Journal of Food Health and Bioenvironmental Science
Journal homepage : http://jfhb.dusit.ac.th/

Nutritional Potential of the Invasive Charru Mussel (*Mytella strigata*): A Focus on Fatty Acid Composition for Aquaculture Feed Applications

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Article info

Article history:
Received : 9 October 2024
Revised : 16 December 2024
Accepted : 24 December 2024

Keywords:
Mytella strigata, Proximate composition, Fatty acid profile

Abstract

The charru mussel, *Mytella strigata* (Hanley, 1843), is an invasive alien species of mussel reported in Thai waters. Originally native to Central and South America, it now poses an economic risk to commercial mussel farming in Thailand, as it commonly co-occurs with the cultured species Perna viridis and exhibits a remarkable tolerance to a wide range of salinities and temperatures. While its geographic distribution in Thailand is well-documented and it is occasionally sold in domestic markets—indicating potential as an alternative protein source for humans or animals—there is limited information regarding its nutritional composition. Therefore, investigating the nutritional properties of *M. strigata* is essential to assess its suitability as an alternative food source. The objectives of this study were to determine the nutritional content of *M. strigata* and evaluate its potential as an alternative food source for humans or animals. Samples of *M. strigata* were collected from Klongdan, Samut Prakan Province. Thirty individuals were selected for the measurement of shell length and width, along with their total weight and wet meat weight. The meat yield was calculated. The wet meat was then dried for proximate analysis and fatty acid analysis. The results found that *M. strigata* had a shell width of 13.6±0.62 mm and a shell length of 43.2±1.19 mm. Their total weight and wet meat weight were 5.22±0.20 g and 1.47±041 g, respectively. The meat yield was 33.3±9.36%. The wet meat exhibited the following composition: moisture (81.4±0.6%), protein (6.65±1.6%), lipid (1.13±0.2%), and ash (0.45±0.1%). The fatty acid composition showed the highest percentage in saturated fatty acids (31.47±1.79% of total fatty acids, TFA), followed by polyunsaturated fatty acids (PUFAs) (23.73±0.38% TFA) and monounsaturated fatty acids (MUFAs) (17.18±0.77% TFA). Eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) accounted for 8.71±0.08% and 7.83±0.16% TFA, respectively. In conclusion, *M. strigata* demonstrates potential as a nutritious food source for humans, owing to its high protein content and favorable n-3/n-6 PUFA ratio. Additionally, its nutritional profile supports its use as an alternative feed source for aquatic animals, such as fish and shrimp.

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Introduction

The mytilid *Mytella strigata* (Hanley, 1843), formerly known as *M. charruana* (d'Orbigny, 1842), is native to the coasts of Central and South America (Lim et al., 2018). It has been identified as an invasive species in Florida and Georgia (Boudreaux and Walters, 2006; Gillis et al., 2009). Although *M. strigata* was not included in Chavanich et al.'s (2010) report on introduced marine species in Southeast Asia, subsequent studies have documented its presence in the Philippines (Rice et al., 2016; Mediodia et al., 2017; Vallejo et al., 2017) and Singapore (Lim et al., 2018). In Thailand, Sanpanich and Wells (2019) reported the presence of *M. strigata* in Samut Prakan Province, raising concerns among local *Perna viridis* farmers. Jayachandran et al. (2019) observed that *M. strigata* grows rapidly and attaches at high densities (120±24 individuals per 25 cm²) to various surfaces, including floating plastic bottles, wooden pilings, fish cage walls, boat hulls, and bottom sediments. More recently, Lodeiros et al. (2021) recorded the first occurrence of *M. strigata* in the Venezuelan Caribbean, following its invasion of a shrimp farm.

In aquaculture, feed is a critical factor. Lipids, like protein and carbohydrates, are an essential group of nutrients. In addition to providing energy, lipids are a source of essential fatty acids. Finfish species are similar to other vertebrates and cannot synthesize either linoleic acid (C18:2 n-6), the precursor of the n-6 family or linolenic acid (18:3n-3) the precursor of the n-3 family (Henderson and Tocher, 1987). These fatty acids, or their highly unsaturated derivatives, must be obtained through the diet. The omega 3 (e.g., eicosapentaenoic acid (EPA; C20:5n-3) and docosahexaenoic acid (DHA; C22:6n-3) and omega 6 (e.g., linoleic acid; C18:2n-6 and arachidonic acid (ARA; C20:4n-6) are considered to be essential for normal growth, food utilization, health, and reproductive viability. Notably, n-3 polyunsaturated fatty acids (PUFAs) are vital for optimal growth, feed efficiency, immunological efficacy, and cardiovascular function in fish (Balfry and Higgs, 2001; Lee et al., 2009; Oliver et al., 2010).

Fishmeal and fish oil are the primary sources of n-3 PUFAs in fish and shrimp feed. However, the increasing demand for farmed fish and shrimp production has resulted in a shortage of these resources. To address this issue, alternative sources of n-3 PUFAs have been explored, particularly from marine environments. These alternatives include marine microorganisms such as yeast, bacteria, and microalgae, as well as zooplankton like copepods and krills, and bivalves (Tan et al., 2020; Gong et al., 2017). Marine mollusks play a critical role in marine ecology and offer significant nutritional value for both aquatic animals and humans. They are a good source of nutrients including high quality of protein, minerals, low lipid content, and essential fatty acids; PUFAs (Orban et al., 2007). PUFAs are essential fatty acids that aquatic animals cannot produce on their own and must obtain through their diet. Among these, special attention is given to n-3 PUFAs, particularly EPA and DHA, which are linked to various health benefits. DHA, in particular, plays a crucial role in brain development and function, photoreception, and the reproductive system (Kris-Etherton et al., 2003; Sidhu, 2003). Similarly, Tocher (2010) reported that DHA plays crucial roles in ontogenesis, cellular structure, immune responses, gene regulation, and homeoviscous adaptation in marine fish. EPA is the precursor of a family of prostaglandins, which control blood clotting and other arterial functions. Although EPA is less critical for shrimp than for fish, González-Félix et al. (2002) reported improved growth in *Litopenaeus vannamei* juveniles when their diet included 2.5 mg/g DHA.

In humans, EPA and DHA are associated with cardiovascular benefits, including reduced risks of mild hypertension, cardiac arrhythmias, and sudden death (Kris-Etherton et al., 2003). They also lower blood triglyceride levels and serve as precursors for resolvins, compounds that help resolve inflammatory processes (Kohli and Levy, 2009). These fatty acids exhibit potential therapeutic effects on various conditions, including skin disorders, asthma, arthritis, nephritis, lupus erythematosus, multiple sclerosis, and certain cancers (Harris, 2010; Massaro et al., 2010).

Given these benefits, the present study aims to evaluate the nutritional quality of M strigata collected from Klongdan, Samut Prakan Province. The focus is on analyzing its proximate composition and fatty acid profile to assess its potential as an alternative nutrient source for both humans and aquatic animals.

Materials and methods

1. Sample collection, preparation and parameter measurement

The *M. strigata* (Fig. 1) was collected from Klongdan, Samut Prakan Province. Identification was conducted using traditional methods based on morphological

characteristics, as described by Sanpanich and Wells (2019). The samples were transported to the laboratory in an icebox to maintain freshness. Upon arrival, they were washed and processed for further analysis.

Measurements were taken from 30 individuals to determine length (maximum measurement along the anterior-posterior axis) and width (maximum measurement along the lateral axis). The total weight and wet meat weight of each individual were also recorded. Meat yield (MY) was calculated using the formula:

Meat yield (MY) (wet sample weight/total sample weight) × 100 (Okumus & Stirling, 1998).

The biometric measurement parameters are shown in Table 1. The wet meat samples were minced and freeze-dried for proximate composition analysis, including crude lipid and crude protein, as well as fatty acid profiling.

Fig. 1 *M. strigata* from Klongdan, Samut Prakan Province

2. Proximate analysis

The moisture, ash, lipid, and protein contents of the samples were determined using standard AOAC procedures (2003). For moisture content, crucibles were preheated at 100°C in a hot air oven for 2 h before use. One gram of wet meat was accurately weighed, placed in a crucible, and dried at 100°C until a constant weight was achieved. After drying, the sample was cooled in a desiccator and reweighed to determine the moisture content. For ash content determination, crucibles were preheated at 550°C in a furnace for 2 h before use. One gram of wet meat was weighed and placed in a crucible, then ignited at 550°C for 6 h. After cooling in a desiccator, the crucibles were reweighed, and the ash content was calculated. The crude lipid content was determined using the Soxtec™ System (AOAC, 2003). Approximately 1 g of the dried sample was wrapped in filter paper, placed in a fat-free thimble, and loaded into the extraction tube. After weighing, cleaning, and drying, the receiving cup was filled with petroleum ether and inserted into the apparatus. The extraction process, initiated by turning on the water valve and heater, lasted 1-2 h. The receiving cup was then transferred to a drying oven at 103°C for 30 min, cooled in a desiccator, and reweighed. The crude protein content was determined using the Kjeldahl method. The samples were digested by heating with concentrated sulfuric acid (H_2SO_4) in the presence of a digestion mixture. After digestion, the mixture was made alkaline, forming ammonium sulfate. Ammonia was released, captured in a 4% boric acid solution, and titrated against standard 0.1 N HCl. The total protein content was calculated by multiplying the nitrogen content by a factor of 6.25. Carbohydrates (nitrogen-free extract, NFE) content was calculated using the formula: NFE (%) = 100 - (lipid + protein + fiber + ash).

3. Fatty acid analysis

Freeze-dried meat samples were accurately weighed, and an internal standard (trinonadecanoin, C19:0) was added. Lipids were extracted using the method described by Folch et al. (1957) and converted to methyl esters using methanolic HCl. Initially, 0.5 g of dried meat was ultrasonicated in 20 mL of ice-cold chloroform/methanol (2:1, v/v) containing 0.1% butylated hydroxytoluene for 20 minutes. The liquid fraction was then transferred to a separating funnel. The residual matter underwent a second extraction, after which the liquid phase was again transferred to the funnel. To separate the nonlipid phase, 0.88% (w/w) KCl (approximately 25% of the total sample volume) was added to the separating funnel. The contents were agitated, then left undisturbed to allow phase separation. The total lipid fraction was collected by filtering the lower phase through anhydrous sodium sulfate and evaporating the solvent.

Fatty acid methyl esters (FAMEs) were prepared by acid-catalyzed transesterification (Christie, 2003). Total lipid samples were treated with 1% sulfuric acid in methanol and incubated at 60°C for 16 h. FAMEs were analyzed using gas-liquid chromatography (Agilent Technologies GC7820A, USA). Individual FAMEs were identified by comparing retention times with known standards (Supelco 37-Component FAME Mix, Supelco, USA). The FAMEs were injected through a capillary column (HP-Innowax, 30 m × 0.25 mm i.d., 0.25 µm film thickness, Agilent J&W, USA) and detected using a flame ionization detector (FID). Helium was used as

the carrier gas at a constant flow rate of 1.1 mL/min. The temperature program began at 120°C (held for 0.5 min), increased to 170°C at a rate of 5°C/min (held for 10 min), then to 190°C at 3°C/min (held for 15 min), and finally to 210°C at 2°C/min (held for 15 min). Injection and detection port temperatures were set at 240°C and 260°C, respectively. Peaks were identified by comparing relative retention times to those of the standards. Fatty acid content was calculated as a percentage of total lipid (%TFA). Results are presented as the mean±SD based on triplicate measurements.

Results and discussion

The present study provided details on biometric measurement parameters; meat yield, proximate composition and fatty acid profiles of the *M. strigata* collected from the wild. In this study, *M. strigata* exhibited a meat yield value of 33.3% (Table 1). Bivalves exhibited meat yield values ranging from 31.4% in *Flexopecten glaber* to 44.5% and 41.2% in *Mimachlamys varia* and *Mytilus galloprovincialis,* respectively (Biandolino et al., 2019). The proximate compositions in 100 g wet weight of *M. strigata* were: 81.4% of moisture, 0.45% of crude ash, 1.13% of crude lipid, 6.65% of crude protein, and 10.37% of NFE (Table 2). The similar values for proximate composition were reported in *P. viridis* collected from Cochin, India; 89.32% of moisture, 1.42% of crude ash, 1.27% of crude fat, 7.14% of crude protein (Chakraborty et al., 2016). Likewise, when compared to proximate composition of scallops *F. glaber* from the Ionian Sea (the Central Mediterranean Sea), the scallops were found to have moisture 84.53%, ash 3.51%, protein 8.50%, lipid 1.45% and carbohydrate 0.03 % (Biandolino et al., 2020). The moisture content of food material affects the physical and chemical aspects, and it is considered a good indicator of freshness and quality of seafood (Aberoumad & Pourshafi, 2010).

Table 1 Biometric measurement parameters and meat yield of *M. strigata* (n=30)

Biometric parameters	Mean ± Standard deviation
Shell width (mm)	13.6 ± 0.62
Shell length (mm)	43.2 ± 1.19
Wet meat weight (g)	1.47±0.41
Total weight (g)	5.22±0.20
Meat yield (%)	33.3±9.36

Table 2 Proximate composition of *M. strigata*.

Parameters	Mean ± Standard deviation
Moisture	81.40± 0.6
Ash	0.45 ± 0.1
Lipid	1.13 ± 0.2
Protein	6.65 ± 1.6
NFE	10.37

Remark: Data are the mean values of three replicates ± standard deviation. Moisture and ash are expressed as % of wet weight; proteins and lipids as g/100 g wet weight, NFE = Nitrogen Free Extract (%).

In Table 3, the fatty acid profile of *M. strigata* revealed that saturated fatty acids (SFA) constituted 31.47±1.79% TFA, with palmitic acid (16:0) being the predominant SFA at 16.45% TFA. This aligns with previous reports indicating that mussel fatty acid profiles typically contain ~30–40% SFA (Alkanani et al., 2007) and C16:0 was the major SFA (Alkanani et al., 2007; Orban et al., 2002).

Monounsaturated fatty acids (MUFA) accounted for 17.18% TFA, with palmitoleic acid (16:1) and oleic acid (18:1) being the most abundant. PUFA made up 23.73% TFA, with EPA (8.71% TFA) and DHA (7.83% TFA) as the predominant n-3 PUFAs. These results are consistent with studies identifying EPA and DHA as key fatty acids in mussels (Alkanani et al., 2007; Orban et al., 2002; Biandolino et al., 2020).

The n-3/n-6 ratio of *M. strigata* was approximately 3.36, which is slightly lower than the 3.7–5.3 ratio reported for *P. viridis.* This ratio is significant for its anti-inflammatory properties, as EPA and DHA are precursors to anti-inflammatory lipid mediators. A balanced dietary n-3/n-6 ratio is crucial in preventing chronic diseases, including cardiovascular conditions (Cordain et al., 2005). The high dietary intake of *M. strigata* with its favorable n-3/n-6 ratio (~4) could help prevent inflammatory and autoimmune diseases, as tissue fatty acid ratios largely reflect dietary intake (Cleland et al., 2006). This study found low n-6 levels (5% TFA) and high n-3 PUFA levels (18% TFA) in *M. strigata* (Table 3), which is comparable to findings in *P. viridis* from Cochin, India, where n-6 levels ranged from 5–7% and n-3 levels from 19–27% (Chakraborty et al., 2016). Such favorable fatty acid profiles have been emphasized in aquafeeds for promoting growth performance, nutrient utilization, and overall health in aquatic species. For instance, a dietary n-3/n-6 PUFA ratio of 0.66–1.35 improved gut health and reduced inflammation in spotted seabass (*Lateolabrax maculatus*) (Dong et al., 2023).

Fatty acid profiles of marine shellfish species, such as blue mussels, scallops, northern horse mussels, and oysters, show similarities, with predominant fatty acids being C16:0, C16:1 cis 9, EPA, and DHA. These species are excellent sources of n-3 fatty acids, and

mollusks are recognized as high-quality, nutritious foods with high protein levels and relatively low lipid content rich in PUFAs (Aanrud et al., 2017; Nichols et al., 1998; Mooney et al., 2002).

As *M. strigata* is well-adapted to a range of salinities (2–35 PSU) and is found in various regions of Thailand, including Songkhla Lakes, the Bang Pakong River estuary, and Bang Saen's open coast (Wells et al., 2024). Its rapid growth and ability to form high-density populations on natural and artificial substrates (Jayachandran et al., 2019) make it a promising candidate for high biomass production. This suggests its potential as an alternative resource for human consumption, animal feed, and aquafeeds.

The use of *M. strigata* in aquatic animal feed has many advantages, such as its ability to produce high biomass and be cultivated in diverse aquatic environments, as it can adapt to a wide range of salinities (Wells et al., 2024). *M. strigata* contains essential fatty acids and proteins that support the growth and health of aquatic animals (Tan et al., 2020). As a filter feeder, it helps improve water quality by removing organic matter, making its cultivation more environmentally sustainable compared to other feed sources (Gallardi, 2014). Its nutritional value depends on its food, such as phytoplankton and zooplankton (Balic et al., 2012). Additionally, it is an ideal candidate for developing alternative, sustainable feed for aquaculture. However, the quality of *M. strigata* should be a concern, as it is a filter feeder that can accumulate heavy metals, pathogens, and other environmental contaminants (Prabitha et al., 2022), which may pose risks to animal health.

Table 3 Fatty acid compositions (% of total fatty acids, TFA) of *M. strigata*

Fatty acids	%TFA
C6:0	0.23 ± 0.04
C12:0	nd
C13:0	nd
C14:0	4.09 ± 0.13
C15:0	0.55 ± 0.03
C16:0	16.45 ± 0.76
C17:0	3.63 ± 0.52
C18:0	6.30 ± 0.28
C20:0	0.23 ± 0.03
C21:0	nd
C22:0	nd
C23:0	nd
C24:0	nd
∑ SFAs	31.47±1.79
C14:1	nd
C15:1	nd
C16:1n7	5.74 ± 0.19
C17:1	1.29 ± 0.13
C18:1n9 (c+t)	4.89 ± 0.17
C20:1n-9	4.96 ± 0.18
C22:1n-9	0.29 ± 0.10
C24:1n-9	nd
∑ MUFAs	17.18 ± 0.77
C18:2n-6	1.72 ± 0.02
C18:3n-6	nd
C18:3n-3	1.51 ± 0.04
C20:2	nd
C20:3n-6	nd
C20:4n-6	3.72 ± 0.05
C20:3n-3	0.24 ± 0.02
C20:5n-3 (EPA)	8.71 ± 0.08
C22:2	nd
C22:6n-3 (DHA)	7.83 ± 0.16
∑ PUFAs	23.73 ± 0.38
n-3	18.29 ± 0.30
n-6	5.44 ± 0.07
n-3/n-6	3.36

Remark: Data are the mean values of three replicates ± standard deviation, nd= not detected. SFAs = saturated fatty acids, MUFAs= monounsaturated fatty acids, PUFAs= polyunsaturated fatty acids.

Conclusion

The invasive alien mussel species, *M. strigata*, was found to have a meat yield comparable to other bivalve species. It exhibited high crude protein and low lipid content, while its fatty acid profile showed high levels of essential fatty acids, particularly EPA and DHA. These findings underscore the nutritional value of *M. strigata* and its potential as a feed ingredient for aquatic animals.

Acknowledgments

We thank Dr. Supannee Leethochavalit for providing the sample. The author also thanks the Director of Institute of Marine Science, Burapha University for facilitating the research activities.

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