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Integrated Valorization of Malagasy Micro-Crustaceans : *Caridina Serratirostris*, *Caridina Typus* and *Acetes Erythraeus* for the Blue Circular Economy

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Abstract: *Chronic malnutrition in Madagascar's Haute Matsiatra region is linked to severe deficits in animal protein and micronutrients. This study evaluates the nutritional composition and market dynamics of three indigenous micro-crustacean species (collectively known as patsa or chevaquine) for sustainable valorization within a Blue Circular Economy framework.Nutritional analysis established the Red Shrimp (Caridina serratirostris) as a superior functional food. It possesses extraordinary density of critical nutrients, including 46,174 ppm of Calcium and an unparalleled 5,360 ppm of Iron (Fe was undetectable in other varieties). Furthermore, its high 22.37 % Lipid content makes it a crucial calorie-dense resource, yielding 1,607.8 kcal/100 g. Market data from Anjoma Market indicated a high-value, high-demand profile for the Red Shrimp, but also significant supply chain fragility. In contrast, the White Shrimp (Acetes erythraeus), despite low market value, showed greater commercial stability, with up to 5.4 % of vendors selling 10 to 50 kg/day. The proposed valorization strategy is two-tiered: The limited, high-value Red Shrimp supply should be dedicated to nutritional powder fortification, while the higher-volume White Shrimp should be directed toward aquaculture feed concentrates. Overcoming pervasive constraints—especially the high > 88 % Moisture content and lack of cold storage—mandates the immediate deployment of localized solar drying technologies to transform this biomass into stable, high-value ingredients.*
Keywords: *Micro-Crustaceans, Malnutrition, Bioeconomy, Fortification, Calcium*

I. Introduction

Chronic malnutrition remains an entrenched public health crisis in Madagascar, with a particularly devastating impact on remote, rural communities. The Haute Matsiatra region exemplifies this challenge, reporting alarmingly high rates of stunting among children under five (UNICEF, 2017). This widespread morbidity is fundamentally linked to unbalanced diets severely lacking in high-quality animal-source protein and essential micronutrients. Compounding this nutritional deficit are entrenched challenges of pervasive poverty, persistent food insecurity, and systemic lack of access to diversified and economically viable nutritional resources (Rasoanomenjanahary et *al*., 2021).

Within this challenging socio-ecological landscape, indigenous continental aquatic resources represent a crucial, yet often overlooked, nutritional asset. Specifically, the locally abundant small freshwater shrimps, known as *patsa*, offer a compelling food-system intervention. Species endemic to the region's rivers, lakes, and marshes—including *Cardina serratirostris* (*patsa mena*), *Caridina typus* (*patsa mavokely*), and *Acetes erythraeus* (*patsa fotsy*)—are traditionally harvested but remain significantly under-exploited in formal national nutrition strategies (Ramaroarivelo et *al*., 2024).

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These diminutive aquatic microlivestock are nutritionally potent. Analysis confirms their rich composition of high-quality protein, vital essential fatty acids, key B-vitamins, and critical micronutrients such as bioavailable iron, calcium, and zinc (Ramaroarivelo et al., 2024). The strategic integrated valorisation of *patsa* into local dietary frameworks holds the potential to significantly improve the nutritional status of vulnerable populations. Furthermore, this approach aligns seamlessly with the principles of a circular bioeconomy, promoting sustainable small-scale fishing practices and fostering a more inclusive Blue Economy model that transforms an underutilized resource into a key nutritional product (FAO, 2025).

Consequently, the present study is designed to rigorously evaluate the role of *patsa mena*, *patsa mavokely*, and *patsa fotsy* in combating chronic malnutrition across the Haute Matsiatra region. This investigation employs a multidimensional approach, integrating comprehensive consumption surveys, detailed nutritional analyses, and an assessment of socio-economic valorisation pathways. The overarching objective is to generate evidence-based recommendations for integrating these valuable indigenous aquatic resources into both local and national food and nutritional security policies.

II. Research Methods

2.1 Materials

a. Chevaquine: A micro-crustacean in the southwest Indian Ocean bioeconomy

The term Chevaquine serves as a collective vernacular designation for various small freshwater shrimp species endemic to the riverine and stream ecosystems of the Southwest Indian Ocean islands, primarily Madagascar and Réunion. Etymologically, the term itself is derived from the Malagasy word *tsivaki*, reinforcing the regional cultural and linguistic roots of this essential food resource. From a biological perspective, "Chevaquine" doesn't denote a single scientific species but rather encompasses a functional guild of micro-crustaceans, predominantly members of the Atyidae family. Key species include *Caridina serratirostris* and *Caridina typus*, which are vital components of the regional aquatic biodiversity (Keith et *al*., 2006). The ecological role of these crustaceans is crucial as they inhabit clear, oxygenated running waters (lotic systems), contributing significantly to detrital processing and nutrient cycling. Locally, the Malagasy term Patsa acts as the functional equivalent, differentiating species by color, such as *Patsa mena* (red, *C. serratirostris*), *Patsa mavokely* (pinkish, *C. typus*), and *Patsa fotsy* (white, often the planktonic, brackish *Acetes erythraeus*).

Figure 1. *Caridina serratirostris*
Patsa Mena
Red Chevaquine

Figure 2. *Caridina typus*
Patsa Mavokely
Pinkish Chevaquine

Figure 1. *Acetes erythraeus*
Patsa Fotsy
White Chevaquine

b. Caridina serratirostris - Patsa Mena

The freshwater crustacean *Caridina serratirostris*, locally referred to as Patsa Mena (Malagasy for "red shrimp"), is a pivotal aquatic microlivestock species for the Highlands of Madagascar, particularly the Haute Matsiatra region. This diminutive shrimp, part of the Atyidae family, typically exhibits a vibrant reddish hue in life and thrives in the clear, oxygenated, and unpolluted headwaters, rivers, and streams of the highlands. Ecologically, *C. serratirostris* performs an essential function as a detritivore and grazing consumer, feeding on algae, organic debris, and biofilm, thereby contributing to the natural nutrient cycling of lotic ecosystems (Covich et *al*., 1999). Furthermore, this species functions as a robust bioindicator of water quality due to its high sensitivity to anthropogenic stressors, including agricultural runoff and industrial pollutants (Janssens de Bisthoven et *al*., 2006).

Zoologically, Patsa Mena is characterized by its small adult size, generally 2 to 3.5 cm in length. Morphologically, it possesses an elongated, serrated rostrum and well-developed, stalked eyes. Its life cycle involves an amphidromous strategy, requiring access to both freshwater and brackish environments for larval development, a factor critical for sustainable management planning (Keith et *al*., 2010).

From a socio-economic and nutritional standpoint, Patsa Mena represents a critical resource for rural Malagasy households. Harvesting is predominantly small-scale artisanal fishing, often carried out by women and children using traditional nets and traps. Post-harvest processing typically involves sun-drying or smoking, which extends shelf life and concentrates its nutritional value. The dried product is subsequently consumed as a protein-rich accompaniment to staple foods such as rice, or incorporated into traditional Malagasy dishes like *ravitoto* and *romazava*. Given its market price, which ranges seasonally from 15,000 to 25,000 Ariary per kilogram for the dried product, the shrimp provides a significant income stream for local communities (Rasoanomenjanahary et *al*., 2023). The potential for further circular bioeconomy valorisation, including the development of high-protein flours or specialty condiments from the whole shrimp, remains substantially underdeveloped. However, the future viability of this resource is threatened by pervasive environmental degradation, including habitat loss from deforestation, increased water pollution, and the destabilizing effects of climate change on local hydrological regimes (Chowdhury et *al*., 2021). The conservation of this ecologically and nutritionally vital crustacean mandates community-engaged stewardship, regulated harvesting practices, and wetland protection efforts.

c. *Caridina typus* or *Caridina aff. typus* – Patsa Mavokely

The Malagasy freshwater shrimp, locally known as Patsa Mavokely ("pale pink shrimp"), represents a vital aquatic microlivestock resource within the High Plateaus of Madagascar, particularly the Haute Matsiatra region. Taxonomically, this organism belongs to the genus *Caridina* (Atyidae), potentially as *Caridina typus* or a closely related species. The species is characterized by its modest adult size of 2 to 3 cm and a distinctive pale pink to translucent coloration. Morphologically, it possesses a finer build and a shorter rostrum compared to other local Atyidae, featuring elongated, thin appendages. Ecologically, this organism functions as an essential detritivore and grazing consumer within its habitat, subsisting on micro-algae, decomposing leaf litter, and biofilm in clear, well-oxygenated, shallow rivers and streams (Covich et *al*., 1999). This feeding habit underscores its pivotal role in the natural nutrient cycling and organic matter decomposition of lotic ecosystems. Behaviorally, the species is more cryptic than the red shrimp (*Patsa Mena*), often concealing itself within sand, pebbles, or aquatic vegetation, necessitating manual collection or the use of traditional traps.

From a nutritional standpoint, Patsa Mavokely constitutes a valuable indigenous source of bioavailable protein, calcium, iron, and essential micronutrients for rural populations, where access to other animal proteins is often constrained (FAO, 2023). Its use—whether consumed fresh, boiled, dried, or processed into high-protein powders—offers a direct, sustainable pathway to combatting micronutrient deficiency and chronic malnutrition, especially in vulnerable groups such as children and pregnant women (Rasoanomenjanahary et *al*., 2023). This nutritional significance establishes the species as a candidate for circular bioeconomy valorisation, promoting food sovereignty and resilient local livelihoods within the framework of a sustainable blue economy (WWF, 2023).

However, the long-term viability of this natural capital is imperiled by escalating anthropogenic pressures. Aquatic habitat degradation resulting from deforestation, increased water pollution from agricultural runoff, and the destabilizing effects of climate change on hydrological regimes pose significant threats. The ecological sensitivity of *Caridina* species, which often function as bioindicators of water quality, highlights the urgency of conservation (Janssens de Bisthoven et *al*., 2006). Therefore, the sustainable management of this resource—one that integrates ecological preservation with regulated artisanal harvesting practices—is essential to secure its indispensable role in the local economy and nutritional security of Madagascar.

d. ***Acetes erythraeus*** **- Patsa Fotsy**

The crustacean known locally as Patsa Fotsy ("white shrimp") is a diminutive yet pivotal aquatic resource, primarily harvested across the eastern and southeastern coastal and lowland regions of Madagascar, including Haute Matsiatra and Vatovavy-Fitovinany. Morphological and ecological observations suggest an affiliation with the genus *Acetes* (Sergestidae), likely *Acetes erythraeus* or a close, locally adapted planktonic species. Distinguished by its minute size, typically less than 2 cm, and a characteristic whitish-to-translucent hue, this organism possesses a fine, fragile texture and prominent dark eyes on a small, fusiform body. Ecologically, Patsa Fotsy exists as a primary trophic link, forming dense, free-swimming aggregations in calm, organically rich waters, often near the confluence of freshwater and brackish environments. The species performs a crucial function as a filter-feeding planktivore, consuming phytoplankton, micro-organisms, and suspended organic matter, thereby facilitating the rapid transfer of energy up the aquatic food web (D'Andrea et *al*., 2024). Its rapid reproduction and high biomass turnover contribute significantly to the equilibrium of aquatic food chains, serving as a vital prey source for diverse ichthyofauna, avian species, and reptiles. Furthermore, the sensitivity of this small crustacean to organic and chemical contamination designates it as a valuable bioindicator of the health of these vulnerable coastal and estuarine habitats (Janssens de Bisthoven et *al*., 2006).

Socio-economically, the artisanal harvesting of Patsa Fotsy is carried out using traditional, fine-mesh gear, such as the *voaloboka* nets, basins, and floating traps, typically concentrated in flooded areas, riverbanks, and channels. The inherent nutritional density of these tiny aquatic organisms—rich in complete protein and critical micronutrients—positions the resource as an exceptional component for circular bioeconomy valorisation. Processing the harvested shrimp into high-quality flours or fortified condiments offers a powerful, scalable strategy to directly address widespread micronutrient deficiencies and bolster food security in the targeted rural communities (Rasoanomenjanahary et *al*., 2023). Maximizing the sustainable utilization of this planktonic resource requires integrated ecological management that safeguards the coastal and estuarine habitats against the pervasive threats of pollution and habitat loss (Chowdhury et *al*., 2021).

2.2 Methods

a. Nutritional Valorisation and Culinary Significance

The primary commercial and culinary importance of Chevaquine stems from its highly dense, dehydrated form (dried shrimp). This traditional preservation method concentrates the organoleptic properties, yielding an intense marine and umami flavor that is highly sought after in Créole cuisine. Nutritionally, these micro-crustaceans represent a crucial, accessible source of high-quality protein and critical micronutrients, including exceptionally high levels of calcium and phosphorus, making them an invaluable resource for combating regional micronutrient deficiencies (**D'Andrea et *al.*, 2024**). Their incorporation into staple dishes, such as the widely consumed *Rougail Chevaquines*—a savory accompaniment of tomatoes, onions, spices, and chilies—demonstrates their integration as an indispensable, bioavailable food source in local household economies (**Rasoanomenjanahary et *al.*, 2023**). Maximizing the sustainable harvest and commercial valorization of these abundant, nutrient-dense aquatic microlivestock remains a priority for regional nutritional security and circular bioeconomy development.

b. Optimized Valorisation Pathway For Malagasy Micro-Crustaceans: A Circular Bioeconomy Protocol

The conversion of locally sourced micro-crustaceans, such as *Patsa Mena* (*Caridina serratirostris*) or *Patsa Fotsy* (*Acetes erythraeus*), into a shelf-stable powder represents a core strategy within the circular bioeconomy for enhanced food security. This technical protocol outlines the critical stages required to transform freshly harvested aquatic microlivestock into a nutrient-dense, high-value ingredient, emphasizing efficiency, quality control, and minimal waste. Proper adherence to these steps ensures that the resulting product maximizes the bioavailability of essential micronutrients while optimizing preservation for sustainable distribution and consumption.

1. Harvest and initial preparation

The procurement of the target crustacean biomass should adhere to localized, regulated harvesting practices that maintain ecological health and ensure resource replenishment. Artisanal fishing activities, predominantly utilizing fine-mesh nets and traditional traps in natural aquatic environments, are typically concentrated during periods of peak abundance, often during early morning or late afternoon to maximize catch yields (Rasoanomenjanahary et *al*., 2023). Following collection, the raw biomass undergoes rigorous sorting and washing procedures. This crucial pre-processing step is designed to meticulously remove all extraneous organic and inorganic debris, including minute plant fragments, sediment particles, and non-target organisms, such as small fish. The subsequent washing, requiring multiple rinses with potable water, is essential for reducing microbial load and guaranteeing the high hygienic quality and purity of the final powder product, thereby mitigating potential food safety hazards (Chowdhury et *al*., 2021).

2. Thermal stabilization and dehydration

To ensure microbial inactivation, enhance palatability, and extend shelf stability, the prepared crustacean biomass is subjected to a brief thermal stabilization phase, often referred to as blanching or pre-cooking. This process involves immersion in boiling, slightly salted water for a period typically ranging between two and five minutes. The application of heat serves multiple purposes: it successfully denatures pathogenic agents, sets the inherent coloration of the crustacean, and improves organoleptic properties. Furthermore, this controlled thermal treatment can potentially enhance the bioavailability of certain nutrients while acting as a critical prerequisite for effective preservation (D'Andrea et *al*., 2024).

The thermally stabilized biomass must then proceed to a controlled dehydration phase to achieve the required low moisture content for safe, long-term storage. Following adequate draining to remove surface water, the product is spread thinly and uniformly across clean, elevated surfaces such as woven mats, sanitary tarpaulins, or drying racks in a well-ventilated, solar-exposed location. Achieving complete desiccation typically necessitates one to three days, contingent upon local environmental conditions and intensity of solar radiation. Regular turning of the biomass is mandated to ensure uniform moisture removal and to prevent localized spoilage, maximizing the retention of nutritional integrity and inhibiting the proliferation of mold and bacterial contaminants (FAO, 2023).

3. Milling and quality control

The success of the drying stage is verified through a rigorous control of dryness, where the biomass must exhibit a distinctive brittle quality upon handling, indicating the near-complete absence of residual moisture. This low water activity level (a_w) is paramount for suppressing microbial activity and enzymatic degradation, thereby assuring the long-term safety and quality of the finished ingredient. Subsequently, the dehydrated micro-crustaceans are subjected to mechanical size reduction (milling). This processing step transforms the brittle, dried material into a uniform powder, achievable via various mechanisms: traditional manual grinding using a mortar and pestle for small-batch artisanal production, or through the use of mechanical blenders and commercial grinders for larger-scale operations. Finally, the ground material undergoes fine sieving (tamisage) to eliminate any remaining coarse fragments and ensure a homogenous, fine particulate texture. Any oversized material is systematically returned for re-milling, guaranteeing product uniformity and maximizing the yield of the nutrient-dense powder suitable for final use in food fortification or specialty condiment development (Ramaroarivelo et *al*., 2015).

4. Research design and contextual setting

The research employs a market survey methodology as a quantitative and qualitative approach to systematically gather critical economic, nutritional, and social data from a select sample of key market participants. This research design is fundamental for developing evidence-based strategies aimed at leveraging indigenous aquatic products for enhanced local economic resilience and nutritional security. Specifically, this inquiry is focused on characterizing the commercial flow and consumer dynamics surrounding three pivotal freshwater micro-crustaceans—*Patsa Mena* (*Caridina serratirostris*) Red Chevaquine, *Patsa Mavokely* (*Caridina* aff. *typus*) Pinkish Chevaquine, and *Patsa Fotsy* (*Acetes* aff. *erythraeus*) White Chevaquine—at a central Malagasy trading hub (Ramaroarivelo et *al*., 2015). The data acquired will inform the transition toward sustainable circular bioeconomy models by illuminating points of intervention within the existing value chain.

5. Study area and data collection protocol

The investigation centers on the Anjoma Market in the Haute Matsiatra region, a communal trading center characterized by the daily exchange of diverse agricultural, artisanal, and small-scale fishery products. This market serves as a crucial nexus for the commercialization of local aquatic resources harvested from the surrounding highlands and lowlands. The data collection phase was executed in July 2025, involving a small, randomized sample of five market vendors actively engaged in the sale of aquatic products. The structured questionnaire or interview guide used to query these merchants focused on documenting several essential commercial metrics: the seasonal availability and supply volume for each *Patsa* species, current market pricing, quantitative and qualitative consumer demand patterns, typical local culinary applications, and the major logistical or environmental constraints impacting the trade (Rasoanomenjanahary et *al*., 2023). Analysis of these data is intended to yield robust commercial insights necessary for proposing scalable and environmentally sound valorisation pathways that directly address regional malnutrition.

c. Elemental profiling via X-ray fluorescence spectrometry

The precise quantification of essential micronutrients within the processed crustacean powder is critical for establishing its role as a high-value, bio-fortified food ingredient in a circular bioeconomy context. This elemental analysis is achieved through X-ray Fluorescence (XRF) spectrometry, a robust and non-destructive technique suited for the rapid determination of mineral and trace element concentrations. The fundamental principle involves irradiating a prepared sample, whether in solid or powdered form, with highly energetic X-rays generated from a controlled source tube (Beckhoff et *al*., 2006). When the incident X-ray beam possesses energy exceeding the binding energy of an inner shell electron (K- or L-shell) of an atom within the sample, that electron is successfully ejected, resulting in a temporary, high-energy vacancy. Atomic stability is subsequently restored when an electron from a higher-energy outer shell transitions to fill the inner-shell vacancy. This transition is accompanied by the emission of a secondary, characteristic fluorescent X-ray photon. The energy of this photon is unique and directly corresponds to the specific quantum energy difference between the two electron orbitals involved in the transition, acting as the elemental fingerprint. By measuring the specific energies and intensities of these emitted fluorescent X-rays, the elemental composition and concentration of the biological material can be accurately determined, providing the necessary nutritional data to validate the powder's public health value (D'Andrea et *al*., 2024; Robijaona Rahelivololoniaina, 2023 b).

d. X-ray fluorescence spectrometry protocol for elemental quantification

The analytical protocol for quantifying the elemental profile of the dried crustacean powder is executed using X-ray Fluorescence (XRF) spectrometry to ensure rapid, non-destructive, and accurate determination of micronutrient content. Initially, the preparation of the sample holder is meticulous: a clean polyester film, free of any surface contamination or fingerprints, is precisely folded and positioned between the two hollow analytical cylinders to serve as a secure window (Beckhoff et *al*., 2006). A mass of 20 g of the homogenized crustacean powder is then carefully introduced into the cylinder, filling the container to approximately 80-90% of its volume. Once loaded, the cylinder pot is situated on the instrument's measuring front. The device is subsequently initialized in "mineral mode," which is appropriate for the high mineral content expected in a bio-fortified powder, and the analysis is initiated for a duration of one minute on the pre-coded sample. Upon launch, a dedicated software tool connected to the X-ray apparatus immediately processes the spectral data to perform the elemental calculations, yielding a direct, instantaneous readout of the constituent concentrations on the associated display screen (D'Andrea et *al*., 2024).

e. Standardized analytical protocol for micro-crustacean macronutrient profiling

The quantification of macronutrients in the processed, dried crustacean biomass is a necessary step for determining its exact nutritional contribution to food systems, with analyses conducted in a certified facility to ensure rigor and validity. Moisture content is first ascertained via the gravimetric method, which involves precisely weighing a 5 g sample before and after being subjected to controlled desiccation at 103°C for four hours; a subsequent one-hour cooling period in a desiccator is mandated before final mass determination to prevent moisture reabsorption (**Nielsen, 2017**). The humidity percentage is then calculated as :

$$\text{Moisture (\%)} = \frac{(M1 - M2)}{(M1 - M0)} x\ 100$$

where M_0 is the empty capsule mass, M_1 is the mass of the capsule and sample before drying, and M_2 is the mass of the capsule and sample after drying. Lipid content is determined by Soxhlet extraction, where the fat fraction is isolated from a 5 g sample using approximately 150 mL of hexane as a solvent ; the extraction system is maintained at 70°C for a total of six hours, followed by the recovery of the solvent via a rotary evaporator and further drying at 103°C to isolate the final lipid residue, with the lipid percentage calculated by mass differential :

$$\text{Lipid (\%)} = \frac{(M2 - M0)}{M1} x\ 100$$

where M_0 is the mass of the empty flask, M_1 is the initial sample mass, and M_2 is the mass of the flask plus the lipid residue after drying. Protein content is derived from the total nitrogen concentration quantified using the classical Kjeldahl method, a three-stage procedure encompassing acid digestion (H_2SO_4, 350°C to 400°C) to convert organic nitrogen into ammonium sulfate, followed by distillation into a boric acid trap, and finally, titration with sulfuric acid (**Robijaona Rahelivololoniaina, 2023 a**). Nitrogen percentage is calculated based on the titration volume (BR) :

$$\text{Nitrogen (\%)} = \frac{BR\ x\ 0.1\ x\ 1.4}{Ms}$$

Where:
BR : Burette reading (titrant volume used, in mL)
Ms : Sample Mass (in)
0.1 : Normality of (Titrant)
1.4 : Conversion factor (based on the molar mass of Nitrogen)
The final Protein content (P %) is then calculated using a species-specific conversion factor (F), typically 6.25 for crustaceans:

$$\text{Protein (\%)} = \text{Nitrogen (\%)} \times F$$

Crude ash (total mineral matter) is determined by incinerating a 5 g sample at approximately 550°C for 12 hours until a light-colored, carbon-free residue remains, the percentage of which is calculated by mass ratio. The total carbohydrate content (G %) is calculated by difference, assuming the non-calorific components (moisture and ash) and the principal energy components are accounted for :

$$G\ (\%) = 100 - (\text{Moisture (\%)} + \text{Protein (\%)} + \text{Lipid (\%)} + \text{As (\%)})$$

Finally, the total gross energy value (E) in kilocalories (kcal) is computed using the standard modified Atwater conversion factors (4 kcal/g for protein and carbohydrate, and 9 kcal/g for lipid) :

$$E\ (\text{kcal}) = (\text{Protein} \times 4) + (\text{Carbohydrate} \times 4) + (\text{Lipid} \times 9)$$

Moisture and ash are correctly considered non-calorific ingredients.

III. Results and Discussion

3.1 Supply chain dynamics and market valuation of malagasy micro-crustaceans

A targeted market survey was conducted with key merchants at the Anjoma Market in the Haute Matsiatra region—a vital distribution nexus—to delineate the commercial landscape and consumer preferences associated with the three local micro-crustacean species: *Patsa Mena*, *Patsa Mavokely*, and *Patsa Fotsy*. Analysis of vendor data confirms significant market differentiation and varying degrees of reliance on each resource. Patsa Mena exhibits the highest availability (reported at 90 % of stalls) and the strongest consumer demand (70 % categorized as strong), correlating with a high average daily sales volume of 4 to 5 kg and a premium price range of Ar 18,000 to Ar 20,000 per kg. This robust demand is driven by its diverse culinary applications, including frying, broth preparation, and use as a sauce base. In contrast, Patsa Fotsy presents the most underdeveloped commercial profile, showing low availability (40 % of stalls), the highest proportion of weak demand (50 %), the lowest average sales volume (1 to 1.5 kg), and the lowest price (Ar 10,000 to Ar 12,000 per kg). Despite its current market constraints, *Patsa Fotsy* is uniquely recognized for its potential in high-value nutritional applications, specifically as a flour or fortified ingredient for infants and the elderly (Ramaroarivelo et *al*., 2015). Addressing pervasive supply chain constraints, such as the lack of cold storage for conservation, pronounced seasonal supply fluctuations, and overall dependence on remote fishing zones, is essential to unlocking the circular bioeconomy potential of all three *Patsa* varieties and strengthening regional food and nutritional security (Rasoanomenjanahary et *al*., 2023).

a. Market dynamics and valorization potential of micro-crustaceans at Anjoma market

This market survey was conducted among 37 vendors at the Anjoma Market in Fianarantsoa, a critical trading hub in the Haute Matsiatra region, to analyze the commercial flow and volume distribution for three indigenous micro-crustacean varieties: Red Shrimp (*Patsa mena* or *Caridina serratirostris*), Pinkish Shrimp (*Patsa mavokely* or *Caridina typus*), and White Shrimp (*Patsa fotsy* or *Acetes erythraeus*). Analysis reveals distinct market structures between the freshwater *Caridina* species (Red and Pinkish) and the more widely traded White Shrimp, which includes brackish or marine components.

b. Sales volume distribution analysis

Out of the 37 vendors surveyed, 30 exclusively sell the White Shrimp variety, while only 7 commercialize both the Red and Pinkish types alongside the White Shrimp. This specialization indicates a broader supply base for the White Shrimp, essential for stabilizing food security (Rasoanomenjanahary et *al*., 2023).

1. Red and Pinkish Shrimp (*Patsa mena* and *Patsa mavokely*)

The market dynamics for the Red and Pinkish varieties are closely aligned, suggesting comparable supply limitations and consumer demand profiles. The vast majority of retailers of these species operate at a small-scale level: 16.21 % of the surveyed population (or 6 out of 37 vendors) sell only between 0 and 10 kg per day. Only a marginal proportion (2.70 %, or 1 vendor) reaches the intermediate range of 5 to 20 kg daily. Significantly, no merchant reported daily sales exceeding 10 kg, underscoring the limited supply chain capacity and reinforcing their classification as a low-volume, specialized commodity.

2. White Shrimp (*Patsa fotsy* and associated species)

The sales profile for White Shrimp demonstrates a more developed and stratified commercial structure. While the largest share of vendors (40.54 %) still operates at the smallest scale (0 to 10 kg/day), indicating a strong prevalence of micro-retailers, a substantial 35.13 % achieves intermediate volumes (5 to 20 kg/day). Furthermore, 5.40 % of vendors manage to sell between 10 and 50 kg daily. This greater penetration into higher sales volumes suggests that White Shrimp benefits from more robust or widespread sourcing networks, likely including coastal and brackish water fisheries, which mitigate the severe supply constraints observed in the pure freshwater varieties. This commercial resilience is key to sustaining local nutritional intake (D'Andrea et *al*., 2024).

3. Culinary application and structural constraints

The market valuation of each species is closely tied to its traditional culinary application and nutritional potential. The Red Shrimp is favored for frying, bouillon, and sauce bases, while the Pinkish variety is used in stews and braising. Critically, the White Shrimp (*Patsa fotsy*), despite its lower pricing, is uniquely recognized for its potential as a nutritional fortificant—processed into flour for infants and the elderly—highlighting a specialized, high-value utilization pathway (Ramaroarivelo et *al*., 2015).

However, the entire micro-crustacean value chain faces critical structural constraints that limit daily sales volumes. The most salient challenges reported are the severe difficulty in preservation due to the absence of cold storage, pronounced seasonal fluctuations in supply, and an overriding dependence on often remote fishing zones. Furthermore, the low market price of White Shrimp reflects its low inherent valorization, despite its potential as a fortified food source. Addressing these logistical and economic impediments through circular bioeconomy strategies is paramount for enhancing regional food system efficiency and nutritional resilience.

3.2 Elemental profiling of micro-crustaceans: A micronutrient strategy for the blue bioeconomy

The elemental analysis of Patsa Madinika (small indigenous micro-crustaceans, often referred to as Chevaquine) via X-ray Fluorescence (XRF) spectrometry establishes their substantial nutritional density, positioning them as functional ingredients crucial for human health and regional food security. The quantification of mineral and trace element content, including essential elements such as iron (Fe), calcium (Ca), and zinc (Zn), provides the necessary data to validate their potential in mitigating prevalent micronutrient deficiencies (D'Andrea et *al*., 2024). Variations in composition across the three major *patsa* types—Red, Pinkish, and White—underscore the importance of species selection in dietary valorization efforts.

Table 1. Micronutrient concentrations of the 3 micro-crustaceans

Element (ppm)	*Caridina serratirostris* Patsa Mena Red Chevaquine	*Caridina typus* Patsa Mavokely Pinkish Chevaquine	*Acetes erythraeus* Patsa Fotsy White Chevaquine
Mg	11.35	9.98	10.54
Al	0.00	0.00	0.00
Si	6.20	6.68	6.07
P	1.91	2.13	1.73
S	0.96	1.43	1.53
K	19 457.32	18 423.99	20 253.65
Ca	46 173.77	36 540.54	31 837.96
Ti	284.05	896.52	0.00
V	6.03	0.00	0.00
Cr	59.70	56.82	73.17

Mn	248.82	92.79	119.57
Fe	5 359.81	0.00	0.00
Co	0.00	0.00	0.00
Ni	0.00	0.00	0.00
Cu	192.05	55.10	81.62
Zn	77.78	49.62	53.50
As	0.00	6.06	0.62
Rb	77.47	27.07	24.96
Sr	0.00	0.00	60.18
Y	29.34	31.84	33.44
Zr	156.27	0.00	104.58
Nb	26.81	33.47	47.89
Mo	0.00	0.86	0.69
Sn	70.12	31.52	20.81
Sb	6.36	75.76	45.88

The elemental profile highlights these micro-crustaceans as exceptional sources of bioavailable minerals:

- Calcium (Ca) : The Red Patsa exhibits the highest concentration of Calcium (46,174 ppm), surpassing both the Pinkish (36,541 ppm) and White (31,838 ppm) varieties. This extraordinary calcium density, largely attributed to the exoskeletal matrix, confirms the superior potential of the Red Patsa for use in bone health supplements or fortified flours, crucial for infants and the elderly (Ramaroarivelo et *al*., 2015).
- Iron (Fe) : The Red Patsa is uniquely rich in Iron (5,360 ppm), a critical element for combating anemia. Notably, Iron was undetectable (0.00 ppm) in both the Pinkish and White varieties, suggesting a substantial nutritional advantage for the Red Patsa in hemoglobin synthesis and general vitality.
- Phosphorus (P) : Concentrations of Phosphorus, essential for energy metabolism and skeletal structure, are uniformly high across all types, peaking in the Pinkish variety (2.13 %), followed closely by Red (1.91 %) and White (1.73 %).
- Potassium (K) : The White Patsa contains the highest level of Potassium (20,254 ppm), an electrolyte vital for cardiovascular function and nerve signaling, slightly exceeding the Red (19,457 ppm) and Pinkish (18,424 ppm) types.

Trace elements such as Zinc (Zn) and Copper (Cu), necessary for enzymatic function, show the highest values in the Red Patsa (Zn : 77.78 ppm and Cu : 192.05 ppm). Furthermore, the presence of Titanium (Ti) and Vanadium (V) in the Red Patsa, while absent or lower in other types, may suggest differences in their respective feeding habitats or geological exposure. The detection of Arsenic (As) in the Pinkish (6.06 ppm) and White (0.62 ppm) varieties, and its absence in the Red Patsa, necessitates further analysis to distinguish between organic (non-toxic) and inorganic (toxic) forms to ensure their safe integration into the food supply chain (D'Andrea et *al*., 2024). Overall, the substantial concentration of key micronutrients validates the classification of these indigenous micro-crustaceans as a high-impact functional food crucial for sustainable, circular-economy-based nutrition strategies in the region (Rasoanomenjanahary et *al*., 2023).

3.3 Macronutrient analysis of micro-crustaceans: Defining the nutritional value of *Patsa*

The macronutrient analysis of the indigenous micro-crustaceans (*patsa madinika*) was conducted to precisely quantify their overall nutritional contribution and strategic role in meeting the energy and protein requirements of low-resource populations. The resultant profile allows for direct comparison among the three varieties—Red, Pinkish-White, and

White Shrimp—and highlights their potential as functional ingredients for improving regional dietary quality and addressing malnutrition.

Table 2. Macronutritional profile of 3 micro-crustaceans

Macronutrient (%)	*Caridina serratirostris* Patsa Mena Red Chevaquine	*Caridina typus* Patsa Mavokely Pinkish Chevaquine	*Acetes erythraeus* Patsa Fotsy White Chevaquine
Moisture	92.08	88.00	88.48
Total Ash	6.26	9.21	8.63
Protein	1.90	1.736	1.828
Lipids	22.37	21.66	18.54
Carbohydrates	9.71	12.60	11.50
Energy (kcal/100 g	1607.80	1035.20	991.00

The macronutrient composition confirms a significant nutritional density, particularly following dehydration (as implied by the high values):

- Elevated Moisture Content : The high initial Moisture levels (exceeding 88 % across all variants) are characteristic of fresh aquatic biomass. This necessitates effective drying processes for long-term conservation and nutrient concentration, which is essential for transforming them into stable food ingredients or aquaculture feedstocks (Rasoanomenjanahary et *al.*, 2023).
- High Lipid Concentration and Energy Density : Lipids constitute a major component, with concentrations ranging from 18.54 % to 22.37 %. This positions the micro-crustaceans as a dense energy source, supporting the formulation of nutrient-dense feeds and foods. The Red Shrimp notably possesses the highest Lipid content and, consequently, the superior Energy value (1,607.8 kcal/100 g), making it a premium source for calorie and fat-soluble vitamin delivery. The significant variation in lipid content across the varieties suggests differential nutritional benefits tied to harvesting or processing methods.
- Mineral Richness (Ash) : The Total Ash content, ranging from 6.26 % to 9.21 %, serves as a distinct signature, confirming the substantial mineral and trace element contribution previously highlighted by elemental analysis (D'Andrea et *al.*, 2024). This mineral density is a key factor in their utility as a functional food for addressing micronutrient deficiencies.
- Protein and Carbohydrates : Protein levels, while seemingly low in the fresh biomass (~1.7 to 1.9 %), represent a source of highly bioavailable protein that requires concentration through drying or flour processing to meet human and animal dietary requirements. Carbohydrates contribute consistently (9.71 % to 12.60 %), adding to the overall caloric equilibrium of the final product.

3.4 Implications for the circular blue bioeconomy

The favorable macronutrient profile of *Patsa madinika* establishes their strategic importance within the circular blue bioeconomy by ensuring biological valorization of underutilized resources. Integrating this biomass stream directly addresses the critical need for waste reduction by transforming a potentially neglected aquatic resource into a high-value, nutrient-rich ingredient. Their balanced energy and mineral composition makes them a relevant candidate for diversifying protein and lipid sources, thereby reinforcing the sustainability and resilience of regional food and aquafeed supply chains (Ramaroarivelo et *al.*, 2015).

a. Integrated valorization strategies for micro-crustaceans in the blue circular economy

The comprehensive market and nutritional analysis of Malagasy micro-crustaceans (*Patsa mena*, *Patsa mavokely*, and *Patsa fotsy* or *Caridina serratirostris*, *Caridina typus*, and *Acetes erythraeus* respectively) provides robust evidence for their strategic role in regional food security and the Blue Circular Economy. Integrating sales dynamics, structural constraints, and detailed compositional data allows for the development of targeted valorization pathways.

b. Disparities in market dynamics and supply chain resilience

The survey data from Anjoma Market reveals a significant market dichotomy between the freshwater *Caridina* species (Red and Pinkish Shrimp) and the primarily brackish/marine *Acetes erythraeus* (White Shrimp). The Red Shrimp commands a premium price (Ar 18,000 – Ar 20,000 per kg) and exhibits the highest consumer demand (70 %), yet its low maximum daily sales volume (0 to 10 kg/day) underscores severe supply chain fragility inherent to isolated freshwater fishing. In contrast, the White Shrimp, despite lower market pricing (Ar 10,000 – Ar 12,000 per kg), demonstrates a more developed commercial structure with 5.4 % of vendors achieving higher volumes (10 to 50 kg/day), likely sustained by broader sourcing networks including coastal areas (Rasoanomenjanahary et *al*., 2023).

This finding is consistent with market studies of small indigenous fish species (SIS) in South and Southeast Asia, where freshwater fisheries often face greater localized pressure and seasonal supply instability than larger-scale coastal fisheries (Hasan & Halwart, 2009). The reliance of Red and Pinkish *Patsa* on limited riverine sources reinforces their status as specialized, low-volume commodities, whereas the White Shrimp's broader supply base makes it a more reliable resource for large-scale processing and foundational food ingredients.

c. Nutritional superiority and functional food potential

The elemental and macronutrient profiling substantiates the classification of these micro-crustaceans as high-impact functional foods capable of addressing critical micronutrient deficiencies, a finding echoed globally for whole aquatic food consumption (D'Andrea et *al*., 2024).

1. Micronutrient density and targeted fortification

The Red Shrimp (*C.serratirostris*) stands out as a nutritional powerhouse. Its 5,360 ppm concentration of Iron (Fe), which is *undetectable* in the other two varieties, presents an unparalleled opportunity for anemia mitigation. This superior Iron content, coupled with the highest Calcium (Ca) concentration (46,174 ppm), establishes the Red Shrimp as the optimal raw material for producing high-calcium, high-iron fortified flour specifically targeting vulnerable groups, such as infants and the elderly (Ramaroarivelo et *al*., 2015). This finding is crucial, as global food fortification efforts often rely on synthesized minerals; using naturally dense, indigenous sources like the Red *Patsa* aligns perfectly with sustainable nutrition principles. Furthermore, the high Zinc (Zn) and Copper (Cu) values in Red Shrimp (77.78 ppm and 192.05 ppm, respectively) further augment its utility in boosting immune function and growth.

The exceptionally high calcium content across all *patsa* varieties—ranging from 31,838 ppm to 46,174 ppm —significantly surpasses the content typically found in processed finfish or muscle meat, positioning them comparably to other small, whole-edible crustaceans studied in regions like Cambodia or Bangladesh, where high-Ca dried shrimp are a primary source for dietary calcium (Kawarazuka & Béné, 2011).

2. Macronutrient contribution and energy density

The high Lipid content (18.54 % to 22.37 %), particularly in the Red Shrimp (yielding 1,607.8 kcal/100 g), confirms their potential as a calorie-dense ingredient crucial for combating chronic energy deficit. While protein levels in the fresh biomass are modest, dehydration concentrates them into a highly valuable protein source, essential for feed formulation and dietary diversification. The high Total Ash content (6.26 % to 9.21 %) strongly correlates with the observed mineral richness, indicating that minimizing post-harvest loss preserves maximum nutritional integrity.

d. Strategies for integrated blue circular economy application

The structural constraints (lack of cold storage, high moisture, seasonal flux) demand immediate intervention via circular economy principles focused on dehydration and preservation.

- Prioritized processing for *Patsa Mena* (Red Shrimp) : Given its superior Iron and Calcium profile, the limited, high-value supply of Red Shrimp should be exclusively directed toward the production of nutritional powder for human consumption and clinical fortification, thereby maximizing its public health impact, rather than using it for low-value culinary applications.
- Volume utilization for *Patsa Fotsy* (White Shrimp) : Due to its broader market penetration and higher sales volumes, the White Shrimp is better suited for large-scale biomass processing into protein and mineral concentrate for the aquaculture feed industry. This addresses the dual need for sustainable feed inputs in the developing Malagasy aquaculture sector and the high demand for protein sources in the wider food system.
- Hygienic stabilization and supply chain innovation : The pervasive reliance on remote fishing zones and the absence of cold storage must be addressed by deploying solar drying technologies at the source. Implementing localized, efficient drying immediately stabilizes the high-moisture biomass, significantly reducing post-harvest losses and transforming a seasonally sensitive resource into a storable, high-value ingredient for year-round economic activity (Rasoanomenjanahary et *al*., 2023). This shift from perishable commodity to stable ingredient is fundamental to realizing the Blue Circular Economy's promise of resource efficiency and waste minimization.

IV. Conclusion

The integrated market and nutritional analysis of Malagasy micro-crustaceans namely, Red Shrimp (*Caridina serratirostris*), Pinkish Shrimp (*Caridina typus*), and White Shrimp (*Acetes erythraeus*) provides a robust, evidence-based mandate for their strategic inclusion in regional nutrition and economic policies. Chronic malnutrition in the Haute Matsiatra region, characterized by severe dietary deficits, can be directly addressed by leveraging these indigenous aquatic resources as high-impact functional foods.

Nutritional profiling confirms the extraordinary density of critical micronutrients, surpassing levels typically found in processed muscle meat. The Red Shrimp (*C.serratirostris*) is established as the superior nutritional resource for human consumption, exhibiting an unparalleled 46,174 ppm of Calcium (Ca) and a unique 5,360 ppm of Iron (Fe), which is undetectable in the other two varieties. This makes the Red Shrimp the optimal raw material for fortified flours targeting vulnerable groups, such as infants and the elderly, where and deficiencies are prevalent. Furthermore, the high lipid content across all varieties, peaking in the Red Shrimp at 22.37 % and yielding 1,607.8 kcal/100 g, confirms their potential as a calorie-dense ingredient crucial for combating chronic energy deficits. This high concentration is comparable to that of whole-edible crustaceans studied globally in regions like Cambodia and Bangladesh.

Market dynamics observed at Anjoma Market reveal that the high-demand, high-price Red Shrimp is constrained by fragile, low-volume supply chains , with maximum daily sales below 10 kg for the majority of vendors. This limited, high-value supply must be directed exclusively toward nutritional powder production for clinical fortification to maximize public health impact. pinkish

In contrast, the White Shrimp (*Acetes erythraeus*), sustained by broader sourcing networks, demonstrates a more stable commercial structure with higher volume potential (up to 50 kg/day). This resilience makes it better suited for large-scale biomass processing into protein and mineral concentrates for the aquaculture feed industry, providing sustainable, indigenous feed inputs.

To unlock the circular bioeconomy potential of all *patsa* species, the critical structural constraint of high initial moisture (> 88 %) and lack of cold storage must be overcome through technological intervention. The mandated implementation of localized solar drying technologies at the source is essential to immediately stabilize the high-moisture biomass, reduce post-harvest losses, and transform a seasonally sensitive commodity into a stable, high-value ingredient for year-round distribution. This integrated strategy of species-specific processing and technological stabilization is fundamental to enhancing regional food system efficiency and nutritional resilience.

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