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A REVIEW OF THE NUTRITIONAL SIGNIFICANCE OF EDIBLE SEA URCHIN GONADS: COMPOSITION, VARIABILITY AND IMPLICATIONS FOR AQUACULTURE

SITI 'AINNUR NAJIHAH MOHD YUSOP[1], SAIRATUL DAHLIANIS ISHAK[2]*, RAHMAN ROMLI[1], WEE CHEAH[3] AND AFIQ DURRANI MOHD FAHMI[1]*

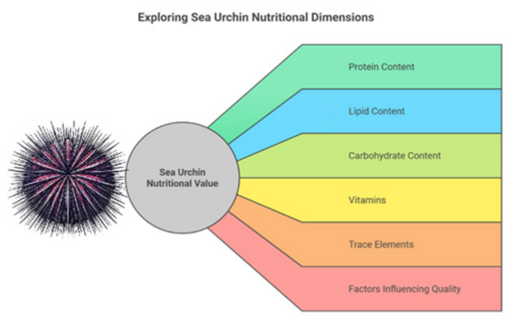
[1]*Faculty of Science and Marine Environment, Universiti Malaysia Terengganu, 21030 Kuala Nerus, Terengganu, Malaysia.* [2]*Higher Institution Centre for Excellence, Institute of Tropical Aquaculture and Fisheries, Universiti Malaysia Terengganu, 21030 Kuala Nerus, Terengganu, Malaysia.* [3]*Insitute of Ocean and Earth Sciences, Universiti Malaya, 50603 Kuala Lumpur, Wilayah Persekutuan Kuala Lumpur, Malaysia.*

**Corresponding authors: afiq.mohd@umt.edu.my; sairatul.ishak@umt.edu.my*

HIGHLIGHTS

- Edible sea urchin gonads are rich in macronutrients and micronutrients.
- Gonad biochemical composition is influenced by diet quality and physiological activities, which affect taste, texture and market value.
- Other factors like seasonal variations, sex and genetic characteristics may impact development and nutrient storage capacities of sea urchins.
- High-quality diet can significantly enhance the gonadosomatic index (GSI), which increases gonad quality.

GRAPHICAL ABSTRACT



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ABSTRACT

Edible sea urchins are highly valued for their gonads, which are rich in essential macronutrients, micronutrients and trace elements. These gonads offer significant dietary benefits, including antioxidant properties and essential amino acids that support cardiovascular health and disease prevention. Key species are from the genus *Paracentrotus*, *Strongylocentrotus*, *Stomopneustes*, *Diadema*, and *Echinus*. Nutritional composition varies across species and is influenced by natural diet, physiological activity, sex, seasonal changes and environmental factors. Notably, nutrient accumulation will peak during the intermittent period between the northeast and southwest monsoons (September to November), which corresponds with their gametogenesis and storage in nutritive phagocytes phase. The literature has reported gonad contents in wet weight (per 100 g), which include protein, ranging from 9.3 g to 19.2 g; lipid from 0.7 g to 30.1 g; and, carbohydrate from 1.6 g to 13.0 g. In general, total saturated fatty acids, mono-unsaturated fatty acids and poly-unsaturated fatty acids range from 21.4% to 61.1%, 12.8% to 30.3%, and 15.9% to 42.6%, respectively. Sea urchin gonads also contain notable levels of vitamins (e.g., A and E) and trace elements (e.g., Fe, Mg, Zn). Sustainable aquaculture practices, such as optimised diet formulations and effective management, are essential for enhancing production and ensuring consistent quality. A deeper understanding of biological and ecological drivers of nutritional variability, along with exploration of genomic tools, will further improve aquaculture efficiency.

Introduction

Sea urchins are invertebrates with a hard, spiky shell (also known as tests). They are classified under the phylum Echinodermata and class Echinoidea, which is the same group as starfish, sea cucumbers, sea lilies and brittle stars (Rahim & Nurhasan, 2016). Sea urchins are harvested for their gonads, which are a delicacy because of their texture, colour, aroma and taste (Brown & Eddy, 2015). Sea urchin gonads contain valuable proteins, polysaccharides, lipids, vitamins and minerals. Meanwhile, their shell and spines are also high in protein, minerals, polysaccharides and pigment, which are used in traditional Chinese medicine (Sibiya *et al*., 2021).

The demand for sea urchins is mainly from Asia, especially Japan, which makes up about 90% of the total. . However, the popularity of sea urchins as a delicacy is increasing in Europe, as well as in North and South America (Sun & Chiang, 2015; Stefánsson *et al*., 2017). The global natural harvest of sea urchins reportedly peaked in 2014 at 42,978 tonnes, whereas its aquaculture production peaked in 2021 at 16,205 tonnes as shown in Figure 1 (FAO, 2025a; 2025b). The latest total natural harvest of sea urchins globally was reported at 30,815 tonnes in 2023. On the other hand, the total aquaculture production in the same year was at 8,150 tonnes, a significant drop compared with its peak in 2021.

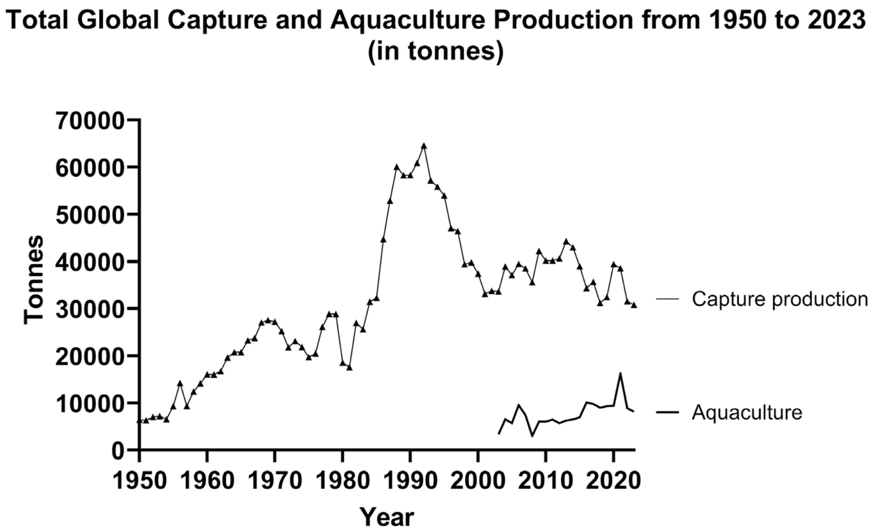

Figure 1: Total of global sea urchin natural harvest and aquaculture production from 1950 to 2023

Source: FAO (2025a; 2025b)

Fisheries are one of the main contributors of food security in low-income countries with large populations (Mathias & Anthony, 2020). Coastal cities have the opportunity to manage and integrate their economy with sustainable marine resources. Aquaculture of sea urchins may contribute to the sustainability of fisheries by reducing the depletion of natural stocks in the wild (Dautov *et al*., 2020). Industrial harvesting of sea urchins could also reduce their grazing impact on macroalgae, especially on kelp beds, as there have been a few reports of kelp beds and sea urchin barrens changing during the last four decades along temperate beaches across the world (Filbee-Dexter & Scheibling, 2014; Suarez *et al*., 2021). In addition, aquaculture may be used to enhance natural stocks with hatchery seed, ensure sustainable supply in the market and add value to present yields (Sun & Chiang, 2015).

Developing nations, such as Malaysia, have potential to sustainably supply sea urchins as a future resource for food security and community income to meet global demand. In Sabah, the locals harvest *Tripneustes gratilla* for food and income, but the numbers have declined (Parvez *et al*., 2016). Therefore, evaluating the nutritional value of sea urchins, along with the factors influencing their quality and nutrient yield, underscores the importance of sustainable management practices in fisheries. This review aims to assess the current knowledge on the nutritional value of sea urchins to identify key species harvested for their benefits, and analyse factors that influence their nutrient quality and yield, ultimately identifying knowledge gaps and potential future directions in incorporating sea urchins into the human diet for health and wellbeing.

Methodology

A systematic search was performed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines based on current knowledge, methods and gaps in existing research (Chen & Song, 2019). Literature search was performed in Scopus and the ISI Web of Science (WoS) Core collection because the two databases contained highly authentic materials that had been extensively peer-reviewed. Specific keywords were used based on study objectives, namely "sea urchin", "distribution", "nutritional values", "gonad", "status", "morphology", "aquaculture", "protein", "carbohydrates" and "diet". The search result was limited to two document types: research and review articles. A final total of 142 abstracts were read and documented, and all related data were organised and compiled using Microsoft Word and Excel. The data included the nutritive value and distribution of sea urchins. Nutritional values of edible sea urchins were extracted from research articles and compiled based on composition and methods used to extract macronutrients (carbohydrate, protei and lipid) and micronutrients (vitamins and minerals).

Biological Features

Sea urchins are benthic and spiky marine species that have existed for 500 million years (Sibiya *et al*., 2021). Classified under the phylum Echinodermata and class Echinoidea, they are related to starfish, sea cucumbers, sea lilies and brittle stars. Their features also include a wide range of colours like brown, black, purple, green, white and red (Rahim & Nurhasan 2016). They have a spherical body divided into five equal segments, with approximately 95% of their external surface covered in spines to assist in movement, provide passive defence, and help capture food particles (Radjab *et al*., 2023).

Between the spines, it has numerous tubular feet or podia with well-developed suckers that are employed for locomotion, food capture and substrate attachment. The mouth is a five-pointed jaw known as "Aristotle's Lantern" and is located at the ventral section of the body (Parvez *et al*., 2016). The peristomial membrane in sea urchins is surrounded by five pairs of external gills for oxygen uptake, whereas the podia helps in the exchange of gases between the internal and external environments (Harris & Eddy, 2015). Sea urchins can stay out of water up to 15 hours, partly as a result of intertidal adaptation (Bennett *et al*., 2024; Narvaez *et al*., 2024). Pictures of a live and cross-sectioned *Diadema setosum* sea urchin, including the gonads, are shown in Figure 2a-2c.

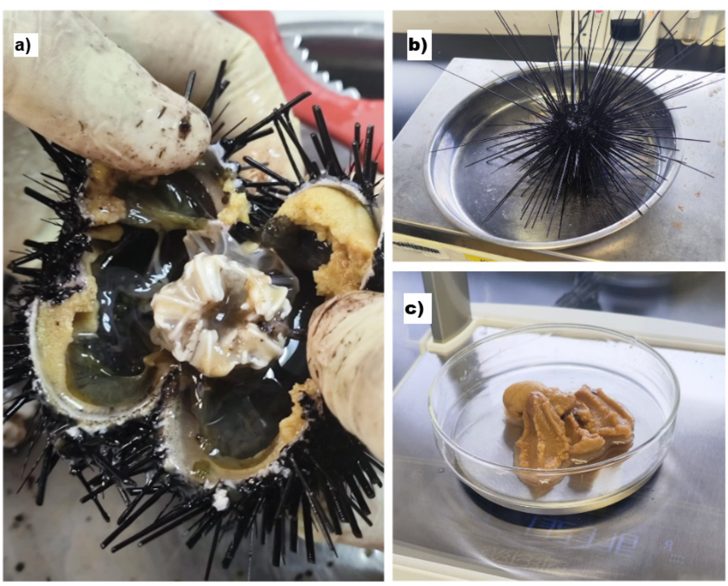

Figure 2: (a) The shell and internal organs of a cross-sectioned *Diadema setosum* sea urchin; (b) sharp spines protruding from the body of a freshly harvested sea urchin; and (c) the gonads which are a prized delicacy.

Sea urchins primarily feed on kelp and algae, but they can also be omnivorous scavengers that eat other marine animals found on the seafloor, indicating a lack of specific feeding preference (Lawrence *et al*., 2007; Steneck, 2013). In enriched environments, its gut passage time is reduced to allow more food to pass through, which may take between eight to 48 hours to digest (Harris & Eddy, 2015). When conditions become scarce, the gut channels slow down and food digestion can be prolonged up to two weeks. The excrement of sea urchins eventually helps release nutrients back into the water column and plays a crucial role in the food chain (Mishra *et al*., 2015).

Furthermore, the digestive tract of sea urchins is home to a diverse range of microbes (Harris & Eddy, 2015). These microbes are thought to aid in the breakdown of macromolecules and help food digestion and assimilation. This allows for the utilisation of dissolved organic materials and provides important metabolites to the host.

Most sea urchins are broadcast spawners. They discharge their eggs and sperm into the water column and fertilisation takes place in vitro. Species and environmental factors, such as temperature and food availability, will determine larval stage length. Harris and Eddy (2015) reported the growth of *S. droebachiensis* from fertilised egg to first pluteus stage could be augmented in warmer temperatures. They observed that it took one month when water temperature was at 0°C, 12 days at 8°C, and six days only at 12°C.

Ecology and Behaviour

Sea urchin is a marine calcifying organism that has significant impact on the populations of marine plants in primary production, algal abundance and scleractinian coral recruitment (Luza *et al*., 2019). Ristanto *et al*. (2018), reported sea urchins adapting and living in sea depths of 0.5 m to 20 m, as long as there was the presence of light for photosynthesis to occur in seagrass and algae. When their populations become large, they may radically change the character and structure of their surrounding ecosystem and trigger catastrophic overgrazing occurrences in algal or sea grass populations. Like their starfish cousins, they can also destroy coral reefs and sea sponges when they colonise the rocky structures in large numbers (Pinna *et al*., 2006; Calderón *et al*., 2007; Harris & Eddy, 2015; Hasan, 2019; Marčeta *et al*., 2020).

Sea urchins also have the ability to withstand significant changes in food source for centuries (Miller *et al*., 2021). Some of the species could survive starvation for long periods by breaking down their own tissues and all metabolisms related to growth and reproduction. Sea urchins are generally nocturnal, hiding in rocky clefts during the day and grazing outside of shelters at night to avoid predators. However, they might end up being eaten by nocturnal predators such as lobsters (Parnell *et al*., 2017).

Over time, sea urchins have developed a variety of unique behaviours, including those known as "covering", "dressing" and "heaping". They involve using their spines and tube feet to attach debris to their dorsal surface, behaviour observed in both shallow and deep-water habitats (Ziegenhorn, 2017). In shallow waters, sea urchins often use shells, rocks, seagrass and drifted algae as covering materials, which they secure using their tube feet. In deeper waters, debris such as shell fragments, bryozoan colonies and pteropod skeletons are commonly used (Pawson & Pawson, 2013). This behaviour serves multiple purposes, including protection from harmful ultraviolet radiation, mechanical defence against predators, maintenance of evolutionary relationships and adaptation to climatic conditions (Ziegenhorn, 2017).

Brothers and McClintock (2015) showed that rising temperatures could increase oxygen consumption, reduce metabolic rates and limit oxygen transport in sea urchin tissues, potentially impacting their behaviour. Sea urchins rely on chemosensory cues to detect predators. Chemicals released by predators can trigger various responses, including cryptic behaviour (hiding in crevices), associative behaviour (group formation), and dispersion behaviour (fleeing) (Zhadan & Vaschenko, 2019). Another important behaviour is "righting", where sea urchins use their tube feet to flip themselves upright, ensuring their aboral side faces upward, which is crucial for avoiding predators, surviving wave displacement and enduring physical disturbances (Wei *et al*., 2016).

Global Distribution

According to the Ocean Biogeographic Information System (OBIS), there are 858 identified species of sea urchins with 292,790 occurrences around the world (OBIS, 2025). More than 40% of sea urchins are found in subtropical regions at temperatures ranging from 10°C to 15°C. and over 50% are found in waters where salinity ranges from 30 to 35 PSU. Sea urchins may also be found in shallow waters with more than 30% living in depths of below 20 m as illustrated in Figure 3. Sea urchins are harvested in the seas of North America, South America, Asia (especially Japan) and even in the freezing Arctic and Antarctic Oceans.

Sea urchins inhabit areas of primary productivity, such as kelp forests in temperate regions and seagrass beds in subtropical and tropical regions. For instance, *S. nudus* inhabits intertidal and subtidal rocky substrates, with its distribution extending from Dalian, China, to Primorsky Krai in Russia, and along the Pacific coast of Japan from Sagami Bay to Hokkaido (Rahman *et al*., 2014). However, they have a diverse life-history trait, such as growth, maturity and longevity, depending on how they live in the habitat (Rahman *et al*., 2014). Research conducted in West Sumatra, Indonesia, by Ristanto *et al*. (2018) found habitat factors, such as substrate and feed availability, could influence the population size of sea urchin colonies.

Market and Demand

As the demand for fish and other marine products expand due to increasing global population and product interest, sea urchins are well-recognised subjects of study in biology, ecology, biodiversity, evolution, aquaculture and conservation (Rahman *et al*., 2015a). They are widely recognised as a main ingredient in food production, with their gonads processed into a delicacy commonly referred to as "sea urchin roe" or "uni", which may fetch a lucrative income for fishermen (Rahman *et al*., 2015b). With its slimy texture and distinctive sweet-salty flavour, sea urchins are highly valued despite its unappealing appearance (Sun & Chiang, 2015).

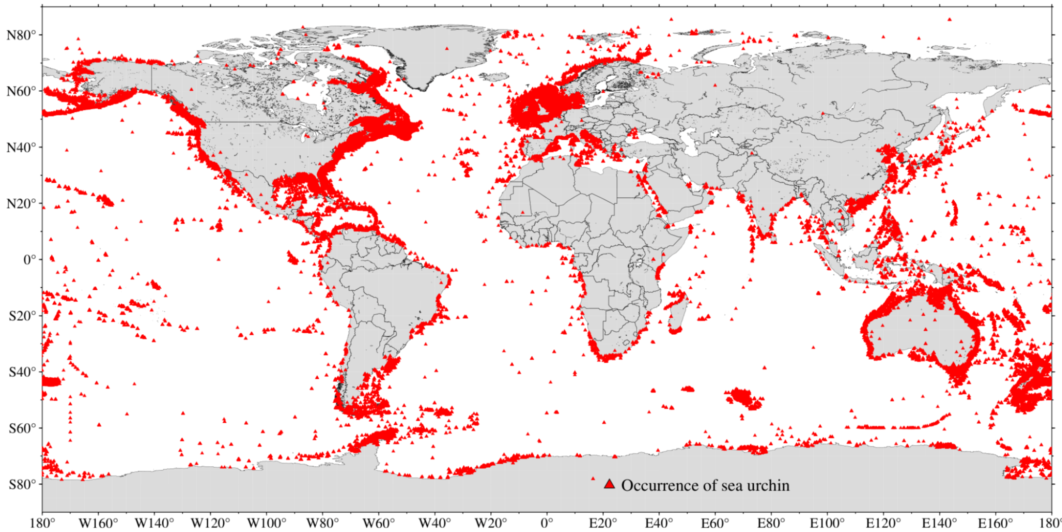

Figure 3: Global distribution of sea urchins based on data retrieved from Ocean Biogeographic Information System (OBIS) on April 9, 2025 (https://obis.org/)

In the United States, high-quality roe products from the red sea urchin (*Strongylocentrotus franciscanus*) and green sea urchin (*S. droebachiensis*) are exported to Japan, Taiwan, Hong Kong and Singapore (Sun & Chiang, 2015). *Paracentrotus lividus*, commonly known as the purple sea urchin, is the most widespread echinoid species in Europe, inhabiting the northerm Mediterranean Sea to the eastern Atlantic coastline. Their populations can be found from Scotland down to southern Morocco, as well as the Canary and Madeira Islands (Fernández-Boán *et al*., 2012; Machado *et al*., 2021). Scotland has a substantial population of edible sea urchins like *Echinus esculentus* and *Paracentrotus miliaris*. In Norway, there is *S. droebachiensis*, but its roe yield is very low or too variable for sustainable production.

In Asia, there are approximately 100 different types of sea urchins, but six only are harvested for food (Stefánsson *et al*., 2017). According to Jinadasa *et al*. (2016), the three countries that consumed the most sea urchins are Japan (*S. intermedius* and *S. nudus*), Chile (*Loxechinus albus*) and the United States (*S. franciscanus* and *S. droebachiensis*). Sea urchins are luxury gourmet items in the Japanese market (Prato *et al*., 2018). The Japanese use the gonads fresh to make sushi and sashimi, or preserve them in brine (Siikavuopio *et al*., 2006).

Sea urchin gonads are one of the most expensive marine food items, with wholesale prices exceeding US$100/kg in 2012 (Williamson & Steinberg, 2012). *M. nudus* is the most expensive as the wholesale price for servings on hardwood trays containing 250 g to 300 g can exceed 100,000 yen (US$1,000) (Takagi *et al*., 2020). However, sea urchins are not frequently eaten in Malaysia. The country has 12 verified tropical species that live on coral reefs (Ristanto *et al*., 2018). Of the total, Mok *et al*. (2023) reported that 10 species could be found in Peninsular Malaysia waters. In Sabah, the Bajau Laut communities will serve sea urchin roe with rice on special occasions, such as the "lepa-lepa festival", weddings and other festive events (Parvez *et al*., 2016).

In Japan, the strong demand for sea urchin roe has resulted in a well-established fisheries and resource management system. Other sea urchin species in Japan, aside from *S. intermedius* and *S.nudus*, are *Strongylocentrotus pulcherrimus, Anthocidaris crassispina, Pseudocentrotus depressus* and *Tripneustes gratilla* (Unuma *et al*., 2015). There are 24 species reported in India, with *Salmacis virgulata* and *Temnopleurusto reumaticus* being widespread near the southeast coast (Sibiya *et al*., 2021).

Benefits for humans

Sea urchins play an important role in human nutrition and health. Their gonads are classified as "healthy" food due to rich nutrients. For example, their polyunsaturated fatty acids (PUFAs), particularly eicosapentaenoic (EPA, 20:5ω-3) and docosahexaenoic (DHA, 22:6ω-3) acids, have been shown to reduce the risk of arrhythmia, cardiovascular disease and cancer (Banaszak *et al*., 2024). According to Pozharitskaya *et al*. (2015), sea urchins have potential to serve as a functional dietary additive to treat inflammatory disorders and diabetes. Studies have also showed that polyhydroxylated naphthoquinone pigments and minerals from *S. droebachiensis* can lower blood glucose levels and enhance hepatic phospholipid synthesis in mice with streptozotocin–nicotinamide-induced Type 2 diabetes. Meanwhile, Matsuno and Tsushima (2001) reported that β-carotene and xanthophylls in sea urchin roes contained high levels of pro-vitamin A and may be utilised to reduce tumour formation and eye pain. Ascorbic acid (vitamin C) and vitamin A are regarded as vital antioxidants for human health because they aid in the formation of essential immune responses, tissue repair, allergic reaction reduction and connective tissue component development (Chambial *et al*., 2013).

Sea urchins have been studied as a source of bioactive chemicals with biomedical uses. According to Sibiya *et al*. (2021), glycosides, acid polysaccharide, sphingoid, glycolipids, sulphate, polysaccharides and phospholipids are some of the bioactive substances present in sea urchin extracts and hydrolysates. These bioactive molecules play a vital role in anti-microbial, anti-cancer, anti-inflammatory and anti-oxidant reactions within the body. Besides, sea urchin gonads are also an important ingredient to make tonics and asphrodisiacs (Rahman *et al*., 2015b). Apart from that, dry calcareous test of sea urchins has also been used in traditional Chinese medicine since ancient times (Sibiya *et al*., 2021).

This invertebrate is also used as a model organism for developmental biology research in a controlled setting. Many studies have used larval sea urchins as biomarkers to assess the environment (Mishra *et al*., 2015). Similarly, research utilising sea urchins have been conducted for assessing microplastics (Sevillano-González *et al*., 2021), ocean acidification (DeMiguel-Jiménez *et al*., 2021) and sunscreens (Cunningham *et al*., 2020). Lastly, the purple urchin *S. purpuratus* has been demonstrated as a model organism to teach cell division and embryonic development (Brown & Eddy, 2015).

Nutritive Value

Sea urchins are a great source of lipids, carbohydrates, proteins and vitamins (Takagi *et al*., 2020). Rocha *et al*. (2019) reported that the protein and lipid content in 100 g of sea urchin gonads was comparable to 100 g fillet of gilthead seabream *(Sparus aurata*), which had roughly 19 g to 20 g of protein and 5 g to 9 g of lipid. However, Archana and Babu (2016) reported that 100 g of *Temnopleurus toreumaticus* sea urchin contained 128 calories, 12 g of protein and around 3 g of fat, while 100 g of *S. variolaris* and *P. lividus* could provide 122.04 kcal and 107.81 kcal of energy, respectively. Proteins and carbohydrates are both substantial components of sea urchin gonads and hence, supply the critical nutrients for their reproduction (Hammer *et al*., 2006). Despite the fact that palatability and non-toxicity are the most important considerations for edibility, the biochemical profile of sea urchin roe has an influence on food perception as well. The flavour, colour, texture and hardness of gonads are determined by their biochemical content (Lawrence *et al*., 2007). The amount of these vital components differs widely among species and is affected by their natural food and physiological activities (Rahman *et al*., 2014).

Protein

Protein is the main macronutrient in sea urchins and because of their delectable roe, they have become a significant source of protein in some countries like Japan (Takagi *et al*., 2020). Dietary protein provides essential amino acids that function as building blocks of proteins, ensuring optimal growth, development and health (Dincer & Cakli, 2007). The highest protein content is found in *E.chloroticus* at 19.2 g/100 g of wet weight, followed by *A. crassispina* (18.8 g), *S. variolaris* (18.81%) and *D.setosum* (18.7 g) (Table 1). However, most of studies used different methods to measure the nutritive value in sea urchins, which makes it difficult to directly compare the results.

Table 1: Protein composition in edible sea urchin gonads

Species	Value Wet weight (Per 100 g)	Method	References
Diadema setosum	11.03	Kjeldahl	Salma *et al*. (2016)
Strongylocentrotus intermedius	13.9 ± 1.1		Matveeva *et al*. (2021)
Strongylocentrotus nudus	13.8 ± 0.7		Matveeva *et al*. (2021)
Stomopneustes variolaris	12.1 ± 0.4		Archana and Babu (2016)
	11.2 ± 0.2 - 18.8 ± 2.1		de Zoysa (2014)
Paracentrotus lividus	9.3 ± 1.5 - 11.8 ± 0.2		Dincer and Cakli (2007)
	12.03 ± 1.26		Archana and Babu (2016)
Anthocidaris crassispina	18.8	Protein-dye binding (Bradford assay)	Chen *et al*. (2010)
Diadema setosum	18.7		Chen *et al*. (2010)
Salmacis sphaeroides	12.8		Chen *et al*. (2010)
Evechinus chloroticus	19.2	Lowry	Phillips *et al*. (2010)

Furthermore, amino acids are a crucial structural nutritional component in sea urchin diet since they are required for upkeep, development and reproduction (Lourenço *et al*., 2019). Sea urchin gonads are a good source of Essential Amino Acids (EAA) and the composition of EAA influences gonad flavour profile. The sweetness of sea urchins is attributed to the glycine and alanine content, whereas bitterness is from valine, and umami is from glutamine (Archana & Babu, 2016). *S. variolaris*, *S. intermedius*, and *S. nudus* gonads were analysed for their amino acid composition and it was reported that these three species had the range of 32.1% to 42.9% EAA and 55.3% to 67.2% non-EAA (Matveeva *et al*., 2021).

Lipid

Lipids include phospholipid, triacylglycerol, diacylglycerols, monoacylglycerols, free fatty acids and cholesterol (Zhou *et al*., 2018). Sea urchins obtain energy by oxidising fatty acids produced from phosphatidylcholine or triglycerides, which are essential for larval development, spermatozoa motility and fecundity (Martínez-Pita *et al*., 2010). The highest lipid values are found in *A. crassispina* (30.0 g per 100 g in wet weight), *E. chloroticus* (20.0 g), and *S. sphaeroides* (13.6 g) using Folch method extraction (Table 2). This suggests that the Folch method is generally superior to the Bligh and Dyer method; however, further investigation is required, as species differences could potentially influence this outcome.

Table 2: Lipid composition in edible sea urchin gonads

Species	Value Wet Weight (per 100 g)	Method	References
Strongylocentrotus intermedius	7.3 ± 1.2	Bligh and Dyer	Matveeva *et al*. (2021)
Strongylocentrotus nudus	6.3 ± 1.5	Bligh and Dyer	Matveeva *et al*. (2021)
Strongylocentrotus droebachiensis	0.7 - 9.2	Folch method	Kelly *et al*. (2008)
Stomopneustes variolaris	4.98 ± 0.3	Bligh and Dyer	Archana and Babu (2016)
	7.4 ± 0.2 - 9.3 ± 0.6	Bligh and Dyer	de Zoysa (2014)
Paracentrotus lividus	2.4 ± 1.1 - 4.3 ± 0.5	Bligh and Dyer	Dincer and Cakli (2007)
	3.05 ± 0.5	Bligh and Dyer	Archana and Babu (2016)
Anthocidaris crassispina	30.1	Folch method	Chen *et al*. (2010)
Salmacis sphaeroides	13.6	Folch method	Chen *et al*. (2010)
Evechinus chloroticus	20.0	Folch method	Phillips *et al*. (2010)
Tripneustes gratilla	4.41 ± 0.03	Bligh and Dyer	Hoa *et al*. (2018)

Moreover, essential fatty acids are crucial as it can also affect flavour profile and storage time. Table 3 shows fatty acids composition in edible sea urchin gonads. *S. variolaris* has high values of saturated fatty acids (SFA) at 61.1% while *S. nudus* has high value of Monounsaturated Fatty Acids (MUFA) at 30.3%. *Arbacia lixula,* however, has high PUFA levels at 42.6%. Archana and Babu (2016) reported significant amount of omega-3 PUFA such as EPA and DHA in *S. variolaris* gonads. Additionally, lipid-soluble yellow and red pigments of carotenoids found in micro- and macro-algae may contribute to the coloration of sea urchin gonads (Liyana-Pathirana, 2002). Ultimately, the nutritional value of fatty acids is contingent upon the diet of the sea urchins.

Table 3: Fatty acids composition in edible sea urchin gonads

Species	Fatty Acid (FA) Component	Value Percentage (%)	References
Stomopneustes variolaris	Saturated	61.1 ± 1.0	Archana and Babu (2016)
	Mono-unsaturated	16.9 ± 0.8	
	Poly-unsaturated	22.0 ± 2.2	

Stomopneustes nudus	Saturated	30.9	Matveeva *et al*. (2021)
	Mono-unsaturated	30.3	
	Poly-unsaturated	33.6	
Stomopneustes intermedius	Saturated	28.5	
	Mono-unsaturated	26.1	
	Poly-unsaturated	39.9	
Strongylocentrotus droebachiensis	Saturated	21.4 ± 0.5 - 26.8 ± 0.6	Kelly *et al*. (2008)
	Mono-unsaturated	12.8 ± 0.5 - 16.6 ± 0.6	
	Poly-unsaturated	15.9 ± 0.6 - 20.4 ± 1.3	
Tripneustes gratilla	Saturated	41.7	Hoa *et al*. (2018)
	Mono-unsaturated	26.5	
	Poly-unsaturated	31.1	
Paracentrotus lividus	Saturated	31.3 ± 0.4	Martínez-Pita *et al*. (2010)
	Mono-unsaturated	21.6 ± 0.2	
	Poly-unsaturated	38.0 ± 0.4	
Arbacia lixula	Saturated	27.9 ± 0.3	
	Mono-unsaturated	19.6 ± 0.3	
	Poly-unsaturated	42.6 ± 0.5	

Carbohydrates

In general, sea urchins have high protein content and are low in calories, fat and carbohydrates as in most marine fauna. Using the phenol-sulphuric acid method, the highest carbohydrate content can be seen in *A. crassispina* (13.0 g per 100 g wet weight) and *S. sphaeroides* (12.8 g) (Table 4).

Table 4: Carbohydrate composition in edible sea urchin gonads

Species	Value Wet weight (Per 100 g)	Method	References
Stomopneustes intermedius	3.5 ± 0.7	High-performance liquid chromatography	Matveeva *et al*. (2021)
Stomopneustes nudus	2.1 ± 0.4		
Stomopneustes variolaris	1.6 ± 0.18	Anthrone-sulphuric acid method	Archana and Babu (2016)
	2.9 ± 2.2 - 7.6 ± 0.4	Calculation difference	de Zoysa (2014)
Paracentrotus lividus	3.02 ± 0.12	Anthrone-sulphuric acid method	Archana and Babu (2016)
	2.0 ± 0.3 - 2.5 ± 0.1	Calculation difference	Dincer and Cakli (2007)

Anthocidaris crassispina	13.0		
Salmacis sphaeroides	12.8	Phenol–sulphuric acid	Chen *et al*. (2010)
Diadema setosum	6.9		

Vitamins and Minerals

The gonads of sea urchin are high in vitamins C, E, A and β-carotene (Jinadasa *et al*., 2016). It is reported that sea urchin gonad contains vitamin A, vitamin B1 (thiamine), vitamin B2 (riboflavin), vitamin B3 (niacin), calcium, magnesium, iron, zinc, selenium, germanium, strontium, copper, manganese, molybdenum (Sibiya *et al*., 2021). Vitamin E concentrations in *D. setosum* gonads were 23.47 mg and vitamin A at 1.79 mg per 100 g, with trace minerals of magnesium at 1.9 mg per 100 g, iron at 0.96 mg per 100 g and Zinc at 0.02 mg per 100 g (Salma *et al*., 2016). Vitamins A and E in sea urchins may aid in homeostasis, immunity support, cellular balance and oxidative damage defence (Salma *et al*., 2016). Minerals are required for various metabolisms, for example, sea urchins require iron as a cofactor, and zinc for wound healing and tissue repair after infection.

Factors Influencing Nutritive Values

Demand for sea urchin gonads is on the rise as a result of a growing market. Due to a decrease in wild fishery productivity in several impoverished areas, aquaculture is needed to boost efficiency in order to meet the growing demand for sea urchin products. Pace of development, size at maturity, and maximum test diameter of sea urchin all depends on food supply, nutritive value, and the hydrodynamics of the local environment (Jacinto *et al*., 2013). The colour of roe is determined by the quality and quantity of the diet's sea urchin and leads to higher gonadosomatic indices (Prato *et al*., 2018).

Diet

The quality and quantity of the gonads are dependent on the diet of sea urchin itself, as good gonad quality will lead to a higher Gonadosomatic Index (GSI) (Prato *et al*., 2018). According to Cyrus *et al*. (2015), high-quality diets help to increase the development rate and improve commercial success of the gonads. It is suggested that formulated feed is able to increase gonad development compared to natural food such as algae (Siikavuopio *et al*., 2006). Many sea urchin species, including *P. lividus, E. chloroticus*, *L. albus*, *P. miliaris*, *S. droebachiensis*, *S. pulcherrimus*, and *S. franciscanus* have been demonstrated to promote gonadal production with formulated diets as formulated feeds are an ideal diet that offers nutritional elements in a balanced method, bringing together in a single food all the necessary nutrients for commercially maximising gonad output (Senaratna *et al*., 2005; Prato *et al*., 2018). Proteins and lipids in formulated diets are the key in nutrition for an effective reproduction and survival. High protein content in formulated diets will result in high GSI (Walker *et al*., 2015). Sea urchins fed with high protein diets have high values of glycogen and amino acid concentration and lower triglyceride content compared with natural food (Phillips *et al*., 2010).

According to Lourenço *et al*. (2020), six diets with protein levels (20% to 46% dry matter from squid meal, fish gelatine, soybean, krill oil, etc. discovered that 30% dry matter of dietary protein with 7% lipids simultaneously induced high nutrient and encouraged the highest GSI. Furthermore, Zupo *et al*. (2019) reported protein content in *P. lividus* diets should be formulated up to 40% to 47% while maintaining low lipid levels (9%), in order to achieve the highest GSI. Besides, formulated diets contain a variety of protein (17%, 23% and 30%) and carbohydrate (42% and 50%) levels that were effective in increasing GSI, but those fed with 30% protein and 50% carbohydrate diet are effective to produce high GSI value in *S. purpuratus* (Cuesta-Gomez & Sanchez-Saavedra, 2018). Walker *et al*. (2015) reported that prepared feeds with excessive protein or imbalanced amino acid profiles might even result in large roes with undesirable colour and off-flavour.

Apart from formulated diets, algal feeds are the simplest and most cost-effective roe enhancement method known in the market. Although macroalgae are low in protein and calories and exhibit seasonal variation in nutritional content, they have been shown to improve roe colour quality (orange-yellow) due to the presence of carotenoid pigments (Eddy *et al*., 2012; Carboni *et al*., 2015; Brewster *et al*., 2018).

Sex

Sea urchin testes are much valued than ovaries for their sensory attributes: A sweet dairy flavour with strong aftertaste (Phillips *et al*., 2009). The study concluded that the flavour could be attributed to high amounts of β-carotene and echinenone found in male gonads. In contrast, female gonads are bitter and sour with metallic aftertaste. In mature ovaries, elevated levels of glutamate and glycine may contribute to the sweet and umami notes, whereas valine and methionine will enhance marine and sulphurous smell, and the sulphur-containing amino acid pulcherrimine is linked to bitterness (Murata *et al*., 2002). For example, *E. chloroticus* gonads have a bitter taste due to pulcherrimine, resulting in the gonads being labelled as low-quality and hindering their export to outside markets (Phillips *et al*., 2009).

Seasonal Variation

Sea urchins are harvested according to the season to obtain the best gonads in terms of taste, colour, texture, nutrition and safety, based on the level of contaminants. Rocha *et al*. (2019) observed that the nutritional quality of gonads would improve during the summer, peak in fall, and decline in winter until the following spring. They attributed this to the annual cycle of gonad development, specifically nutrient storage process and gametogenesis. During fall, gonad growth will peak as the sea urchins replenish their food reserves in nutritive phagocytes, which causes protein, lipid, and energy levels to accumulate in their body (Walker *et al*., 2013). Once these biochemical components are accumulated by phagocytes, they will be transferred to the gonads for developing gametes (eggs and sperm).

Gametogenesis occurs between winter and spring, which depletes the nutritional content in the sea urchins' gonads (Walker *et al*., 2013). During spring, lipids are the most effective energy source, but they are the least effective during winter. This is because food is plenty in summer but scarce in winter. Based on a Japanese study, 95% of subjects who tasted the ovaries of mature female green sea urchins *H. pulcherrimus* harvested in autumn and winter reported a bitter taste, whereas the testes never had bitter taste when harvested in any of the four seasons (Murata *et al*., 2002). According to Liyana-Pathirana (2002), *S. droebachiensis* would eat less in winter and more in spring and summer. Meanwhile, *D. setosum* is harvested based on the lunar cycle as this species will spawn during the full moon (Pearse, 1975). In Malaysia, according to Muthiga (2005), the best time to harvest *T. gratilla* is between the end of the northeast monsoon in March and in June, when the southwest monsoon begins.

Disease

Sea urchin disease can occur both in wild and cultured populations. Several types of infection have been discovered and they could affect the nutritive value of sea urchins. Their pathogens may range from bacteria to decapods parasites. Diseases have mostly been observed in 30 sea urchin genera, including *Diadema*, *Strongylocentrotus*, *Echinus*, *Psammechinus*, *Arbacia*, *Paracentrotus*, *Cidaris*, *Lytechinus*, *Heterocentrotus*, *Temnopleurus*, *Tripneustes*, *Hemicentrotus*, *Holopneustes*, *Pseudocentrotus*, *Echinothrix*, *Heliocidaris* and *Coenocentrotus* (Wang *et al.,* 2013; Feehan & Scheibling, 2014).

Bald illness is a well-known contagious disease caused by bacteria that affects sea urchins in the Mediterranean sea and North American coastline. In Japan, there are two common bacterial diseases known as Togenukesho and spotting disease (Wang *et al*., 2013; Federico *et al*., 2023; Shaw *et al*., 2024). These diseases infect juveniles and small sea urchins and may cause great economic losses. Meanwhile in China, black mouth disease is reported due to increase in production of hydrogen peroxide (H_2O_2), and bacteria proliferation increases the consumption of catalase (CAT) superoxide dismutase (SOD) (Tian *et al*., 2024).

Chilled Storage Period

It is necessary to have proper technology to store sea urchin roe and prevent them from degrading too fast. Matveeva *et al*. (2021) proved that salting or freezing could damage the structure and consistency of sea urchin gonads. The flavour and colour may also change due to high level of enzyme activity, such as proteolysis, lipid hydrolysis and oxidation of glycogen, phosphocreatine and ATP. In the meantime, the nutritive values could also change. Phillips *et al*. (2009) reported after 10 days of refrigerated storage, the freshness and sweet dairy flavour of sea urchin testes decreased significantly while marine odour increased, indicating decomposition. However, in the case of ovaries, storage will also cause a decrease in the unpalatable sulphur and metallic flavours without compromising other tastes. No detrimental flavour was described other than the loss of qualities associated with freshness.

Genetic

Bulking is a method of increasing gonad output in sea urchin aquaculture by increasing their gonad sensory qualities and manipulating their reproductive cycle (Walker *et al*., 2015). However, a lack of genomic resources has influenced sea urchin aquaculture, with minor instances of triploids being produced to boost roe size by suppressing gametogenesis and increasing nutritional phagocyte production (Machado *et al*., 2022). Studying genetic resources not only assists in better understanding of sea urchin keystone species, but also has a substantial influence on aquaculture. Few studies have been conducted on protein patterns in male and female gonads at various stages of development (Ghisaura *et al*., 2016) and the expression in pollution indicators after metal exposure (Di Natale *et al*., 2019). Besides, Machado *et al*. (2022) had analysed male and female gonads using the transcriptome method, which provided the groundwork for future research into gonad development, sex differentiation, growth, and lipid and colour features.

Conclusions

The accumulation of micronutrients and macronutrients is directly influenced by the organism's living environment, the type of food available and the conditions necessary for the organism to continue its life cycle. This review also finds the need to standardise methods of measuring the nutrient value. In addition, the number of studies on the nutritive value of edible sea urchins is not as extensive as other commercial species. Sea urchin gonads have high levels of macronutrients (protein, carbohydrates, lipid), vitamins (A and E) and trace elements (Fe, Mg and Zn), all of which are influenced by biological and ecological factors. Therefore, sea urchin gonads can be promoted as a nutritive food source. Nevertheless, more research regarding the nutritive value of edible sea urchin is needed to understand the factors that influence its yield and quality.

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Conflict of interest

The authors declare that they have no conflict of interest.

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