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Reviews in Aquaculture

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OPINION

REVIEWS IN Aquaculture

Enhancing the nutritional values of farmed fish production systems

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1 | INTRODUCTION

As with any food production system, aquaculture will be challenged to provide sustainable food to a human population expected to exceed 9 billion by mid-century. The strive for sustainable food production systems is increasingly recognized globally, including a landmark 2021 UN Food Systems Summit which highlighted the need for '*Stepping up and Going Further to Implement the Transformations Needed in Our Food Systems to Achieve the SDGs by 2030*', with aquaculture and fisheries receiving attention as key subjects for policy action.[1]

Transformation is needed because of disturbing trends reported within current food systems. Willett et al.[2] stated, '*food systems have the potential to nurture human health and support environmental sustainability; however, they are currently threatening both. Providing a growing global population with healthy diets from sustainable food systems is an immediate challenge*'. A recent international symposium on aquaculture agreed a 'Shanghai Declaration'[3] that among other things recommended '*adopting a nutrition-sensitive approach which considers the nutrient content of farmed aquatic foods*'. The global production of food (calories) has outpaced population growth, although over 820 million people are food insecure and even more have poor diets that contribute to severe health problems such as obesity and non-communicable diseases, such as coronary heart disease, stroke and diabetes.[2]

Although the nutritional characteristics and health benefits of consumption of aquatic foods are well known,[4,5] their contribution to food and nutritional food security is often underappreciated.[5,6] Here, we start from the premises that aquaculture will be essential in providing the world with sustainable supplies of affordable seafood; that aquaculture is currently contributing to human health and food security; and that aquaculture can and should do more. We focus on several strategies with potential to deliver improved nutrition and health outcomes: aquaculture feeds; genetic selection; whole fish and system approaches, and ecological aquaculture farming systems.

2 | MORE NUTRITIOUS AQUACULTURE FEEDS

In contrast to wild capture fisheries, the nutritional profile of cultured fish can be enhanced by dietary manipulation and/or dietary fortification to meet consumer needs and desires. There is considerable scientific evidence for the health benefits of omega-3 polyunsaturated fatty acids (omega-3s), and as a result, research on increasing the levels of these nutrients in farmed fish through diet supplementation has been ongoing.[4] Omega-3 levels have been increased in a variety of aquatic species including, Atlantic salmon, channel catfish, Nile tilapia, rainbow trout and whiteleg shrimp.[4] Other nutrients such as selenium, iodine, trivalent chromium and fat-soluble vitamins such as vitamin E can also be increased. Moreover, the concentration of environmental pollutants that may be present in feed using wild fish can be reduced within farmed fish (if deemed a problem) through the dietary substitution of contaminated fish oils and fish meals from wild-caught fish with less contaminated lipid and protein meals from other sources, including plants,[7,8] providing options for improvements and better control of health and nutrition profiles in aquaculture products.

3 | GENETIC IMPROVEMENT OF FARMED TYPES

In order to reduce aquaculture's reliance on fish oils, feed manufacturers try to replace fish and fish oil in diets with plant-based oils.

Because replacement of fish oils in aquafeeds with plant-based oils can lead to decreased levels of omega-3s in farmed fish,[9] improving fish' natural ability to convert the fatty acids in plants to the beneficial omega-3s would produce a more nutritious product. Similarly, fish with low omega-3/omega-6 ratios, particularly freshwater fish, could be made more nutritious by genetically increasing omega-3 levels.

Increasing the nutritive value of farmed types through genetic technologies has shown promise in some species for some nutrients. However, in general nutrition has not been a criterion used in genetic improvement.[10] Improvement of omega-3 levels through genetic selection has been on-going in Atlantic salmon for decades[11] and might be applied to other popular farmed species.[12] Genetic improvement of fish' ability to digest carbohydrates has shown promise in some species.[13] However, genetic improvement of protein content has been shown to have low potential for genetic improvement in sea bream, European whitefish and rainbow trout.[14]

There are scarce data available on the use of genetic technologies in improving other nutrients in farmed types. A search of the SCOPUS bibliographic database (www.scopus.com) using keywords: aquaculture AND genetics AND nutrient OR vitamin OR mineral OR element returned no additional information addressing genetic improvement of these components for human nutrition.

4 | WHOLE FISH NUTRIENT RECOVERY AND CONSUMPTION

Although 'whole' fish contain many highly nutritious parts, aquaculturists often culture fish species for the production of fillets. Fillets provide important protein and essential oils, but other parts of the fish provide additional nutrients that fillets do not. There are significant opportunities to recover nutrients, for example in aquaculture derived trimmings and fillet off-cuts for direct human consumption whenever possible, including the production of lower-cost fast-food aquatic products for mass domestic consumption using innovative processing techniques[15] or even nutraceuticals.[16]

Direct consumption of smaller fish offers another pathway to utilize 'whole' fish nutrients. In Asia, many small indigenous fish species (SIS) have high levels of nutritionally important fatty acids and micronutrients such as iron and iodine that become available to consumers when consumed whole.[17–19] SIS commonly frequent South Asian wetlands, including rice paddies, whose design and management can be modified to produce a supplementary crop of highly nutritious fish.[20] Although existing inland farms in Bangladesh could not replace important micro-nutrients and vitamins available from capture fisheries, models showed that re-orienting existing fish farms to produce 30% or more SIS could completely replace or surpass the nutrient contribution of capture fisheries.[6] Once seen as competitors or 'weed species' SIS are now appreciated as complementing pond production, increasing production, income and profits for producers and providing a food-based solution to food and nutrition security.[21]

Although in many Asian countries small traditional ponds do supply a mix of species of all sizes, with apparent nutritional benefits, large markets for such products may not exist. However, there is a market for small-sized fish for domestic consumption, as is currently being practiced in several Asian countries, such as whole small plate-sized (ca. 100 g) catfish (authors' personal observation). There has been little evaluation of the potential of farming SIS in Africa. An alternative here and elsewhere might be to manage pond aquaculture of fish such as tilapias to maximize production of small fish that can be eaten whole.

The popular discourse on small versus large fish, often with comparisons of nutrient values in fillets and whole small fish, needs to shift to a food system approach, seeking to better recover and utilize nutritionally valuable nutrients from all parts of the fish and aquaculture system, including parts of larger fish, such as eyes, bones and liver. There needs to be a shift of thinking from 'whole' fish to 'whole food system' nutrient flows, stimulating new ideas and management strategies to emerge that can maximize benefits of human nutrition from aquaculture.

5 | IMPROVED FARMING SYSTEM

About 75% of fish and shrimp produced through aquaculture are cultured in ponds[22] and this percentage is growing.[23] Nearly all finfish raised in ponds are cheaper than the global production weighted average cost[24] and accessible to the majority of the population, generating income and contributing to food security.[25] However, nutrient cycling and waste treatment in ponds are extremely complex and often not well managed.

At pond level, several strategies for improved nutrition have emerged, such as management of ponds to maximize production of tilapia that can be eaten whole, or the use of 'nutritious pond' concepts.[23] Farmers can provide additional material to ponds to supplement aquafeeds, for example, carbohydrate to increase the C:N ratio of the total nutrient input to the pond. This approach works in all types of ponds, from extensive to intensive.[26] Addition of indigestible fibre that spreads through the pond in faeces can reduce carbon emission and provide substrate for micro-organisms to mineralize wastes and stimulate natural food production. By supplementing formulated diets with missing nutrients, farmers often outstrip the capacity of ponds to mineralize wastes. Modern feeds provide sufficient energy for cultured species to digest the feed, but the resulting waste is energy poor and nutrient rich (e.g., low carbon content and high nitrogen and/or phosphorus). Microorganisms in the pond cannot fully mineralize such waste because energy is lacking. A nutritious pond diet provides missing energy, improving production, farmer income and protein use efficiency, and provides essential nutrients often lacking in formulated feeds.[27,28] A healthy pond cost-effectively produces healthy fish that are nutritious to the consumer.

6 | CONCLUDING SECTION

The strategies presented here are not equal in their applicability and complexity. One solution for improved nutrition is farming different

species. Over 600 aquatic species are farmed[29]; this diversity of species is accompanied by a diversity of nutritive values.[5] Improved nutrition in farmed fish through supplemental feed is the most studied and applied strategy, but other strategies represent new research opportunities to enhance aquaculture's nutritional benefits. Traditional selection is effective at improving omega-3 levels in some species. However, there are logistic problems associated with measuring and selecting broodstock,[30] and selecting for other nutrients has not been widely researched. This lack of research is logical given that aquaculturists prioritize maximizing yield of quantity, rather than nutritional yields. FAO revealed that genetic technologies are not being fully utilized in aquaculture even though the gains could be substantial.[31] Breeders may start selecting for omega-3 or other important nutrients when nutrition is prioritized over quantity of fillets. Farming SIS and consuming them whole has contributed to human nutrition in some parts of Asia, but needs to be explored in other parts of the world. Further research and extension to address consumer acceptance, costs and marketing of SIS would be beneficial as would examining the possibility of producing and marketing popular farmed species at a smaller size that could be eaten whole. Ponds produce the majority of farmed fish, yet insufficient research has been directed at managing ponds for more nutritious fish or at enhancing the diversity of production in marine systems by complementing high value farmed species with lower value species that are more financially accessible. Farmers and feed manufactures may be unaware of how the complex interactions between diet, uneaten food and pond micro-organisms impact the nutrient content of farmed fish.

The aquaculture world has historically focused on *producing* more fish; but rarely adopted a food systems approach to optimize human nutrition and health outcomes. This review also omits post-harvest and marketing strategies. In our opinion, pursuing the promising strategies from several disciplines presented here, anchored in a food systems approach, would benefit farmers and consumers, and can help strengthen the role of aquaculture as a key producer of nutritious and healthy food to the world.

AUTHOR CONTRIBUTIONS

Devin M Bartley: Conceptualization; project administration; writing – original draft. **Malcolm Beveridge:** Conceptualization; writing – original draft; writing – review and editing. **Michael J. Phillips:** Conceptualization; writing – original draft; writing – review and editing. **Albert Tacon:** Conceptualization; writing – original draft; writing – review and editing. **Marc Verdegem:** Conceptualization; writing – original draft; writing – review and editing.

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ETHICS STATEMENT

There are no ethical concerns with the article.

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