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The Contributions of Shellfish Aquaculture to Global Food Security: Assessing Its Characteristics From a Future Food Perspective

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The United Nation's 2030 development agenda adopted in 2015 outlines 17 Sustainable Development Goals (SDGs), and the organization has continued to put food security in the center of its vocalization. Aquaculture is currently the fastest-growing food production sector globally and a sustainable option for attaining food security. Food as a basic necessity for man's survival is always a timely issue. Hence, owing to aquaculture's unique role, it is expected that the demand for aquatic products (especially seafood) will continue to increase due to geometric population growth. Many seafood products are among the critical protein sources in the world. This is partly because they have micronutrients and essential fatty acids that are not present in land-based protein sources. According to the Food and Agriculture Organization, shellfish is one of the main cultured aquaculture groups in the world. Hence, the development of shellfish aquaculture has an important role in sustainable food supply and food security. In this article, an overview of the current and projected contributions of shellfish aquaculture to global food security is presented. Apparently, shellfish aquaculture in the next few decades will have to be intensified to bridge the gap between demand and supply in a cost-effective manner. Also, food waste would have to be reduced and natural resources should be used more efficiently to minimize the negative impacts on aquaculture on the environment.

Keywords: aquaculture, breeding, food security, future foods, shellfish, sustainability, sustainable development goals

INTRODUCTION: AQUACULTURE INDUSTRY

Per the United Nations' agenda for the 2030 sustainable development goal, the relationship between food production and population growth is a very critical issue of discussion. Future food debates have only recently emerged, with the global population projected at 10 billion by 2050, the bulk of whom will be residents in developing countries (5.6–7.9 billion). Food as a basic necessity for man's survival is one of the most popular topics in the last decades, as reflected by the number of publications recorded in the Web of Science database. As depicted in **Figure 1**, the number of food-related publications continuously increased from 2014 to 2019. This number is projected to increase, reaching 85,000 in 2024 alone, as shown by the time series forecast of the Auto Regressive Integrated Moving Average (ARIMA). Therefore, at the current publication rate, the total publication hits might reach 1.25 million by 2024 (**Figure 1**).

There is currently no "one size fits all" approach to meet the expected increase in the demands for food. However, short-term recommendations have been provided to ensure more sustainable food production for current and future human consumption, one of which is aquaculture. Aquaculture is popularly known as the fastest-growing food production sector globally. Hence, it could be exploited to provide sustainable food production in the future. Global seafood consumption (which includes finfish and shellfish), for instance, is growing faster at a mean annual rate of 3.1% (projection from 1961 to 2017) than the global population growth of 1.6% (within the same period). This growth rate is also higher than the growth rate of other livestock and animal production sectors at 2.1% per year (FAO, 2020). This might be because the fisheries and aquaculture sector creates more economic value through production, trade, and marketing (Cai et al., 2019). In addition to that, seafood of aquaculture and wild origin is a significant source of animal protein; hence, it contributes substantially to the overall health as it contains micronutrients and essential fatty acids that are not found in many land-based protein sources (FAO, 2016). Besides the high nutritive content, shellfish culture are ecologically beneficial systems to the environment as they are involved in nutrient cycling. More so, the simple culture techniques help eliminates the need for energy-intensive processes characterized by other aquatic species. Despite the mentioned advantages, sustainable aquaculture production would require knowledge and skills, environmental requirements for culture, favorable policy framework for aquaculture practices, and availability of a large market to drive the production and supply of the cultured species (Broitman et al., 2017). It was estimated some decades ago that a large percentage of the food consumed by man would originate from the sea (Rothschild, 1981). However, as it stands currently, aquaculture accounts for about half of the world's fish supply, and it is projected to grow even further, becoming a crucial part of high-quality protein supply for the global population (Tacon, 2020). Terrestrial and aquatic animal protein sources account for about 43% of the world's protein supply. Given their nutritional values mentioned earlier, they are critical in mitigating malnutrition, especially in low-income countries (FAO, 2010). A significant proportion of global seafood consumption occurs in East Asia and Pacific countries, which could be attributed to the fact that most aquaculture production comes from this geographical region[1].

According to FAO, shellfish[2] are the aquatic invertebrates possessing a shell or exoskeleton. Shellfish consist of mollusks and/or crustaceans, such as mussel, clam, crab, lobster, shrimp or prawn, etc. FAO also defines seafood[2] as human food derived from the sea or marine aquaculture. Future food was described by Parodi et al. (2018) as food whose production capacity is rapidly developing owing to technological advancements, offering the potential to scale up production level. Such capacities also include the ability to reduce production costs and environmental concerns. On the other hand, Karlsson et al. (2018) described future food as nutritious food accessible to everyone with a less negative impact on the environment. Several authors have also given different indirect definitions, including that of Gebbers and Adamchuk (2010). They defined future food as a product of adequate quantity and quality, obtained through sustainable exploitation of resources, and hence, it is environmentally-safe. A more recent definition by McClements (2020) described future food as an affordable, convenient, safe, nutritious, and sustainable product without posing any harm to the environment. Based on these definitions, future food must possess the following four characteristics: (i) adequacy in supply, (ii) reduced production cost, (iii) being environmentally friendly, and (iv) produced through sustainable exploitation of resources.

This paper focuses on the potential contribution of shellfish to global food production, supplies, and food security in the years ahead. Also, an overview of the main criteria of shellfish selection as a future food is provided herein.

SHELLFISH PRODUCTION

There are currently 73 important global aquaculture species listed by FAO along with their "Species Fact Sheet Information," which details the steps to their production and their various cultural aspects. Most of the shellfish species on the FAO list are marine-based and constitute more than half of the total fish group (52.2%) (**Figure 2A**). Therefore, this emphasizes the importance of shellfish as a potential contributor to global future food production, originating from the saltwater ecosystem. Notable among them is the whiteleg shrimp *Litopenaeus vannamei*, Red swamp crawfish *Procambarus clarkii*, Chinese mitten crab *Eriocheir sinensis*, Giant tiger prawn *Penaeus monodon*, and Mud crab *Scylla* sp. based on the latest aquaculture production value and statistics (Tacon, 2020). This is not to say that other crustacean has less potential as future food. It is opined that as research on other candidates intensifies, their production, consumption, and values are likely to increase hence becoming important future food candidates.

Global aquaculture production projections have shown that shellfish are among the most valuable groups for culture (**Figure 2B**). In this report, we analyze the development of shellfish aquaculture using FAO data on global aquaculture production projections (FAO, 2020). Although the data generated affirms the popularity of finfish as the most cultured group of aquatic species (**Figure 2Bi**), the shellfish groups are also top the list in terms of value when compared to other individual groups of finfish or aquatic plant (**Figures 2Bii,iii**). The growth in global shellfish aquaculture production from 1985 to 2018, shown in **Figure 2C**, reveals that the production of shellfish has increased by 10-folds with a total production capping at 27 mmt in 2018 as compared to 2.76 mmt in 1985. This resulted in an increase

[1]Data taken from: https://ourworldindata.org/

[2]Definition of the term available at: http://www.fao.org/faoterm/en

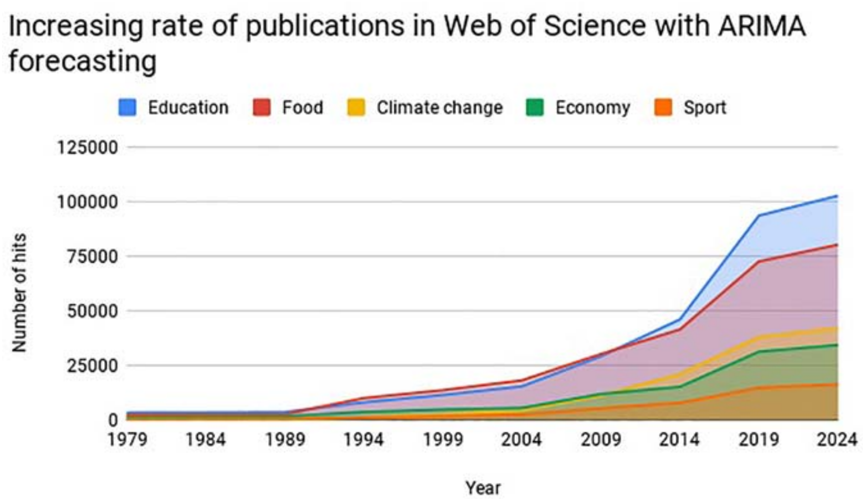

FIGURE 1 | Increasing rate of publications in the Web of Science database between 1979 and 2019 on the topic of food. The red curve represents the cumulative number of documents (left-hand scale). The dark blue column represents the number of documents published per year (right-hand scale). Data taken from https://apps.webofknowledge.com, searched on 15 October 2020. The 2024 data was estimated using Auto Regressive Integrated Moving Average (ARIMA) time series p,d,q: 1,1,1.

in shellfish global revenue from USD 3.56 billion in 1985 to USD 104.55 billion in 2018.

SHELLFISH AS POTENTIAL FUTURE FOOD: INDICATORS

Identifying suitable seafood as future food requires information from a multitude of sources, including research articles, patents, strategic reports by international organizations, and notes from think tanks support groups. This section identifies five indicators shellfish are required to comply with to qualify as potential future food. Three of these indicators are linked to the production phase (i. response and tolerance to biotic and abiotic stress, ii. availability of biological and technical knowledge, and iii. life cycle and broodstock maturation period, while two concern the consumption phase, iv. nutritional value and health benefits, and v. demand, cost, and affordability).

Response and Tolerance to Biotic and Abiotic Stressors

As climate change continues, potential future food (i.e., shellfish) will be those species that can mitigate the climate effects as dictated by the changes in the biotic and abiotic stressors of the environment. The study by Gong et al. (2015) revealed that low temperatures decrease growth and lengthen the intermolt periods of mud crabs, *Scylla paramamosain*, while elevated temperatures stimulate growth and shorten intermolt periods. Azra et al. (2019) also noted that the blue swimming crab, *Portunus pelagicus*, instars had a decreased intermolt period and duration of exuviation when reared at a high temperature of about 32°C. Although many marine shellfish species are more versatile than others in terms of thermal tolerance (Sunday et al., 2012), there are shortcomings to their consideration as primary future food sources. One of which is their low survival rate in captivity (Azra et al., 2019). Consequently, this is an important priority area requiring immediate research attention to enhance shellfish survival through improved breeding technologies (i.e., genetic improvement) and optimization of environmental conditions during culture. Enhanced survival and production characteristics of shellfish in the presence of rapidly changing biotic and abiotic stressors caused by efforts put into maintaining or increasing production efficiency is also another essential domain of research to be considered.

Availability of Biological and Technical Knowledge

Plenty of successes in aquaculture operations can be attributed to a sufficient understanding of the biological and technical aspects of the cultured species. For example, efforts put into perfecting the intensive culture of *Litopenaeus vannamei* since 1973 have led to widespread culture around the world (Briggs et al., 2004). However, the inadequate knowledge about the breeding technology for commercially valuable crabs (e.g., *Scylla olivacea*) has staggered the growth of the industries as its captive culture relies heavily on wild-caught seedlings and gravid females (Ikhwanuddin et al., 2014). Thus, for every potential future seafood candidate, information about their biological and culture techniques must be researched to attain sustainable mass production. Today, sufficient biological and technical information/knowledge are available on some crabs, marine bivalve, shrimps and many other shellfish. This partly justifies their candidature as potential future food.

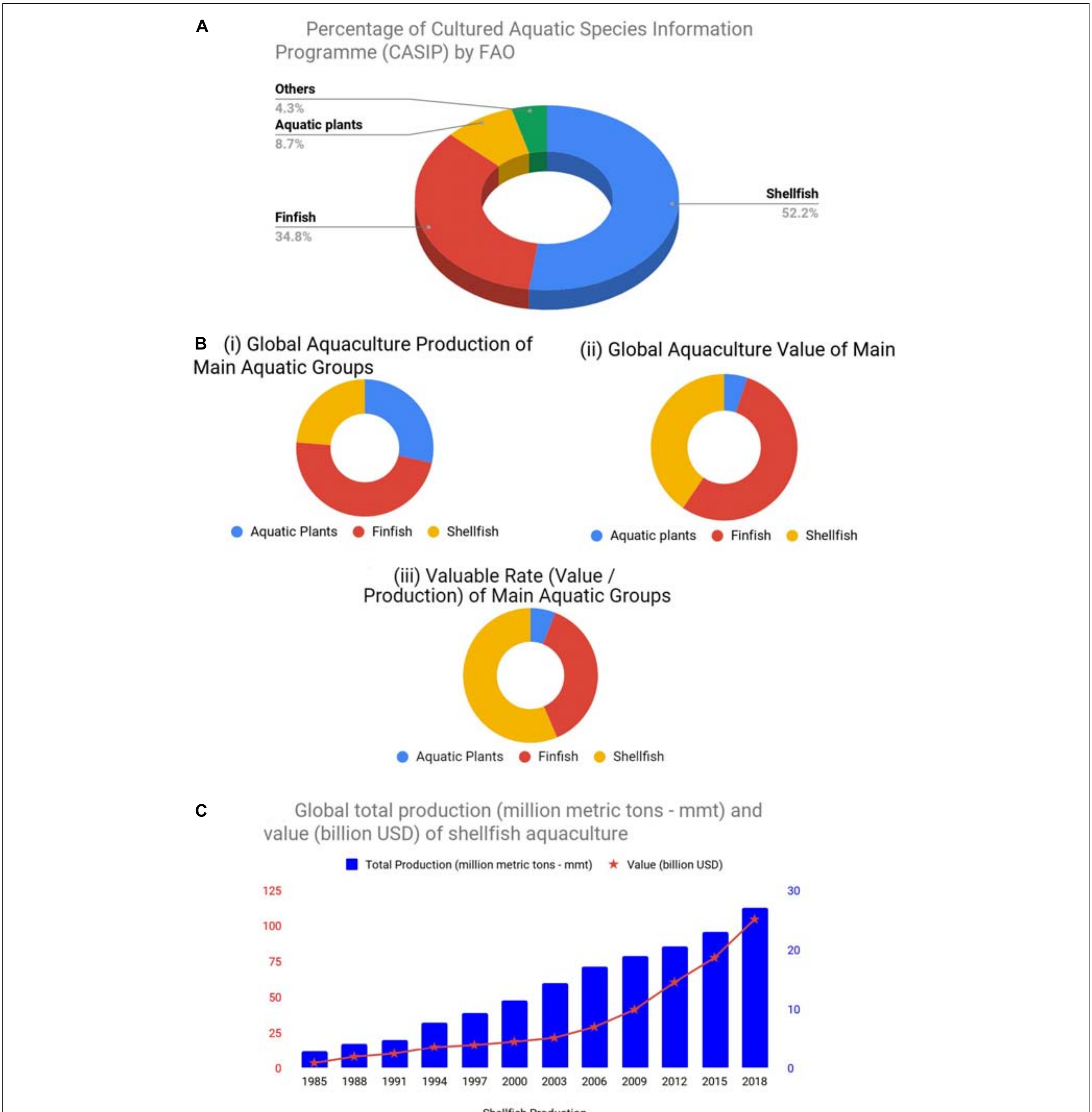

FIGURE 2 | (A) Global species information provided by FAO, excluding the anadromous and catadromous fish species on the original list. **(B)** Comparison of (i) aquaculture production with their (ii) value and (iii) rate for the main aquatic groups of finfish, shellfish, and aquatic plants in 2018 and **(C)** global total production (million metric tons) (bar graph) and its value (billion USD) (line graph) of shellfish aquaculture from 1985 to 2018. Data taken from http://www.fao.org, searched 15 October 2020.

Life Cycle and Broodstock Maturation Period

It is important to note that a cultured species' short life cycle will be translated to fast food production. Hence, to generate enough future food originating from seawater, species with relatively shorter life cycles must be considered. Most marine shellfish fall into this category when compared to the relative life cycles of marine fish species. This includes their embryonic development up onto the market size. Taking mud crab *Scylla serrata* and *S. olivacea*, for instance, the embryonic stage to market sizes ranges between 8–12 months (1-year-old), and at 18–24 months, they are matured to be used as broodstock (Phelan and Grubert, 2007; Alberts-Hubatsch et al., 2016). However, grouper fish would require about 6-year to attain the age of sexual maturity, about twice the time needed for crabs (FAO Fact Sheets[3]). Therefore, many shellfish species have great potential to become sources of future food based on their shorter life cycles.

Nutritional Value and Health Benefits

Shellfish are also among the largest sources of animal protein in the world (FAO, 2016). Moreover, most shellfish contain appreciable quantities of digestible proteins, essential amino acids, bioactive peptides, long-chain polyunsaturated fatty acids, astaxanthin, and other carotenoids, vitamin B12, and minerals (including copper, zinc, inorganic phosphate, sodium, potassium, selenium, iodine) (Venugopal and Gopakumar, 2017). The nutritional components of shellfish and their beneficial health effects have been comprehensively reviewed by Venugopal and Gopakumar (2017). The crude protein contents of green crab *Carpocoris mediterraneus* ranges from 13 to 18.2% depending on the body part enumerated (Cherif et al., 2008). The brown shrimp *Crangon crangon* has high contents of EAAs and non-EAAs (Turan et al., 2011). While the edible portions of Asian hard clam *Meretrix lusoria* contain about 188 mg of EAAs per gram dominated by leucine and lysine (Karnjanapratum et al., 2013). Some shellfish such as marine mussels have also been demonstrated to be promising sources of bioactive compounds that can be exploited for other uses in different industries (Grienke et al., 2014).

Demand, Cost, and Affordability

Consumer demand for shellfish and other seafood is one of the critical drivers of the current expansion in aquaculture activities, with a total production of 73.8 MMT in 2014 and estimated value of US$ 160 billion (FAO, 2016). The increase in demand is partly due to many factors, among which nutritional value and health benefits top. With the current trend of human population and health needs, it can be well-hypothesized that the demands for aquaculture products such as shellfish will only continue to increase in the next few years. However, it is noteworthy that despite the current increasing demands for shellfish from different consumer groups, the full potential of this sector of the aquaculture industry has not yet been fully understood. Moreso, the demand-driven planned production of these aquaculture species should meet the consumers‘ and farmers' needs at the best and most affordable prices. Although it is expected that the prices of shellfish will increase along with growing demands, efforts must be put in place to make them affordable; or else, households within the low-income class may face economic difficulties in obtaining these products. Therefore, removing the barriers to accessing these products is essential to realize them as future food. It should be highlighted that food security is not only dependent on the availability of produces in adequate quantities but also on their affordability by the large section of the populace (Teneva et al., 2018).

[3]Available information at: http://www.fao.org/fishery/culturedspecies/search/en

ISSUES TO BE ADDRESSED

This section briefly discusses the issues associated with seafood aquaculture-based products designated as "Future Food candidate." As earlier reiterated, the indicators that qualify shellfish as potential future food candidates are related to their production and consumption characteristics. Based on those indicators, there are still a few issues and problems related to shellfish aquaculture that need to be resolved. For example, the cannibalism behavior of most shellfish is a critical source of loss and an aspect that needs more fundamental research to mitigate. Manipulation of husbandry requirements and other abiotic/biotic factors to reduce cannibalism during different life stages is one of those research domains. Cutting down the production cost to increase the affordability of the cultured shellfish is another critical issue to tackle and will largely depend on reducing feeding costs. Therefore, research into various unconventional feeding practices and nutrient optimization is essential in this regard. Genetic manipulation of shellfish for the production of fast-growing strain progenies can also help reduce the life cycle and increase the aquaculture ventures' productivity. In this regard, the perfection of the all-male progeny production through biotechnology techniques is much needed. The application of other green farming techniques in the production of shellfish is also an area of future research that must be exploited in the quest of realizing the future food potential of the sector.

CONCLUDING REMARKS AND PROSPECTS

The present paper has provided a perspective on why many shellfish could be considered potential future food candidates. Since future food by definition has to be produced sustainably, efficiently, sufficiently with less cost, and using minimum natural resources without negative impacts on the environment, necessary measures should be taken by all the stakeholders involved (ranging from academicians and researchers to government officials and supply chain players) to ensure these elements will be effectively implemented by the shellfish industry.

DATA AVAILABILITY STATEMENT

All datasets generated for this study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

MA produced the first draft of the manuscript. VO produced the revised version of the document. MT, MH, and MI contributed to the conceptualization and design of the study. All authors read and approved the final version of the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2021.654897/full#supplementary-material

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