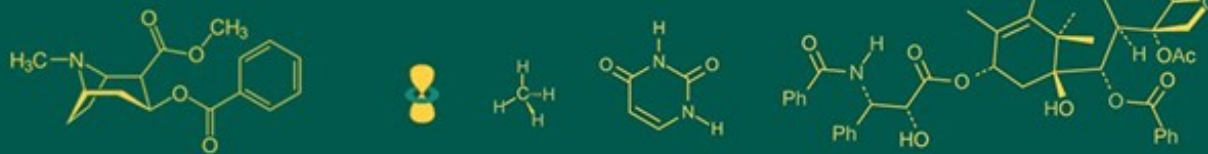


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Green mussel processing: Present status and future prospectus

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ABSTRACT

Green mussel (*Perna viridis*) found in the Indo-Pacific region has very high nutrition level, which contains about 36.15% protein, 24.54% carbohydrates and 19.72 % lipid (on dry weight basis). Mussels are not consumed raw but rather are processed through pre-cooking, followed by freezing or sterilization. Some other processing techniques mainly include canning, marinating, smoke drying, thermal processing etc. The processing effects on mussel composition are primarily caused by material exchange between mussel meat and processing media (water, steam, brine, and air) and thermal inactivation by high temperature (molecular lysis or reaction) when mussels are sterilized. The main effect of processing on mussel components is their concentration due to water loss. Though green mussels have high nutritional values, lack of awareness about their consumption style, limited availability, issues with cold chain, difficulties in pre-processing etc, resulted in their less significance than other established seafoods in the market. Therefore, the present article gives insight into the availability of green mussels throughout India and the world, the current status of utilization, and future prospectus that will be useful for aquaculturists, industries, and academicians.

Keywords: Bivalves, Green mussel, Processing, Prospects, Biochemical composition

Introduction

Bivalves are invertebrates belonging to the Phylum Mollusca. They are found in both marine and freshwater environments, and approximately 15,000 different species of bivalves are known (Gosling, 2004) [1]. One specific bivalve species is *Perna viridis*, commonly known as the Asian green mussel. This species falls under the Phylum Mollusca, Class Bivalvia, and Family Mytilidae, with *Perna* being one of the 32 genera within Mytilidae. Among these genera, *Perna viridis* is particularly noteworthy (Gosling, 2004; Rajagopal et al., 2006) [1, 2].

The Asian green mussel, *Perna viridis*, can be found in the coastal waters of the Indo-Pacific region. It can survive a wide range of temperatures, ranging from 11 to 32 °C, and it thrives in a salinity range of approximately 18-33 ppt. The meat of these mussels is highly favoured in certain countries. It is known for its high protein content and distinctive sweet flavor, attributed to significant amounts of glycogen present in it (Balachandran et al., 1980) [3].

Green mussels are rich in nutritional contents, containing approximately 36.15% protein, 24.54% carbohydrates, and 19.72% lipids on dry weight basis (Saritha et al., 2015) [4]. They are particularly abundant in essential vitamins, with vitamins A and C being the most notable. These nutritional attributes make green mussels a valuable food source for human consumption, primarily due to their high-quality protein and dietary composition.

However, it's important to note that green mussels are susceptible to environmental factors and have a relatively short lifespan (Farber et al., 2000) [5]. Therefore, they require careful handling to maintain their quality. They are processed in various ways worldwide, including canning, freezing, marinating, smoking, drying, and grinding into powders. In the Jibong region of Samar, Philippines, green mussels are even transformed into products like Adobong Tahong (NSCB, 2006) [6], and this practice is also widespread in other Samar districts, including Jibong, Villareal, Tarangan, and Motiong.

The volume of mussel production in the Samar region of the Philippines is sufficient to meet both the demand for fresh and processed mussel products. Developing value-added products from mussels can provide additional income opportunities for mussel farmers and fisherfolk. It is crucial to study, process, and diversify mussel products to enhance the mussel industry. This article aims to provide insights into the global distribution and nutritional aspects of green mussels (*Perna viridis*) and the various methods employed in their processing (Ramachandran et al., 1998) [7].

Global scenario of green mussel availability

The green mussel is a prevalent species in the marine waters of the Indo-Pacific region, as well as certain coastal areas of Peninsular Malaysia, particularly Johor, which serves as the primary producer in Malaysia. The notable mussel harvesting area, such as Kampung Pasir Puteh, is situated near the Pasir Gudang Seaport and industrial zones. In 1999, this species was first observed in Tampa Bay, a large subtropical estuary in peninsular Florida, USA, and has since spread to various locations in the southeastern USA. The introduction and distribution of *Perna viridis* in the Atlantic Basin have been extensively studied by various researchers.

Apart from the Indo-Pacific region, green mussels are also found in the southern Caribbean, Persian Gulf, South Pacific, Papua New Guinea, Hong Kong, Mexico, the USA, Thailand, and India. They thrive in warm waters with salinity levels ranging from 0 to 64 parts per thousand and temperatures between 6 and 37.5 °C. The coastal ecosystems of Southeast Asia play a crucial role in supporting marine life, and *Perna viridis* is present in all Southeast Asian countries. For instance, it has been documented in six major estuaries near significant rivers in Thailand, including the Tachin, Tapi, Meklong, Bangpakong, and Chao Phraya Rivers.

Resource availability of green mussel in India

Green mussels, are found along both the east and west coasts of India, including the Andaman Islands. On the east coast, they are found in areas such as Chilka Lake, Kakinada, Chennai, Pondicherry, Cuddalore, and Porto Novo. Likewise, on the west coast, they are found from Quilon to Kasargod, including locations like Alleppey, Cochin, Calicut, Mangalore, Karwar, Goa, Bhatia Stream, Malvan, and the Gulf of Kutch. Their distribution extends along the Indian coasts, with presence observed in Kerala, Maharashtra, and Karnataka States. In particular, they are found in Ratnagiri, Malwan, and Mumbai in Maharashtra and around Karwar, including the Kurmagad Islands in Karwar Bay.

Perna viridis thrives in the intertidal rocky coastal areas of the Kanyakumari region. This known for extensive mussel beds in the rocky coastal waters, and mussel fishing is a regular activity conducted from September to March at various locations with mussel beds in shallow or slightly submerged rocks near the shore. Key mussel fishing areas on the southwest coast of India include Kovalam to Pulinkudi in Trivandrum district, Kerala, and Enayam, Colachel, and Kadiyapattinam in Kanyakumari district, Tamil Nadu.

Green mussels are also found in high densities on the Tranquebar bank of Nagapattinam district of Tamil Nadu. They proliferate consistently in the rocky habitat of this region. Additionally, these mussels are present around St. Martin's Island and Moheshkhali channel in the Bay of Bengal. Along the Kerala coast, mussel fisheries hold significant importance due to the presence of extensive mussel beds and local culinary preferences. Along the Tamil Nadu coast, mussels can be found from Colachel to Cape Comorin at various locations, including Kodimunai, Vanikudi, Kurumpanai, Enayam, Enayam-Puthenthurai, Ranranlhurai, Kadiapatnam, Colachel, Muttom, and Kovalam near Kanyakumari.

In Andhra Pradesh, mussel beds are primarily observed in Kakinada, particularly along the Kakinada Upputeru, where mussels extend for about 1.5 kilometers along the creek. Locally, the green mussel is known as "Aalichippalu." In Odisha and West Bengal, no mussel fishery has been documented, likely due to the sandy nature of the coast in those regions.

Nutritional aspects of green mussel

The meat composition of green mussels is influenced by a range of environmental and internal factors, including water temperature, salinity, food availability, and the reproductive patterns of these organisms, as reported in AOAC (1990) [8]. Bivalve molluscs are known to serve as a valuable source of lipids and proteins with high

biological value, as documented by Nagabhushanam and Dhamane in 1977 [9]. *Perna viridis*, collected from different seasons, have been found to be particularly rich in proteins while having a low-fat content. Consequently, they represent an important dietary component due to their nutritional significance.

Protein

The protein content in *Perna viridis* is notably higher compared to carbohydrates and lipids, suggesting its potential as a valuable protein source for food production (Catedral *et al.*, 1977) [10].

Amino acids

Analyses have shown that mussel meat is rich in essential amino acids (12.489%) when compared to non-essential amino acids (10.856%). Bhaskar (2002) reported that the total amino acid content in *Perna viridis* is 95.76% of the total protein.

Vitamins

Vitamins play a crucial role in promoting growth, reproduction, and overall bodily health and function. *Perna viridis* has notably higher levels of vitamins A and C compared to other vitamins, as reported by Saritha *et al.* (2015) [4]. Ozden *et al.* (2011) [11] found the presence of vitamin B in the muscle of testicles and eggs.

Minerals

The concentration of calcium (Ca) and magnesium (Mg) in *Perna viridis* exceeds levels typically reported for bivalve molluscs (Shafee, 1978) [12]. Zinc (Zn) is the second most abundant trace element in *Perna viridis* and has attracted attention due to its potential role in disease pathophysiology (Parulekar *et al.*, 1982) [13]. Other important macro minerals, such as sodium, potassium, magnesium, calcium, iron, phosphorus, and sulfur, are present at significant levels and are essential for human nutrition. A deficiency in these minerals can lead to various biochemical and pathological changes. Calcium levels were high, while copper levels were low in *Perna viridis*, and other macro minerals like potassium, sodium, and iodine were present at critical levels, while magnesium and iron were present at lower concentrations (Erkan *et al.*, 2007) [14].

Lipids

Perna viridis has a relatively high lipid content ($8.92 \pm 0.219\%$) compared to *Perna indica*, which has a lower lipid content ($6.73 \pm 0.121\%$) (Saritha *et al.*, 2015) [4]. Although there are differences in lipid levels between these two species, they are not significantly distinct. Fatty acid analysis of lipids from both *Perna viridis* and *Perna indica* revealed the presence of 30 fatty acids, including ten saturated fatty acids (SFA), six monounsaturated fatty acids (MUFA), and fourteen polyunsaturated fatty acids (PUFA). Palmitic acid was the predominant saturated fatty acid in *Perna viridis* ($25.03 \pm 0.03\%$), accounting for 47.89% of the total SFA content. Monounsaturated fatty acids were also present, with oleic acid being the most abundant ($25.09 \pm 0.04\%$ in *Perna viridis* and $18.37 \pm 0.07\%$ in *Perna indica*), followed by palmitoleic acid (Dalin *et al.*, 2017) [15].

Present status of utilization of green mussel

Mussels have been consumed and utilised by people throughout the world. Green mussels are highly nutritious which has made it a valuable food source for human consumption especially because of its high-quality protein and well-balanced nutritional composition. The mussel meat is processed in various different forms in many parts of the world including dried mussel meat, smoked and dried mussel meat, frozen mussel meat marinated mussel meat, mussel meat pickle, mussel meat chutney powder, canned mussel meat, ready-to-serve and ready-to-eat fried mussel meat, vacuum packaged mussel meat (ICAR, 2003).

Processing of green mussels

a) Fresh Consumption

- a) Mussels are consumed in raw condition in some countries like Phillipines while other have reported consumption of raw mussel meat with vinegar (Endoma *et al.*, 2022) [16]. Mussels are typically cooked by boiling them until their shells open and their flesh turns from gray to orange. This indicates that the mussels are fully cooked and ready to be eaten (Samsudin *et al.*, 2021) [17]. Apart from the raw or boiled consumption, the mussels are consumed in the form of mussel curry, mussel soup, mussel escabeche, mussel paste, mussel powder, mussel fritters and many others (Ismail and Hasni, 2014, MacKenzie *et al.*, 1997; Sumagaysay, 2014) [18, 19]

b. Thermal processing

The increasing popularity of ready-to-eat (RTE) or ready-to-cook (RTC) fish has led to a growing demand for convenient heat-treated mussels (Bongiorno *et al.*, 2018) [20]. The Food and Agriculture Organization (FAO) and the World Health Organization (WHO) (FAO, 2020 ; WHO, 2020) have described methods for heat-treating bivalves, including boiling water immersion, steaming, and dry heat. High-temperature water immersion or blanching (at 85 °C for 2 minutes) has been used for green mussels pre-treated with natural acids (Arcales *et al.*, 2018, 2019) [21]. One kilogram of cleaned and unopened green mussels was placed in net bags for steaming, with one set of mussels for each treatment. A Hot Shot Electric Heater (MB-6) was used for steaming, and the temperature was monitored using a test thermometer. The mussels were steamed at 80 degrees Celsius for 6 minutes. After steaming, the green mussels were promptly placed in polyethylene (PE) bags and immersed in an ice bath (in less than a minute) to halt the prolonged heating process (Leonilo *et al.* 2021).

c. Canning

Mussel meat has been found to deliver itself well for canning. The purged mussel is either heated in open tanks or steamed in an autoclave, and the meat is shucked out. The shucked meat is washed in water and whitened in a 5% bubbling saline solution for 5 minutes. Whitened meat is stuffed in jars loaded with either hot salt water or oil, depleted, sealed and heat processed, followed by cooling. This method has yielded products with excellent organoleptic and preservation characteristics (Balachandran *et al.*, 1975) [22].

In South India, the mussel is available far from the canning industries, which critically includes a transportation component. Conventionally, transporting live mussels includes the heft of shell, thus constituting shell waste, hence adding to the expense. Few examinations have been embraced on the timeframe of realistic usability of mussel, entire or meat, and transportation of entire mussel and meat in ice under various circumstances eventually to be utilized for canning. These investigations have demonstrated that canned products arranged out of entire mussels or newly shucked meat yielded canned products with great organoleptic characteristics when chilled and put away for upto two days. These products are recommended for their ability to enhance the variety, flavor, and overall palatability of the meat when compared to canned meat that is prepared from relatively chilled, stored, boiled, and shucked meat, as described by Balachandran and Prabhu in 1980.

Canning in tin-free steel cans

In the past, tin cans were commonly used for preserving fish products. However, these tin containers had several disadvantages, including high costs, the need for special coatings to prevent rusting, a tendency to impart a metallic taste to the food, and difficulties in opening them. A recent innovation in rigid containers involves the use of polymer-coated tin-free steel cans with easy-to-open lids, which effectively address many of the issues associated with traditional metal cans. The suitability of these polymer-coated tin-free steel cans for canning fish and preparing ready-to-eat squid masala was examined (as docu-

mented in studies by Mallick *et al.* in 2006 and Gopinath *et al.* in 2007) [23]. These versatile containers can also be used for packaging various mussel-based ready-to-serve products, offering improved convenience and quality in food preservation

d) Freezing

There is a limited amount of research available on the freezing of mussel meat. One study by Chinnamma George, 1974 [24] investigated the storage characteristics of frozen mussel meat. It was found that mussel meat, which had been chilled and then frozen for 8 days, remained in acceptable condition for up to 15 weeks, whereas freshly frozen mussel meat remained in satisfactory condition for a longer period. This suggests that the freshness and quality of frozen mussel meat can vary depending on the storage conditions and processing methods used.

e) Dried mussel meat

The most cost-effective method for preserving mussel meat involves achieving a stable product within a reasonable timeframe, and this is achieved through the process of drying. To accomplish this, mussel meat that has been removed from freshly harvested mussels and blanched in a 5% brine solution for 5 minutes is dried by spreading it on a plate, either exposed to sunlight or in an artificial drying apparatus, until the moisture content reaches 10% or lower. After allowing the moisture to equilibrate by storing the dried product in a sealed container for a brief period, it can be efficiently packaged and distributed. The estimated shelf life of this dried mussel meat is six months. Upon reconstitution in water for 30 minutes, it can be used in various culinary preparations as if it were fresh meat (Anon, 1980) [25]. Smoked dried mussel meat

Lightly smoked and dried mussel meat is a product appealing to buyers and is currently in demand from international markets. The preparation process involves drying blanched mussel meat in the sun or using an artificial dryer for one hour until the moisture level reaches 40-45%. Then, the meat is smoked in a furnace for 30 minutes and further dried until the moisture level is reduced to 10% or lower. Once the dried mussel meat has stabilized in terms of moisture content, it can be packaged for distribution. Lightly smoked and dried mussel meat tastes better than heavily smoked varieties, so shorter periods of cold smoking are preferable. To generate smoke, coconut husks and sawdust can be used as a source (Muraleedhara *et al.*, 1979) [26].

f) Marinated mussel meat

A cost-effective innovation gaining popularity in international markets is the marination of mussel meat. The process, originating from the U.K., involves several steps. First, live mussels are briefly immersed in boiling saltwater for 4-6 minutes, the duration depending on their size. After shucking, the mussel meat is soaked in a mild brine solution with 2-3% salt content for 2-3 hours. Subsequently, the meat is drained and packed into containers, typically glass jars, and submerged in vinegar containing 4-6% acetic acid. It's worth noting that the vinegar used for marinating mussels is often flavored before application (Balachandran *et al.*, 1980) [3].

Other applications

a)

Medicinal Uses of *Perna viridis*

Perna viridis is known to have demonstrated antiviral properties against flu, herpes, and hepatitis strains (Patent No, RU 2043109). Additionally, it has shown potential anti-HIV activity in vitro. There is also evidence suggesting its effectiveness in treating inflammatory joint diseases (Miller *et al.*, 1993) [27].

b. *Perna viridis* as a Building Material

Traditional concrete production relies on calcium carbonate materials like limestone, marl, or chalk (Mohamed *et al.*, 2012) [28]. However, the cement industry's growth has led to environmental issues such as

deforestation, resource depletion, pollution, and air contamination (Peter *et al.*, 2008; Dennis *et al.*, 2009) [30, 29]. To address these concerns and reduce carbon emissions, the adoption of green construction practices has become crucial (McCraven, 2013) [31]. Finding alternatives to improve or maintain concrete properties while reducing production costs is highly beneficial. Materials like oil palm shell and glass are widely used in construction as additives to replace cement and reduce costs. Interestingly, mussel shells, composed of over 90% calcium carbonate, have been explored as a potential construction material in Malaysia (Kocaman *et al.*, 2016; Hamester *et al.*, 2012) [33, 32].

***Perna viridis* - a bioindicator of heavy metal accumulation**

The accumulation of heavy metals in mussel tissue can pose health risks when consumed over time. Heavy metals, harmful to the human body, can be carcinogenic if ingested (Yona *et al.*, 2021; Buddo *et al.*, 2012) [35, 34]. Asian green mussels are a popular local food source but can threaten public health due to heavy metal accumulation. Therefore, studying the concentration of heavy metals in green mussel tissue in coastal areas is crucial, with numerous studies highlighting the role of green mussels as seawater bioindicators and the associated health risks of consuming mussels contaminated with heavy metals. Research in this area is actively conducted in Indonesia (Saleh *et al.*, 2021) [36].

Future prospectus

a. High hydrostatic pressure processing (HHP) innovation has found applications in various food product categories such as meat, dairy, seafood, fruits, vegetables, and beverages. In this method, food sealed in flexible packaging is subjected to pressures ranging from 100 to 700 megapascals (MPa) for a specific duration, depending on the intended purpose and equipment capacity (Cheftel, 1995; Farkas *et al.*, 2000) [37, 38]. The process occurs within a sealed chamber filled with a pressure-transmitting fluid, often water, to eliminate all air. Once the desired pressure is achieved, it is maintained for the set time, and at the end of this cycle, the chamber is depressurized. This HHP treatment minimizes the risk of contamination between different food items during processing and is relatively resilient to operational errors, reducing the chances of spoilage (Pereira *et al.*, 2010) [39].

b. Microwave-Assisted Induction Heating (MAIH) Technology

The microwave-assisted induction heating (MAIH) method—an emerging thermal technique—was studied to heat the pre-packaged raw hard meat (Lee *et al.*, 2021) [40]. The cooking effects on microbial and physiochemical qualities of bivalve meat were investigated. After the heating of the meat samples, the aerobic plate count (APC), psychrotrophic bacteria count (PBC), and total volatile basic nitrogen (TVBN) levels decreased with increasing heating time. However, the shucking ratio, area shrinkage, and texture (hardness, cohesiveness, and chewiness) increased. In addition, the meat samples' L* (lightness) and W (whiteness) increased significantly at the beginning of the heating period, whereas they decreased significantly with extended heating time. However, a* (redness) had the opposite trend. This study found that when meat was heated for more than 120 seconds at 130 °C or 150 s at 90 °C, it displayed apparent shrinking and a yellow-brown appearance, indicating overcooking. After heating by MAIH for at least 110 s at 130 °C or 130 s at 90 °C, the samples were cooked well and gained a complete shucking, with no microbial count detected. Therefore, the results indicated that the optimum heating conditions for pre-packaged hard clams subjected to an MAIH machine were 130 °C for 110 s or 90 °C for 130 s. This method has already been used for processing clam meat (Lee *et al.*, 2021) [40].

c. Steaming

Steaming green mussels at different time and temperature combinations affects their physical and chemical properties. Steaming is an effective method for ensuring the safety of green mussels by reducing harmful bacteria like *E. coli*, *Salmonella spp.*, and *Vibrio spp.* without compromising their yield, shell opening, microbiological, or physical characteristics. While depuration or transferring is typically necessary in mussel processing, small-scale processing facilities in villages prefer steaming as a practical way to provide safe and minimally processed mussels before further cooking. Steaming plays a crucial role in mussel processing, unlike other methods that often require longer cooking times at higher temperatures, resulting in greater cooking losses (Leonilo *et al.*, 2021).

Conclusion

The present review explains the different processing methods of green mussels *Perna viridis*, which include freezing, marinating, canning and smoke drying. Since mussels are highly perishable, they must be processed as soon as they are collected from their sources (sea and oceans). This will help reduce the loss that may occur due to mussel spoilage. Secondly, the development of value-added products from mussels such as mussel noodles, mussel spread, mussel pickle etc will not only avoid spoilage but will also increase the interest of consumers to have mussels in different forms, which indirectly improves the economy of a country.

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Conflict of interest

There is no conflict of interest among the authors.

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