certain minerals, including sodium, due to environmental exposure and feeding strategies (Raymond et al., 2020). These differences also highlighted potential implications for human health, particularly regarding sodium intake and cardiovascular risk (Mogobe et al., 2023). Zinc (Zn) concentrations were generally modest but were higher in pond-cultured tilapia (0.98 ± 0.45 mg/100 g) compared to wild tilapia (0.68 ± 0.12 mg/100 g; $p = 0.03$), while tank- and cage-cultured tilapia exhibited intermediate values that were not significantly different from pond-cultured fish ($p > 0.10$). Both iron (Fe) and zinc (Zn) demonstrated substantial variability across aquaculture systems. Pond-cultured tilapia exhibited higher concentrations of both zinc (0.98 mg/100 g) and iron (9.62 mg/100 g) compared to wild tilapia (0.68 mg/100 g and 3.41 mg/100 g, respectively). This variation was nutritionally significant, as tilapia serves as an important dietary source of iron and zinc, which are essential for physiological functions such as oxygen transport and immune response. The importance of these nutrients is particularly pronounced in rural populations where dietary alternatives may be limited. The use of fortified feeds in aquaculture likely enhanced the micronutrient profile of farmed tilapia, thereby improving their contribution to dietary zinc and iron intake (Islam et al., 2021; Kingsley et al., 2022).

Contribution of Tilapia to Cardiovascular Health

The differences in sodium–potassium (Na/K) ratios across tilapia farming systems further highlighted the potential health implications of consuming farmed fish compared to wild fish (Table 3). A reduced Na/K ratio (<1) was considered beneficial for cardiovascular health, as it improved fluid balance and reduced the risk of hypertension. The Na/K ratio of tank-cultured fish is 0.35, cage-cultured fish is 0.89, pond-cultured fish is 1.31, and wild fish has a ratio of 0.92.

The study found that pond-cultured tilapia exhibited the highest Na/K ratio (1.31), indicating a potentially increased sodium load for consumers of fish from pond systems. In contrast, wild and cage-cultured tilapia demonstrated more favourable Na/K ratios, with values approaching unity. This observation was particularly relevant to global efforts to reduce salt intake and improve cardiovascular health, given that elevated sodium levels have been associated with hypertension and other cardiovascular conditions (Raymond et al., 2020). Potassium (K) and sodium (Na) are recognised as essential elements in the regulation of blood pressure and overall cardiovascular function. Cardiovascular health status is closely linked to the Na/K ratio. High salt intake is associated with elevated blood pressure, a major risk factor for cardiovascular diseases (CVD). In contrast, potassium mitigates the effects of sodium by promoting vasodilation and lowering blood pressure. Bu et al. (2012) suggested that an optimal meal should have a Na/K ratio below 1, thereby reinforcing the nutritional value of wild-caught, tank-cultured, and cage-cultured fish.

The findings of this study were consistent with those reported by Ullah et al. (2022) and Njinkoue et al. (2016), who emphasised the health benefits of consuming fish with higher potassium content and lower sodium levels. Although wild and cage-cultured tilapia remained within a range that may be considered acceptable for most individuals, they were comparatively less favourable than tank-cultured tilapia in terms of cardiovascular risk.

Potential contribution of tilapia to the recommended nutritional intake

Using the small-portion framework (50 g/day for adults and PLW; 25 g/day for young children/infants) and the $\geq$ 25%-of-RNI benchmark for "nutritionally beneficial" fish, zinc and calcium contributions from tilapia fillets were uniformly modest across production systems and population groups. In contrast, iron varied by system and was highest in pond-cultured

Table 4. Estimated contribution of various cultured systems of tilapia to the average daily RNI (%) based on assumed portions

System	Zinc (mg)			Calcium (mg)			Iron (mg)		
	Children	Adult	PLW	Children	Adult	PLW	Children	Adult	PLW
AD RNI	2.4	6.0	3.6	700	1000	1200	10	16	18
Tank-cultured	9.6	7.7	12.8	0.5	0.6	0.5	10.5	13.2	11.7
Cage-cultured	9.3	7.4	12.4	0.6	0.9	0.7	14.7	18.4	16.4
Pond-cultured	10.2	8.2	13.6	0.7	0.9	0.8	24.0	30.1	26.7
Wild	7.1	5.7	9.4	0.3	0.5	0.4	8.5	10.7	9.5

Note: PLW = Pregnant and lactating women; RNI = Recommended nutritional intake; AD RNI = Average daily Recommended nutritional intake. Optimal nutritional fish are those that, if given in 50g, 50g, and 25g portions, respectively, might possibly account for ≥25% of the daily RNIs for adults, PLW, and children of public health relevance. AD RNI values from Byrd et al. (2021); Kingsley et al. (2022); Magna et al. (2025).

fish, as shown in Table 4. Specifically, zinc contributed 7–10% of RNI for adults, 9–10% for children, and 9–14% for PLW, depending on the system; calcium was <1% of RNI for all groups and systems, consistent with low Ca density in boneless fillet. As illustrated in Table 4, iron contributions were 10.5–24.0% for children, 10.7–30.1% for adults, and 9.5–26.7% for PLW, with pond-cultured tilapia peaking at 24.0% (children), 30.1% (adults), and 26.7% (PLW). Thus, only adults and PLW consuming pond-cultured tilapia achieved or exceeded the 25% threshold for iron from a single small portion; children were just below the cut-off at 24%. No system tilapia met ≥25% of the zinc or calcium requirement. Under the document's strict definition, ≥ 25% for three or more essential nutrients from the same portion—tilapia fillet does not qualify as "nutritionally beneficial" based on Zn–Ca–Fe alone, although inclusion of other nutrients (e.g., vitamin B12, selenium, and DHA) not presented in the study could alter that classification.

These findings were consistent with well-established patterns in fish-as-food nutrition. First, the edible portion was shown to be decisive: calcium contributions increased substantially when bones were consumed (e.g., in small whole fish), but remained negligible for de-boned tilapia fillets. This explained the uniformly low Ca %RNI observed despite differences in production systems. Second, portion size and the choice of reference RNIs materially influenced the reported percentages. Because relatively small, policy-relevant portions (50 g/25 g) and WHO/FAO RNIs were applied, the resulting %RNI values were lower than those reported in studies modelling 100 g servings or using alternative RNI tables. Third, the production environment appeared to exert the strongest influence on iron content. Pond systems, characterised by distinct feed regimes, water chemistry, and sediment–fish interactions compared to cages or tanks, plausibly accounted for the higher Fe values observed in pond-cultured tilapia. Fourth, analytical conventions—including wet- versus dry-weight reporting, assumptions regarding moisture and cooking losses, and expression per 100 g versus per portion—were found to contribute to variability across studies, underscoring the importance of methodological harmonisation in comparative analyses. Collectively, these factors explained the consistently low Zn and Ca values, the comparatively higher (but system-dependent) Fe values, and the variability in %RNI reported across studies for similar species.

From a dietary and programmatic perspective, the results supported the positioning of pond-cultured tilapia as a meaningful source of iron for adults and pregnant and lactating women at realistic portion sizes, with contributions for children approaching adequacy thresholds. However, tilapia fillets did not provide ≥25% of the RNI for calcium or zinc under the same assumptions. The combination of tilapia with calcium- and zinc-rich foods, including dairy products, legumes, and fortified staples, was identified as a viable strategy for improving micronutrient intake. Additionally, the inclusion of diverse fish consumption patterns—particularly small, bone-in species when culturally acceptable—and further research into product formulations that preserve nutrient-dense components (e.g., soft-bone processing techniques or blended fish powders) were considered promising approaches to enhance the availability of calcium and zinc. On the production side, optimisation of feed composition and tissue development objectives was identified as a potential pathway to increase tissue mineral content without compromising sustainability or growth targets. Finally, future analyses were recommended to extend beyond calcium and zinc to include other micronutrients to which tilapia contributes significantly, particularly vitamin B12, selenium, and long-chain omega-3 fatty acids, in order to better align with the "three-or-more-nutrients ≥25%" criterion. Such an expanded analytical framework would provide a more comprehensive representation of tilapia's nutritional profile, rather than focusing on a limited subset of nutrients (Zn, Ca, Fe).

Conclusion

In this study, it is demonstrated that tilapia produced under various aquaculture systems, especially pond-cultured tilapia, has the potential to significantly contribute to the nutritional needs of poor people in Ghana, particularly regarding iron, calcium, and zinc. However, alterations in lipid content reflect the influence of farming conditions; proximate composition analysis reveals that tilapia is a lean fish with a consistently high protein-to-lipid ratio across systems. The role of pond-cultured tilapia in iron consumption is important, as this food contributes to the recommended nutrient intake for adults and pregnant or lactating women, making it one of the most important foods for managing iron deficiency. Wild tilapia contributed less to the significant components of calcium and zinc in the RNIs, despite their value. The study on the importance of farmed tilapia in cardiovascular health shows that tank-reared tilapia has the most favourable sodium-to-potassium ratio, which aligns with health recommendations to reduce the risk of hypertension. The findings can be used to improve aquaculture processes to enrich the mineral composition of tilapia and ensure that it is an effective and nutritious food source for rural communities in Ghana. In a bid to attain the full spectrum of RNIs, the results reveal the necessity of multi-purpose meal plans that incorporate tilapia and other nutritious foods. It would enhance the food security and nutritional performance among the vulnerable populations. The issue of sustainable aquaculture practices is essential to enhancing the availability of nutrient-rich fish and, by extension, to the broader societal health goal of reducing micronutrient deficiency.

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