Fish Farming Techniques

Subjects: Fisheries

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World aquaculture is increasingly diversified and intensive, due to the use of new technologies, having grown a lot in recent decades and contributed significantly to improving food security and reducing poverty in the world, with fish farming being a promising activity for the production of protein with high nutritional value.

aquaculture culture fish farm

1. Introduction

Aquaculture is the cultivation of aquatic organisms, with human intervention in the breeding process to increase production in operations, such as reproduction, storage, feeding, and protection against predators, among others [1].

According to the FAO [2], in 2020, the world fish production (fishing and aquaculture) was approximately 177.8 million tonnes, with 90.3 million tonnes coming from fisheries and 87.5 million tons coming from aquaculture. World exports of aquatic products in 2020, excluding algae, totaled about 60 million tonnes of live weight, worth 151 billion USD. Only in relation to aquaculture was the largest amount produced in fresh water (54.4 million tons, 62.2% of the world total), when compared to brackish and salt water (33.1 million tons, 37.8% of the world total). Global aquaculture production retained its growth trend in 2020 amid the worldwide spread of the COVID-19 pandemic, albeit with differences among the regions and among the producing countries within each region. Finfish farming remained steady, with minimal fluctuation around 66 percent, and accounted for the largest share of world aquaculture for decades. In 2020, farmed finfish reached 57.5 million tonnes (146.1 billion USD), including 49.1 million tonnes (109.8 billion USD) from inland aquaculture and 8.3 million tonnes (36.2 billion USD) from mariculture in the sea and coastal aquaculture on the shore [2].

Additionally, according to FAO [2], in 2020, the group of organisms that presented the greatest prominence in aquaculture was freshwater fish, followed by seaweed, showing the great importance of fish farming in food production worldwide. According to the data, aquaculture development has exhibited different fluctuating patterns in growth among regions. In the largest producing region, Asia, the growth in the 1990–2020 period was relatively steady in the major aquaculture countries, although with decreasing growth rates. Other regions had had relatively fluctuating growth in the same period, while experiencing negative growth in some years. Asia has overwhelmingly dominated world aquaculture for decades, producing 91.6 percent of global aquatic animals and algae in 2020. However, there are huge differences in the level of aquaculture development between countries within Asia.

Countries such as Mongolia and Timor-Leste, as well as some countries in Central and West Asia, are in need of accelerated aquaculture development to exploit their aquaculture potential [2].

The proportion of fisheries and the aquaculture production of the aquatic animals used for direct human consumption increased significantly from 67 percent in the 1960s to about 89 percent in 2020 (that is over 157 million tonnes of the 178 million tonnes of total fisheries and aquaculture production, excluding algae). The remaining 11 percent (over 20 million tonnes) was used for non-food purposes; of this, 81 percent (over 16 million tonnes) was reduced to fish meal and fish oil, while the rest (about 4 million tonnes) was largely utilized as ornamental fish, for culture (e.g., fry, fingerlings, or small adults for on growing), as bait, in pharmaceutical uses, for pet food, as raw material for direct feeding in aquaculture, and for the raising of livestock and fur animals [2]. Fish farming is a modern agricultural production system. To obtain the planned results, modern methods must be used, based on scientific, ecological, technological, and economic principles [3]. For the sustainability and competitiveness of fish farming, it is not enough just to fit it into the current environmental legislation, but it is necessary to define the good management practices (GMPs) that establish adequate procedures, regarding the ideal stocking density, the intensity of the cultivations, and the maximum amount to be used for both feed and chemical and organic fertilizers, among others, so that it can operate with zero effluent and harvesting techniques that minimize the contribution of both solids and nutrients to the environment. For this, it is necessary that the ponds be built properly, and the existing ones adapted, so that fish farming can develop in a responsible and competitive way [4].

Aquatic animal farming systems are very diverse, in terms of culture methods, practices, facilities, and integration with other agricultural activities. Land ponds remain the most common type of facility used for freshwater aquaculture. However, in recent years, rapid and significant advances in improving freshwater aquaculture farming systems, integrated with agricultural systems, have resulted not only in higher productivity and better efficiency in the use of resources, but also in an impact on the environment [5].

According to the institution, in freshwater aquaculture, the dominant position of fish has been gradually reducing, from 97.2% in 2000 to 91.5% in 2018, reflecting the strong growth of other groups of species, particularly the creation of crustaceans in freshwater in Asia, including prawns, crayfish, and crabs. Thus, fish farming, the most diversified subsector of aquaculture, contains 27 species and groups of species, which represented more than 90% of the total fish produced in 2018, where the twenty most important species represented 83.6% of the total fish production. Compared with fish, fewer species of crustaceans, mollusks, and other aquatic animals are farmed [5].

According to the institution, in the global production of aquaculture in brackish and salt water in 2018, the biggest highlights were mollusks, with 17.3 million tons, followed by fishes (7.32 million tons) and crustaceans (5.73 million tons); fish, that is, marine fish, farming ranked second in the segment, in relation to the volume produced in the world in 2018 [5].

2. Considerations about World Fish Farming

In marine and coastal aquaculture, production is currently concentrated mainly on crustaceans and mollusks, with Atlantic salmon (*Salmo salar*) being the species whose production has expanded the most in recent years. Other species that also had a significant increase in production were European sea bass (*Dicentrarchus labrax*) and gilthead (*Sparus aurata*). In some European countries, technological developments have made the sea bass and snapper industries grow remarkably in the past decade [6].

There are few species produced on a large scale and at costs that satisfy the items established by the market, such as some mollusks and Atlantic salmon. The distinction made, in relation to these two market segments, is relevant, due to the high expectations that aquaculture raises at a global level [7].

The success of salmon farming in Norway and Chile is known worldwide. The governments of these countries have stimulated the production of Atlantic salmon, *S. salar*, with the feasibility of spaces for aquaculture in coastal waters. There are thousands of kilometers of practically intact coastline and hundreds of sheltered areas, where marine farms find ideal conditions for their implementation and development. Countries whose coastlines do not have natural shelters have the option of farms in the open sea (“offshore”) [8]. Still, according to the author of [8], the great challenge is to develop structures capable of withstanding the severe disturbances caused by bad weather. Thus, large aquaculture companies that recognize the potential of this new modality, with advantages in the environmental component, as well, have invested in researching more resistant and functional models. Its installation in deeper oceanic areas, far from the coast, aims to take advantage of the best water quality, as it is far from riverside pollution. On the other hand, it does not suffer from the competition resulting from the great real estate speculation and the use of these spaces for water sports and recreation.

3. Recirculation System in Fish Farming

The water recirculation system in aquaculture has aroused great interest worldwide. However, its production in a commercial scale has not yet been achieved, even with the advances that research has provided in the past few decades [9]. Energy costs, associated with intensive fish production, are the main obstacles to expanding investments in this technology. Biological filtration, aeration, water circulation, and temperature control are necessary for obtaining good results. Therefore, the use of motors, pumps, heaters, and ventilation devices make energy a fundamental element in the entire process [10]. Although, in parts, it is not yet possible to confirm the economic viability of this system, as it largely depends on the balance between the high capital to be invested and operating costs [11].

If the water recirculation system intends to compete directly with other forms of production, such as excavated ponds and cages, the need to reduce costs cannot interfere with the quality of the water that must be supplied for long periods, because the fattening process only becomes profitable if repeated constantly [12]. At high densities, the possibility of reusing water is an important alternative to conventional systems that normally impose environmental restrictions and generate conflicts over the availability of land and water [13]. According to Blancheton [14], this system allows for the rapid growth of fish and the adequate use of natural resources, advantages that can undoubtedly favor its economic viability.

Feeding fish in captivity is processed differently from what happens in a natural environment, where decisive factors, such as the nutritional contribution of natural aquatic organisms in the farming ponds, as well as the effect of food on water quality and loss of nutrients, if the food is not consumed immediately, interfere with the zootechnical performance. The adoption of more effective cultivation technologies, which allow for good growth rates, reaching industrial production is only possible with food that meets the nutritional requirements of the species. Thus, in highly modified environments, such as floating cages, “raceways”, or ponds stocked with high densities, successful fish farming depends on nutritionally balanced foods [15].

The deficiency of a single nutrient in the diet, combined with stressors agents inherent to confinement, can compromise growth, feed conversion, handling tolerance, and disease resistance, causing inadequate productive performance and high mortality [16].

Almost all commercially cultivated marine species have carnivorous feeding habits; therefore, their dietary protein requirements are relatively high. Thus, feeding is one of the most important aspects in the cultivation of aquatic organisms, as the costs can become rather high, depending on the feeding strategy adopted [17].

Araujo et al. [18] evaluated the zootechnical performance of Nile tilapia, *Oreochromis niloticus*, varying the amount of daily feeding in the masonry tanks for 154 days, and observed that this species, being fed in daily amounts of 20 and 30% of food (morning) and 20 and 30% of food (afternoon), showed a better zootechnical performance at the end of the experiment, when compared to the control, mainly noticed in biomass, final average weight, and feed conversion.

4. Importance of Live Food in Aquaculture

The supply of live food optimizes the growth and weight gain in the first days of the lives of the cultivated species, with several technological strategies aiming to reduce costs and increasing production, without losing essential nutritional characteristics [19].

The larval stage of cultivated aquatic organisms demonstrates a certain need for care, regarding food and nutrition, as this stage is where high mortalities occur, due to inappropriate use and choice of food to be offered [20]. During this phase, in the first days of life, many larvae of different species are not able to consume inert food, and the individuals still do not have the complete digestive tract, making it difficult to digest and absorb the nutrients present in the food. As an alternative, the use of live food enables production in larvicultures, with increased feed efficiency [21].

Live food constitutes a large part of the diet of cultivated species, due to its excellent nutritional potential, as it has a high-value biochemical composition, mobility, and variable sizes and formats, important characteristics to be offered as food for a vast number of species of cultivable aquatic organisms. Other essential factors required for safe production are ease of cultivation, resistance to contamination, and rapid growth [22].

Several organisms are used as live food, highlighting microalgae, rotifers, copepods, cladocerans, and brine shrimp as the most produced. Other species are also offered, such as polychaetes, micro-worms, beetles, and insect and mosquito larvae, mainly in ornamental aquaculture [23].

Microalgae are the most used live food, being the basis of the modified food chain in aquaculture, as they serve as food for both cultivated species and live food. They have a high content of protein and polyunsaturated fatty acids, as well as essential pigments, vitamins, and minerals. The strains used in aquaculture, in this context, have dimensions from 0.2 to 500 µm and are cultivated in fresh or saltwater environments, enriched with nutrients, according to the microalgal species cultivated. The most used are those of the genera *Arthrospira* (Cyanobacteria), *Chaetoceros*, *Thalassiosira* (Bacillariophyta), *Chlorella*, *Dunaliella*, *Tetraselmis* (Chlorophyta), *Nannochloropsis* (Ochrophyta, Eustigmatophyceae), *Isochrysis* (Haptophyta, Coccolithophyceae), and *Schizochytrium* (Labyrinthulea) [24]. **Table 1** shows the classes, genera, and main species of the microalgae currently cultivated as live food in aquaculture and their utilization. **Table 2** shows the zooplankton and micro-worms most used as live food in aquaculture.

Table 1. Classes, genera, and species of major currently named microalgae grown for food in aquaculture and their main utilization. FFL: food for fish larvae; FBML: food for bivalve mollusc larvae; FSL: food for shrimp larvae. Source: modified and updated from Silva et al., [24] and Muller-Feuga [25].

Class	Genus	Species	Main Utilization
Cyanophyceae (blue-green algae)	*Arthrospira* (*Spirulina*)	*platensis*, *maxima*	FFL
Bacillariophyceae (diatoms)	*Skeletonema*	*costatum*, *pseudocostatum*	FBML, FSL
	Phaeodactylum	*tricornutum*	FBML, FSL
	Chaetoceros	*calcitrans*, *gracilis*, *punilum*	FBML, FSL
	Thalassiosira	*pseudonana*	FBML
Chlorophyceae (green algae)	*Chlorella*	*minutissima*, *virginica*, *grossii*	FFL
	Dunaliella	*tertiolecta*, *salina*	FFL, FSL
	Nannochloris	*atomus*	FBML
	Haematococcus	*pluvialis*	FFL
Prasinophyceae (scaled green algae)	*Tetraselmis* (*Platymonas*)	*suecica*, *striata*, *chuii*	FFL, FBML, FSL
	Pyramimonas	*virginica*	FBML
Cryptophyceae	*Rhodomonas*	*salina*, *baltica*, *reticulata*	FBML, FSL

Class	Genus	Species	Main Utilization
Eustigmatophyceae	*Nannochloropsis*	*oculata*	FFL, FSL
Prymnesiophyceae (Haptophyceae)	*Isochrysis* *Pavlova* (*Monochrysis*)	*galbana*, aff. *Galbana*, *'Tahiti'* (*T-iso*) *lutheri*, *salina*	FBML, FSL
Dinophyceae (dinoflagellates)	*Crypthecodinium*	*cohnii*	FFL
Thraustochytriidae	*Schizochytrium*	sp.	FFL

FSL: food for shrimp larvae. Source: modified from Silva et al. [21].

Organism	Genus	Species	Main Utilization
Rotifer	*Brachionus*	*rotundiformis*, *plicatilis*	FFL, FSL
Cladocera	*Daphnia*	*carinata*, *magna*	FFL, FSL
	Ceriodaphnia	*carnuta*	
	Moina	*macrocopa*, *micrura*	
Copepod	*Tigriopus*	*californicus*, *brevicornis*, *japonicus*	FFL, FSL
	Tisbe	*biminiensis*, *holothuriae*	
	Acartia	*tonsa*, *clausi*, *hudsonica*, *omorii*	
	Paracalanus	*parvus*	
	Cyclops	*bicuspidatus*, *strenuus*	
	Thermocyclops	*parahastatus*, *parvus*, *thailandensis*	
Artemia	*Artemia*	*franciscana*, *salina*	FFL, FSL
Micro-worms and Protozoan	*Enchytraeus*	*albidus*	FFL
	Paramecium	*caudatum*	
	Anguillula	*silusiae*	
	Limnodrilus	*hoffmeisteri*	

Rotifers range in size from 50 to 2000 µm, acting as a nutritional capsule, transferring nutrients required by larvae of the cultivated aquatic organisms. Its reproduction is by parthenogenesis, making cultivation easier and faster. The two most used species as live food are *Brachionus rotundiformis* and *B. plicatilis* [26].

Copepods are more numerous and diversified in the marine environment, with sizes of 0.3 to 3.2 mm. They have sexual reproduction and present sexual dimorphism. Its cultivation alternates from the selected individuals to the wild ones collected in natural environments. In the feeding of fish and shrimp, copepods act as bio-capsules, transferring energy from microalgae and enriched foods. Copepods have a high reproductive capacity, resulting in high population densities. The most used groups are *Cyclopoida*, *Calanoida*, and *Harpacticoida* and are offered as food at different stages of life (nauplius, copepodite, and adults) [27].

The cladocerans are predominantly from freshwater, with few marine species, ranging from 0.2 to 3 mm. In addition to having good nutritional characteristics, they are also used as bio-capsules for transferring enriched foods to cultivated organisms. They have a life cycle of 1 to 2 weeks, with reproduction by parthenogenesis or sexual means. Its cultivation is practical, being able to offer microalgae and biological yeast for food maintenance. The most used are *Daphnia* and *Moinas* [28].

Artemia have excellent nutritional value, which can be influenced by their diet and can be enriched with microalgae and nutritional additives, characterizing brine shrimp as bio-capsules, as they transfer these compounds to the larvae of cultivated aquatic organisms. Its cultivation is easy, as they are marketed as dehydrated cysts, easy to hatch and maintain, and can be offered as live food in their various stages of life, from cysts to the nauplius, meta-nauplius, pre-adult, and adult stages. The most commercialized and used species as live food is *Artemia franciscana* [29].

Polychaetes, micro-worms, beetle larvae, insects, and mosquitoes are most used in ornamental aquaculture, being offered from the larval to adult stages to fish and shrimp (**Table 2**). They are organisms that are easy to grow and of great economic importance, as they contribute up to 80% of the diet of some species of ornamental fish. They can be offered directly or mixed with foods, increasing the palatability of the inert food [30].

The main obstacle to the use of live food is the high cost, compared to inert foods, as maintenance requires a small-scale trophic strategy, sometimes requiring the cultivation of several basis organisms of the trophic chain to maintain the organisms that will be used as live food, as an example of the use of zooplankton, which need microalgae in their diet. One of the alternatives is the cultivation of low trophic level organisms, as it reduces the diversity of species used as food, in addition to facilitating the gradual weaning for feeding with inert food, without causing undesirable results in the zootechnical indexes of the cultivated organisms. Another way is to work with the species of high commercial value, which can cover the costs of production and maintenance of live food [31][32].

5. Sustainability in Marine and Coastal Fish Farming

To increase the production of aquatic organisms, it is necessary to raise the stocking density in the cultivation facilities. Cultivation at high densities can cause negative environmental repercussions like as chemical and biological pollution, disease outbreaks, unsustainable feeding, and competition for coastal area and may also compromise, to a certain extent, the environment [33].

Jiang et al. [34] developed a food-energy-water-carbon (FEWC) sustainability index, from 0 to 100, to assess the global sustainability of aquaculture among countries. Results indicate that the overall sustainability of global aquaculture is low (average score = 26) with none achieving a high sustainability score (75–100) and almost all practicing aquaculture in a relatively low sustainable way (0–50). Considering the sub-sustainability at a sector level, 80% of countries had at least two sectors among FEWC falling into the low sustainable zone (score less than 25). China led all countries by contributing to more than half of global aquaculture water consumption and greenhouse gas emissions, followed by India and Indonesia.

5.1. Classical Methods to have Fish Farming More Sustainable

Among the most sustainable practices in fish farming, researchers can highlight the use of moderate densities, feeding strategy and location, verified through the level of cortisol in fish, an indicative factor of stress in farmed animals, observed, for example, by Hanke et al. [35].

Kumaran et al. [36] observed favorable technical indicators (fish survival, feed conversion, growth rate and productivity), economic parameters (cost-benefit ratio, payback period and internal rate of return) and indicators of livelihood security in the cultivation of barramudi *L. calcarifer* when cultivated in the three-phase system in India, comprising larviculture, pre-growing and final grow-out in cages, and thus showed that this system is technically and economically viable, socially acceptable and, therefore, sustainable.

Calleja et al. [37] found a high potential for marine aquaculture, specifically for large and medium-sized enterprises. Three out of each five species studied show high suitability in most study sites (Central and Northern Pacific coast of Costa Rica) and the other two species show promising results in the Gulf of Nicoya. At a regional scale, the Pacific coast of Costa Rica presents high potential for fish aquaculture, being a promising development medium for coastal communities as long as it is environmentally sustainable and compatible with other coastal activities such as tourism.

5.1.2 IMTA

Another point to comment is the discharge of effluents from aquaculture, mostly obtained through the foods used in cultivations, which can greatly affect the environment if not treated correctly. Based on this notion, the IMTA (Integrated Multi-Trophic Aquaculture) concept was developed, which applies a simplified food web structure to a farming system of fed-species, such as fish and shrimp, in conjunction with extractive organisms, such as mollusks and seaweed, which suck up particles and nutrients from the environment [38]. On this point, when designing an effluent treatment unit, such as a recirculation system (RAS), use of macrophytes or adsorbents, fish farmers must consider a variety of factors. Through appropriate treatment methods, the objective is to reduce environmental pollution [39]. A greater input, mainly, of nitrogen and phosphorus in aquatic ecosystems will be evidenced in eutrophic environments, which means an increase in primary production in water bodies [39].

Current RAS knowledge and technology make these systems viable and economical only for the production of high-value species at the moment, but other aquatic species may become sustainable with alternative choices like as aquaponics. Many present and future advancements in renewable energy production will lower RAS operating costs. To lower RAS costs, aquaculture producers, scientists, and engineers must collaborate to properly design and constantly improve every component of RAS. Through research and field tests, greater information about RAS technology is gathered, as also a better understanding of the interplay between its numerous components. RAS technology will continue to alter and modernize the aquaculture sector, including local production in or near metropolitan areas, as well as in locations and nations with limited water resources, where more traditional aquaculture systems will be implemented [40].

5.2. Technological Evolution in Fish Farming

Industry 4.0 is associated with engineering and computer science knowledge coupled with multisensory schemes for aquaculture systems associated with online servers and/or workstations with the most appropriate software to manage and control the system, thereby contributing to improved aquaculture productivity and efficiency while lowering overall costs [41]. Aquaculture 4.0 technologies are a long-term solution for increasing production (quantity and quality) while decreasing expenses and pollution in aquaculture [42]. Because aquaculture can be offshore or onshore, abiotic and biotic factors influence the aquaculture system, which has a high influence on aquaculture productivity. The 4.0 technologies and methods must be developed to deal with the environmental demand from the aquaculture location and species cultivated [43].

Numerous technologies are now being used in different domains that can be included in Aquaculture 4.0: Recirculation Aquaculture Systems (RAS), smart aquacultures (offshore and onshore), and real-time water quality [41].

Aquaculture 4.0 programmes provide farmers with real-time monitoring of water quality and aquaculture conditions. These systems can provide a large amount of information at intervals of seconds or minutes, allowing for more accurate planning of aquaculture activities and the possibility of prompting alarms in case of unsafe water conditions/quality or weather alerts (e.g., allowing the offshore systems to descend the fish cages to deep sea weight, reducing the negative effects of sea waves and bad weather in the aquaculture system). Also, the creation of a comprehensive database that will aid in precise and specialised research to improve the efficiency of aquaculture over the medium and long term, minimising risks and elevating fish farming productivity.

One of the key benefits of aquaculture 4.0 is the remote control and viewing of the RTD on a cloud-based platform, particularly in marine farms where cages cannot always be entered quickly and at the desired moment. Onshore fish farmers applaud the cloud-based system of onshore aquaculture characteristics, which can be accessible from anywhere [41]. Thus, the evolution of the fish farm pass for an adaptation to IMTA protocol to reduce wastes in the aquatic systems.

Offshore aquaculture is still a new business that needs to include additional technology, such as artificial intelligence and augmented reality, that can improve and automate numerous activities remotely, such as feeding, sampling, monitoring, and surveillance. More study on the implications and repercussions of offshore aquaculture on seafood security and marine habitats, as well as the social dimensions and effects of offshore aquaculture, is required.

5.3. Feed and Nutrition in Fish Farming

Rising fish feed prices, as well as the environmental consequences of over-harvesting forage fish for feed and fish oil, have led to a rise in the rearing of herbivorous fish (carp and tilapia) and omnivorous fish (barramundi), which use significantly less fishmeal to generate protein. Furthermore, antibiotics or pesticides used on farmed fish can have an impact on other marine species or human health. These nutrients and pollutants fall to the ocean floor, where they may have an influence on the biodiversity. Meanwhile, research to discover alternatives to fishmeal feed or methods to make it more sustainable is continuing. Thus, finding the finest fish feed formulae also include attempting to attain the lowest feed conversion ratio—the amount of feed supplied in relation to the weight acquired by the fish [44].

The production of feed based on new ingredients is important due to raw materials for feed increase price and sustainability, therefore, there is an increase to exploit more sustainable and economic raw source for feeds. At this moment, vegetables (non-competing vegetables for animal feed or human food) and insects based feeds can be an economic and efficient alternative to the traditional feeds [45]. Thus, the exploitation of microalgae, macroalgae, bacteria, yeast, and insects can substitute the actual forage fish, particularly in high-value species such as salmonids, will be critical for fed aquaculture sustainability [45]. Furthermore, nutrition is vital player in fish farming economy, since feed accounts for almost half of the variable production cost. In recent years, fish nutrition has evolved substantially with the development of new, balanced commercial diets that support optimal fish growth and health. The creation of novel species-specific diet formulas helps the aquaculture sector expand to meet rising demand for economical, safe, high-quality fish and seafood [46].

Other of the aquaculture problem is overfeeding, which wastes valuable feed. Water contamination, low dissolved oxygen levels, higher biological oxygen demand, and increased bacterial loads are other consequences. Fish should typically be fed simply the quantity of feed that they can ingest fast (in less than five to 10 minutes). A decent general rule of thumb is to give the fish around 80% of what they want to consume (satiation). In this method, you feed for one day as much as the fish will ingest on a regular basis, possibly twice a month [46]. Thus, the new feed need to have higher nutritional values.

Due to the antibiotics and pharmaceuticals restriction used in the fish cultivation. The industry's future development is heavily reliant on the sustainable use of natural resources. Nutraceuticals are being used in aquaculture to improve disease resistance, growth performance, food conversion, and product safety for human consumption. Probiotics boost growth and feed conversion, enhance health, promote disease resistance, reduce stress sensitivity, and boost overall vigor. Currently, the majority of nutraceuticals come from terrestrial sources rather than fish. Host-associated (autochthonous) nutraceuticals, on the other hand, are expected to be more durable in the gastrointestinal system of fish and, as a result, may have longer-lasting benefits on the host. Nutraceuticals candidates are often evaluated *in vitro*, however the transition to *in vivo* testing is frequently difficult [47]

Although, the administration of adequate doses of immunostimulants or immunomodulatory agents promotes an increase in resistance to different diseases and improves the animals' health status. Some studies demonstrate that the administration of an optimal dose of an immunostimulant is extremely important to obtain an effective response. These effects were proven in the cultivation of Asia seabass (*Lates calcarifer*), and the *Kappaphycus alvarezii* (Rhodophyta) addition showed an excellent immunostimulatory activity, constituting a good immunostimulant/immunomodulating agent in the fish aquaculture field, although more trials are needed [48].

The use of natural substances capable of immunomodulating the fish reaction to stress factors, combined with good management of cultivation, emerges as a promising tool for aquaculture, as it promotes action against the negative effects, reducing mortality during the production process of these organisms.

5.4. Biosecurity in Fish Farming

According to FAO, biosecurity is a comprehensive and integrated strategy that encompasses both policy and regulatory frameworks aimed at analysing and managing relevant hazards to human, animal, and plant life and health, as well as associated environmental problems. It is a comprehensive concept that addresses food safety, zoonoses, the introduction and management of animal and plant illnesses, as well as invasive alien species. It also addresses the introduction and dissemination of live modified organisms and their by-products [49]. Failure to apply biosecurity can result in disease outbreaks, which, as previously said, can reduce farm output, pose hazards to human health, give fish a terrible flavour and look, and obstruct farm access to markets. All of this, of course, reduces a farmer's cash return. Globalization, for example, has increased the risk of disease spread due to the increased volume, diversity, and social-economical relevance of aquatic animal trafficking. Several stages must be performed in order to build a successful biosecurity plan. These processes are as follows: hazard identification and prioritisation; risk-impact assessment; identification, mitigation, management, and remediation of critical control points through which diseases may enter or leave the epidemiological unit; development of a contingency plan if a disease is discovered in the unit through disease surveillance, monitoring, and determination of disease status or freedom in the epidemiological unit; and periodic audition of procedures. Veterinarians test these procedures, and government veterinary authorities should evaluate and approve them [50].

Aquaculture has been demonstrated to have the potential to contribute to socially beneficial global food production. However, in order to address the expanding global food security issues, the aquaculture blue revolution must be accelerated, but corrective techniques to mitigate its negative repercussions must also be developed. While contributing to global food production and boosting per capita animal protein intake, aquaculture has depleted resources that sustain regional and global food security in some circumstances. Indeed, certain aquaculture methods are viewed as a danger to food security [51].

Most aquaculture laws and certification programmes are geared toward individual farms. Even if everyone follows the rules, having a large number of producers in the same location might have a cumulative environmental impact, such as water pollution or fish infections. Spatial planning and zoning can help to guarantee that aquaculture activities stay within the carrying capacity of the surrounding environment while also reducing disputes over resource usage. For example, Norway's zoning restrictions guarantee that salmon farmers are not unduly concentrated in one location, decreasing disease risk and helping to manage environmental repercussions.

Many fishponds in China, Thailand, and Vietnam have been converted from rice fields, a practise that China has since prohibited owing to national food security concerns. More crucially, it represents a change from producing a main food crop for local populations to producing a commodity for the export market, and so food security is a major concern for some small farmers who have converted good rice fields into fish farms [52].

According to Beveridge et al. [53], the contribution of aquaculture to food security is dependent not only on where it happens, but also on culture species, product price, and fish size - all of which impact availability and usage by poor customers. Farmers can be incentivized to conduct more sustainable aquaculture through a range of governmental and commercial programmes. Thailand's government, for example, has offered free training, water supply, and wastewater treatment to shrimp farmers working lawfully in aquaculture zones. The government has also offered low-interest loans and tax breaks to small-scale farmers, assisting them in adopting superior technology that has enhanced production and decreased the need to clear additional land [54]. Thus, to inspire farm workers to execute biosecurity measures, they should be instructed on biosecurity by reputable and credible sources, such as veterinarians, so that they understand the benefits of implementing biosecurity measures as well as the costs of not implementing them.

A biosecurity strategy must be evaluated and updated on a regular basis to reflect changes in internal infrastructure, production, and external exposure, as well as regulations. The most effective strategy to establish robust biosecurity at an aquaculture plant is to create a documented biosecurity plan based on risk assessment and utilise audits to determine how well the plan meets the risks and hazards present. The grading method will be critical in determining the relative relevance of the many elements and activities included in the plan, both individually and as part of a biosecurity farm programme. A biosecurity strategy will not be effective unless it is adequately taught and adopted by farm employees as a routine operating procedure. Biosecurity cannot be cost-effective unless farmers collaborate transparently at the regional, national, and international levels. Transparent reporting of critical data and information exchange on the area health status, particularly the prevalence of infectious illnesses and increasing mortality occurrences, is critical. Transparent collaboration among stakeholders is the only way for the industry to effectively prevent and control disease outbreaks [55].

5.5. Fish Genetics on Farming

Appearance factors in fish, or those exterior body qualities that impact consumer acceptability at the moment of sale, have risen to prominence in commercial fish farming, as culture success is strongly tied to control of these traits. Body form and skin pigmentation are the two most important physical characteristics. An examination of the genetic basis of these qualities in various fish finds considerable genetic diversity among populations, indicating the possibility of genetic improvement. Work on determining the minor or main genes driving commercial fish aesthetic attributes is growing, with significant success in model fish in terms of discovering genes that regulate body form and skin colors [56].

As a result, in order to meet current market expectations and maximize profitability, manufacturers are being obliged to regulate outward features, particularly body form and skin color, more intensely on an industrial scale. In commercial fish, such as common carp, tilapia, sea bream, and salmonids, this genetic strategy is supplemented previous progress based solely on breeding values estimated with phenotypic and genealogical information or classical genetics, which has enabled the development of new strains, for example [56][57].

This is not a simple operation, however, because body form and skin colour in fish are complicated features influenced by a variety of hereditary and environmental variables. Thus, development in this subject will be dependent, in part, on unravelling the underlying genetics of these traits in order to use current selection procedures, such as marker-assisted selection based on molecular data, in the future [56].

This type of selection approach has resulted in new fish populations with greater market involvement, contributing to better profitability of fish cultures. Because of the sophistication of the market in many parts of the world, this tendency is projected to continue in the coming years. As a result, there is interest in fish selection to ensure visually pleasing species, such as tilapia, rainbow trout, common carp, gilthead sea bream, and sea bass [56].

To address this challenge, however, fish producers must adapt and connect their selective breeding objectives with market expectations. One older and antique approach that might be used to attain this goal is the finding of quantitative trait loci (QTLs) or genes that underpin body form and skin colour, where continuous variation of the various qualities that comprise these traits is typically found. This knowledge might be utilized to conduct marker-assisted selection, which is based on molecular markers that are strongly related to QTLs that affect several appearance features of economic relevance. This technique still is widely applied in various countries for the rainbow trout, common carp, gilthead sea bream, and sea bass farming [56].

However nowadays, the trend is the selective breeding using genomic selection, which has an enormous potential to increase aquaculture efficiency and minimize its environmental footprint [58]. This genomic selection is based in enhanced genomic tools during the last decade. Thus, these genomic tools are extremely useful for the sustainable genetic improvement. Nowadays, these tools have low cost and ease of use, mean that they can now be used at all stages of the domestication and genetic improvement process, from informing the selection of base populations to advanced genomic selection in closed commercial breeding nuclei [58][59]. With the high interest in this genetic technology, equipment companies are being interested to develop equipment for the fish farming. Thus, R&D and fishery-related laboratories can sequence a target fish species' genome, eliminating the need for the coordinated effort and financing that resulted in the first farmed animal species' reference genome assemblies (for example the QTLs method) [58].

Furthermore, genomics technologies are useful for addressing species-specific breeding and production difficulties associated with the very diversified biology of aquaculture species. The introduction of well-managed selective breeding programs for aquaculture based on pedigree recording and routine trait assessments has resulted in increased output of various species (QTLs method). This previous work which can be upgraded with these new genomics technologies can drive the fish farming to a new a level of aquaculture in safety, economic and efficiency levels [58].

In conclusion, biotechnological developments have the potential to overcome productivity constraints in aquaculture if the all the work done is coupled with new technologies and not start from the zero.These advancements include the use of genome editing technologies to make targeted changes to aquaculture species' genomes, resulting in improved health and performance, the use of reproductive biotechnologies such as surrogate broodstock to accelerate genetic gain, and combinations of both approaches [58].

5.6. Dangers Nowadays in Fish Farming

Finally, Mahamud et al. [60] discuss the factors associated with the introduction of macro and microplastics (MPs) in aquaculture, via fishmeal obtained from animals caught in natural environment that can accumulate these materials. There are great consequences of MPs on cultivation ponds, in fish physiology and consumer health. The authors recommend taking necessary care to improve the PM screening process during fish food production and focus on further studies to elucidate the impacts of MPs on sustainable aquaculture production.

Because there are several international and national aquaculture certification systems, the FAO created technical criteria for aquaculture certification as well as an evaluation methodology. However, although many big fish farms are obliged to do environmental impact studies and get certification, small farms, many of which are unsustainable, are not. Many nations have lax regulations managing responsible aquaculture development [44].

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