# Chapter 9
# Sustainable Tilapia Farming, the Role of Culture Systems


**Hien Van Doan**

**Abstract** Considering environmental sustainability and vulnerability to the effects of climate change on fish production, sustainable and adaptable aquaculture systems are necessary". Biofloc technology (BFT) and recirculating aquaculture systems (RAS) are eco-friendly, water efficient, highly productive intensive farming systems, which are not associated with adverse environmental impacts, such as habitat destruction, water pollution and eutrophication, biotic depletion, ecological effects on biodiversity due to captive fish and exotic species escape, disease outbreaks, and parasite transmission. Moreover, BFT and RAS operate in an indoor controlled environment, and thus, are only minimally affected by climatic factors, including rainfall variation, flood, drought, global warming, cyclone, salinity fluctuation, ocean acidification, and sea level rise. This chapter provides into insight the application of these techniques for sustainable tilapia production, which focuses on their effects on growth performance, immune response, and disease resistance.

**Keywords** Tilapia · Sustainable · Biofloc technology · RAS

## 9.1 Introduction

Aquaculture, is one of the fastest food-producing sectors, with an average annual growth rate of 5.3% during the period 2001–2018, and production has increased by over 600% since 1990 (FAO 2020b). Global aquaculture production achieved 82.1 million tons in 2018, of which inland aquaculture produced 51.3 million tons (62%), while coastal and marine aquaculture1 reached 30.8 million tons (38%) (FAO 2020b). Aquaculture is performed in various environments and regions, employing various technologies, and cultured systems, and raising many species (Ahmad et al. 2022). Asia accounts for around 90% of global aquaculture production (FAO 2020a, b), and aquaculture, with its expansion outpacing global population growth,

H. Van Doan (✉)
Department of Animal and Aquatic Sciences, Faculty of Agriculture, Chiang Mai University, Chiang Mai, Thailand



S. H. Hoseinifar, H. Van Doan (eds.), *Novel Approaches Toward Sustainable Tilapia Aquaculture*, Applied Environmental Science and Engineering for a Sustainable Future, https://doi.org/10.1007/978-3-031-38321-2_9

is playing an important role in boosting food production for contribution to food security and human nutrition (Pradeepkiran 2019). Although the expansion of aquaculture, the challenge of feeding a growing global population, which is expected to reach 9.7 billion by 2050 (Bahar et al. 2020), is a vivid reality, which is central in global political and scientific debates (Berners-Lee et al. 2018). Because of population growth and stagnation of capture fisheries, global aquaculture production is challenged to achieve remarkable targets, estimated to possibly reach 109 million tons in 2030 (FAO 2020a, b), and 140 million tons in 2050 (Waite et al. 2014).

To achieve the required further increase in global seafood production, aquaculture is envisaged as the only available solution, but it could bring additional adverse environmental effects if its expansion is not based on sustainable farming systems (Ahmed and Turchini 2021). Accordingly, the rapid growth of aquaculture has been linked to raising concerns about its environmental sustainability (Ahmad et al. 2022; Tom et al. 2021). Broadly, aquaculture has already been increasingly associated with a great variety of negative environmental impacts, including habitat destruction, water pollution and eutrophication, biotic depletion, disease and parasite transmission, and greenhouse gas (GHG) emissions (Ahmed et al. 2019; (Carballeira Braña et al. 2021; Adegbeye et al. 2019; Kosten et al. 2020). For example, some intensive aquaculture practices have been reported to cause antibiotic pollution, eutrophication, land occupation, and other environmental hazards (Dauda et al. 2019). The invasion of exotic fish species in some aquaculture systems has been reported to have potentially negative effects on biodiversity and the ecosystem; (Banha et al. 2022; Kiruba-Sankar et al. 2018). Freshwater aquaculture, particularly tilapia, has been reported to cause adverse effects on water resources with a broad range of impacts on the biodiversity, ecosystems, and societies (Bashir et al. 2020; Kaleem and Bio Singou Sabi 2021; Moyo and Rapatsa 2021). Tilapia aquaculture has also been censured for a variety of environmental issues, including water pollution and pathogen transmission to wild fish (Shaaban et al. 2021). The environment, on the other hand, has a series of impacts and imposes certain limitations on aquaculture, with climate change posing a significant threat to increasing global fish production (Baag and Mandal 2022; Maulu et al. 2021). A wide range of climatic factors, such as rainfall, flood, drought, cyclone, global warming, sea surface temperature change, salinity fluctuation, ocean acidification, and sea level rise have a significant impact on aquaculture practices (Ahmed et al. 2019). In essence, future climate change will certainly have adverse impacts on sustainable increasing aquaculture production (Ahmed et al. 2019; Boyd et al. 2020). It is therefore necessary to develop and implement adaptation strategies to cope with these challenges.

Considering the environmental concerns and impacts, as well as the vulnerability to the effects of climate change and other environmental variables of fish production in aquaculture, one of the potential and increasingly proposed adaptation strategies is the implementation of sustainable aquaculture systems, such as BFT and RAS. These systems allow for rising fish in a land-based, indoor, and controlled environment to minimize the direct interactions between the production processes and the environment (Ahmed and Turchini 2021; Khanjani et al. 2022). They offer benefits

in improving aquaculture production that could contribute to the achievement of sustainable development goals (Bossier and Ekasari 2017; Nguyen et al. 2021). This technology could result in higher productivity with less impact on the environment. Furthermore, biofloc systems may be developed and performed in integration with other food production, thus promoting productive integrated systems, aiming at producing more food and feed from the same area of land with less input (Nisar et al. 2022). The chapter aims to address different aspects of BFT and RAS as alternatives for sustainable tilapia production.

## 9.2 Biofloc Technology

### *9.2.1 History of Biofloc Technology (BFT)*

The biofloc system (BFT) evolved as an alternative to the conventional aquaculture system that is used in shrimp and tilapia productions (Ulloa Walker et al. 2020). It originated in the 1970s at the French Research Institute for Exploitation of the Sea (IFREMER) with Gerard Cuzon as the pioneer (Emerenciano et al. 2012; Devi and Kurup 2015). The BFT was then widely applied in commercial shrimp farming (Samocha et al. 2019). In the 1990s, different studies at pilot and commercial scales were conducted in the USA with penaeid shrimp led by J. Stephen Hopkins and with finfish at the Technion-Israel Institute of Technology led by Yoram Avnimelech (Emerenciano et al. 2013). In the mid-2000s, several studies on penaeid shrimp were conducted at the Federal University of Rio Grande-FURG (Brazil) led by Wilson Wasielesky and the Texas A&M University (Corpus Christi Campus, USA) led by Tzachi Samocha. After that, there was a significant increase in the number of scientific publications about biofloc technology worldwide. The number has increased from less than 10 in 2009 to more than 100 publications in 2018, with studies conducted mainly in Brazil, China, the United States of America, Mexico, and India (Ulloa Walker et al. 2020), helping to strengthen the technology and boost the industry. Another important factor for such progress was the wide range of courses and lectures offered in both scientific and commercial events for the scientific community, academia, and aquaculturists. However, despite the progress and benefits of BFT as reported by the scientific community and academia, there is still room for its commercial expansion. For example, in Indonesia, it is estimated that only 20–25% of shrimp production has occurred using biofloc technology (Thong 2014). Among the reasons behind such a scenario are the higher implementation and production costs compared to traditional land-based systems, and the complexities in the management and implementation of the technology, which requires greater technical knowledge and permanent monitoring of water quality (Avnimelech 2015).

### 9.2.2 Principles of Biofloc Technology

The BFT operates on the principle of nutrient recycling by maintaining a higher carbon: nitrogen (C: N) ratio above 15 to stimulate the mass growth of heterotrophic bacteria (Guo et al. 2020). Higher C: N ratio is maintained when more carbon sources, such as molasses, cassava, hay, sugarcane, starch, wheat bran, cellulose, etc., are sprayed on the surface of pond water with continuous aeration (Ogello et al. 2021). Under favorable BFT conditions, up to 0.5 g of heterotrophic bacterial biomass $g^{-1}$ substrate of carbon can be produced (Eding et al. 2006). With the information that 1 g of carbon produces 0.5 g of bacteria, farmers can estimate quantities of floc in the culture systems (Nisar et al. 2022). The biofloc process stimulates the natural growth of macro-aggregates of organisms that enhance self-nitrification in the culture water (Jamal et al. 2020).

In outdoor BFT systems, the photosynthetic pathway that produces algae normally precedes the bio-flocking process (Ogello et al. 2021). The algae provide a substrate to which the bioflocs attach and are usually referred to as green bioflocs (Ahmad et al. 2017; Khanjani and Sharifinia 2020). Under indoor conditions, bioflocs are mainly bacteria and are referred to as brown bioflocs (El-Sayed 2021; Emerenciano et al. 2021). With the addition of an adequate carbon source bacterial floc stimulates a second production line that involves the degradation of organic wastes by bacteria to produce billions of bacterial cells under optimum aeration conditions (Khanjani et al. 2022). During this process, autotrophic and heterotrophic bacteria proliferate and attract billions of other cells including diatoms, fungi, algae, protozoans, and various types of plankton (Avnimelech 2007; Bossier and Ekasari 2017). The traditional aquaculture ponds lack injection of carbon source, and aeration mechanisms and thus harbor fewer and less diverse bacterial communities, as opposed to BFT (Felix and Menaga 2021). Small quantities of bacteria cannot form substantial flocs in the culture system. The sediment of traditional ponds accumulates higher quantities (49%) of nitrogenous waste while the BFT pond sediments have less (5%) nitrogenous waste (Ogello et al. 2021).

### 9.2.3 Biofloc in Tilapia

Tilapia has played an important role in global aquaculture in recent decades (FAO 2020a). It ranks the second most cultured fish species worldwide due to its fast growth, resistance to various environmental conditions, and capability of being produced in dense and ultra-dense forms (Menaga et al. 2019; Avnimelech 2007; Avnimelech 2015; Khanjani et al. 2021). Moreover, tilapia is an omnivore species that filter food particles and easily feeds on a rich natural food source and biofloc-dependent microorganisms (Durigon et al. 2020; Prabu et al. 2019). Considering the above considerations, tilapia is a suitable candidate for the biofloc system (Khanjani et al. 2022). The biofloc technique has been accepted in many countries over the past

decade (Vyas 2020). Currently, the biofloc technique has been successfully developed in large-scale farms in Asia (China, South Korea), Latin America, and Central America, as well as on a small scale in the United States, Italy, and other countries. In addition, many research centers and academic institutions are expanding BFT, mainly in key areas such as growth, nutrition, reproduction, microbial ecology, biotechnology, and economics (Khanjani and Sharifinia 2020).

#### 9.2.3.1 Biofloc as Growth Promoters

In situ utilization of microbial flocs generated in biofloc systems by some aquaculture organisms as well as the utilization of processed biofloc as a feed ingredient has been well documented (Kuhn et al. 2009; Kuhn et al. 2010; Anand et al. 2014). It has been demonstrated that the concentrations of free amino acids such as alanine, glutamate, arginine, and glycine, which are known attractants in the shrimp diet, are present in biofloc (Vyas 2020; Ahmad et al. 2017). Levels in biofloc were found to be comparable to that of the shrimp commercial diet suggesting that biofloc are likely to be recognized as food particles by some aquaculture organisms. Furthermore, biofloc technology application in larviculture may provide an easily accessible food source for the larvae outside the regular feeding moments, thus minimizing possible negative social interaction during feeding (Ekasari et al. 2015b).

Studies by various researchers have reported that the biofloc system improves the growth performance of the Nile tilapia (Azim and Little 2008; Luo et al. 2013; Mirzakhani et al. 2019; Khanjani et al. 2021; Table 9.1). The improved growth performance was attributed to optimum water quality and continuous production of biofloc. Biofloc contains poly beta-hydroxybutyrate (De Schryver and Verstraete 2009) and bioactive compounds, such as carotenoids, chlorophylls, and phytosteroids that promote the growth of cultured aquatic organisms. The adaptability of tilapia to biofloc consumption and digestion of microbial protein has been demonstrated in several studies (Azim and Little 2008). Avnimelech (2007) reported that the production of biofloc in fish ponds can meet 50% of tilapia's protein requirements. Khanjani et al. (2021) found that tilapia feed better on the biofloc impacted by molasses daily, resulting in the highest biomass increase and the lowest feed conversion ratio. Based on their results, the highest feed conversion ratio and the lowest protein efficiency were observed in the control treatment without biofloc. Researchers have found that a combination of biofloc and artificial foods improves feed conversion ratio and feed efficiency (Khanjani et al. 2021; Mirzakhani et al. 2019).

Biofloc includes bacterial proteins, polyhydroxy butyrate, and bacteria containing peptidoglycan or lipopolysaccharides, which can promote growth performance (Khanjani and Sharifinia 2020). In addition, biofloc have probiotic properties that help fish in digestion and absorption of artificial diets. In the study using orange peel-derived pectin (OPDP) added to the biofloc system, Doan et al. (2018) indicated that the inclusion of 10 g $kg^{-1}$ OPDP significantly improved the growth performance and feed utilization of Nile tilapia. Similarly, a significant increase in growth

**Table 9.1** Weight gain (WG), Specific growth rate (SGR), Food conversion efficiency (FCE), Food conversion ratio (FCR), Protein efficiency ratio (PER), Survival rate (SR), and digestive enzyme of Nile tilapia in biofloc and RAS systems

| Studied systems | Studies parameters | Fish species | Doses and supplementations duration | Results | References |
|---|---|---|---|---|---|
| BFT | Orange peels derived pectin (OPDP) | Nile tilapia (*Oreochromis niloticus*) (9.09 ± 0.05 g) | 0 (control in clear water), 0 (control in biofloc system), 5, 10, and 20 g $kg^{-1}$ OPDP for 8 weeks | SGR, WG, and FW ↑<br>FCR ↓ | Doan et al. (2018) |
| BFT | Stocking density | Tilapias (0.51 ± 0.05 g) | 166 orgs $m^{-3}$ (LD, low density), 333 orgs $m^{-3}$ (MD, middle density) and 600 orgs $m^{-3}$ (HD, high density)<br>120 days | Growth performance ↓<br>FCR ↑ | Liu et al. (2018) |
| BFT | Carbon sources | Nile tilapia (*O. niloticus*) 2.7 ± 0.4 g | 100% of MO, 75% of MO+ 25% of WF, 50% of MO+ 50% of WF, 25% of MO+ 75% of WF,and 100% of WF | Growth performance ↑ | Mirzakhani et al. (2019) |
| BFT | Pizzeria by-product | Nile tilapia (*O. niloticus*) (2.90 ± 0.02 g) | 0, 20, 40, 60, 80 and 100%<br>38 days | Growth performance ↑<br>Economic benefits ↑ | de Sousa et al. (2019) |
| BFT | Dietary digestible protein and digestible energy | Nile tilapia (*O. niloticus*) (1.25 ± 0.15 g) | Digestible protein (22, 26 and 30% DP) and digestible energy (3000, 3150 and 3300 kcal $kg^{-1}$)<br>42 days | Pepsine activity ↑<br>Trypsine activity ↑ | Durigon et al. (2019) |
| BFT | Carbon sources | Fingerlings | Corn flour (CF), wheat flour (WF), sugar (SU) and a control (C) | FCR and water ↓<br>Survival rate ↑ | García-Ríos et al. (2019) |
| BFT | OPDP and *L. plantarum* | Nile tilapia (*O. niloticus*) (1.25 ± 0.15 g) 5.92 ± 0.08 g | Diet 1 (0 g $kg^{-1}$ OPDP and 0 CFU $g^{-1}$ *L. plantarum*), diet 2 (10 g $kg^{-1}$ OPDP), diet 3 (108 CFU $g^{-1}$ *L. plantarum*), and diet 4 (10 g $kg^{-1}$ OPDP +108 CFU $g^{-1}$ *L. plantarum*) | Growth performance ↑<br>FCR ↓ | Van Doan et al. (2019) |

| | | | | | |
|---|---|---|---|---|---|
| BFT | *in-situ* and *ex-situ* biofloc | Nile tilapia (*O. niloticus*) (5.1 ± 0.05 g/fish) | T1-biofloc developed within the culture systems (*insitu*), T2-biofloc supplementation in fish feed (*exsitu*) and C- Control without biofloc | Growth performance ↑ | Menaga et al. (2019) |
| BFT | Biochar | Nile tilapia (*O. niloticus*) (36.2 g/fish) | B; only biochar, GB; biochar + glucose, while for the control (G) only glucose | Growth performance → | Abakari et al. (2020) |
| BFT | Jaggery-based BFT | Nile tilapia (*O. niloticus*) (32.2 ± 10.1 g/fish) | 22.5%, 27.7%, and 32.3% digestible protein (DP) and 6% lipid | Growth performance ↑ | Elayaraja et al. (2020) |
| BFT | Chestnut polyphenols (CSP) | Nile tilapia (*O. niloticus*) (12.77 ± 0.17 g) | 0, 1, 2, 4, and 8 g $kg^{-1}$ of CSP | Growth performance ↑ | H. Van Doan et al. (2020a) |
| BFT | Watermelon rind powder (WMRP) | Nile tilapia (*Oreochromis niloticus*) (17.14 ± 0.12 g) | 0 (Diet 1- control), 20 g $kg^{-1}$ WMRP (Diet 2), 40 g $kg^{-1}$ WMRP (Diet 3), 80 g $kg^{-1}$ WMRP (Diet 4), and 160 g $kg^{-1}$ WMRP (Diet 5) | Growth performance ↑<br>FCR ↓ | Hien Van Doan et al. (2020b) |
| BFT | Phosphatidylcholine | Nile tilapia (*O. niloticus*) 8.03 ± 0.03 g | 0, 400, 800 and 1200 mg/kg of feed<br>40 days | Growth performance →<br>Energy metabolism ↑ | Sousa et al. (2020) |
| BFT | *Tenebrio molitor* meal (TM) | Nile tilapia (*O. niloticus*) (2.08 ± 0.19 g) | 0% or control, 5, 10, 15 and 20% of TM | Productivity and survival rate ↑ | Tubin et al. (2020) |
| BFT | Density and dietary carbon sources | Nile tilapia (*O. niloticus*) (50.47 ± 0.05 g) | Stocking densities [20, 40 and 60 fish per $m^3$] and fed the basal diet without carbon sources or with broken rice flour (BRF) or broken wheat grain flour (BWGF)<br>84 days | Growth performance ↑<br>Feed utilization ↑ | Zaki et al. (2020) |

(continued)

**Table 9.1** (continued)

| Studied systems | Studies parameters | Fish species | Doses and supplementations duration | Results | References |
|---|---|---|---|---|---|
| BFT | Pineapple peel powder (PAPP) | Nile tilapia (*O. niloticus*) (20.91 ± 0.11 g) | 0, 10, 20, 30 and 40 g $kg^{-1}$ PAPP 8 weeks | Growth performance ↑ FCR ↓ | Van Doan et al. (2021a) |
| BFT | Watermelon rind powder (WMRP) + *L. plantarum* | Nile tilapia (*O. niloticus*) (16.57 ± 0.14 g) | Diet 1 (0 g $kg^{-1}$ WMRP and 0 CFU $g^{-1}$ L. *plantarum*) (control), Diet 2 (40 g $kg^{-1}$ WMRP), Diet 3 ($10^8$ CFU $g^{-1}$ LP), and Diet 4 (40 g $kg^{-1}$ WMRP + $10^8$ CFU $g^{-1}$ LP) 8 weeks | Growth performance ↑ FCR ↓ | Van Doan et al. (2021b) |
| BFT | Pineapple peel powder (PAPP) + *L. plantarum* | Nile tilapia (*O. niloticus*) (20.91 ± 0.11 g) | Diet 1 (0 g $kg^{-1}$ PAPP and 0 CFU $g^{-1}$ L. *plantarum*) (control), Diet 2 (10 g $kg^{-1}$ PAPP), Diet 3 ($10^8$ CFU $g^{-1}$ LP), and Diet 4 (10 g $kg^{-1}$ PAPP + $10^8$ CFU $g^{-1}$ LP) 8 weeks | Growth performance ↑ FCR ↓ | Van Doan et al. (2021d) |
| BFT | Amla (*Phyllanthus emblica*) fruit extract | Nile tilapia (*O. niloticus*) (10.48 ± 0.56 g) | 0, 5, 10, 20, and 40 mg $kg^{-1}$ AFE 8 weeks | Growth performance ↑ FCR ↓ | Van Doan et al. (2022b) |
| BFT | Light levels | Nile tilapia (*O. niloticus*) (1.73 ± 0.16 g) | 24 h of light (24hL), 12 h of light/12 h of darkness (12hL/12hD) and 24 h of darkness (24hD) | Carcass quality ↑ Digestive and hepatic enzymes ↑ | Khanjani and Sharifinia (2021) |
| BFT | Symbiotics | Nile tilapia (*O. niloticus*) (30–35 g) | BFT with and without symbiotics 40 days | Growth performance ↑ | Laice et al. (2021) |
| BFT | Stocking densities | Nile tilapia (*O. niloticus*) (133.91 g) | 18.75, 37.50, 56.25, and 75.00 fish·$m^{-3}$ 260 days | Growth performance ↑ | Manduca et al. (2021) |

| | | | | | |
|---|---|---|---|---|---|
| | Beneficial bacteria | Nile tilapia (*O. niloticus*) (8.63 ± 3.35g) | T1, SR control; T2, SR + SSP; T3, SR + MSP; T4, BF + MSP; T5, BF + SSP; T6, BF control<br>112 days | Growth performance ↑ | Mohammadi et al. (2021) |
| BFT | Coffee silverskin (CSS) | Nile tilapia (*O. niloticus*) (15.54 ± 0.21 g) | CSS1 (Control), CSS2 (10 g kg−1), CSS3 (20 g kg−1), CSS4 (40 g kg−1), and CSS5 (80 g kg−1)<br>8 weeks | Growth performance ↑<br>FCR ↓ | Van Doan et al. (2021c) |
| BFT | Carbon sources and stocking densities | Nile tilapia (*O. niloticus*) (5.15 ± 1.12 g) | Low stocking density (LSD), 140 fish /$m^3$ and high stocking density, (HSD), 280/$m^3$<br>98 days | Growth performance ↑ | El-Hawarry et al. (2021) |
| BFT | Salinities | Nile tilapia (*O. niloticus*) (13.78 ± 0.62 g) | T1 (5 ppt), T2 (10 ppt), T3 (15 ppt), T4 (20 ppt) and control (0 ppt)<br>90 days | Growth performance ↑<br>Survival rate ↑<br>Carcass quality ↑ | Kumari et al. (2021) |
| BFT | Dietary phytase | Nile tilapia (*O. niloticus*) (29.8 g) | 6-phytase (3000 FTU/kg; Quantum Blue™; P-F + Phy), and positive (C) and negative (P-F) control<br>154–156 days | Growth performance → | Green et al. (2021) |
| BFT | Spent coffee grounds (SCG) | Nile tilapia (*O. niloticus*) (15.25 ± 0.07 g) | SCG1 (control), SCG2 (10 g $kg^{-1}$), SCG3 (20 g $kg^{-1}$), SCG4 (40 g $kg^{-1}$), and SCG5 (80 g $kg^{-1}$)<br>8 weeks | Growth performance ↑<br>FCR ↓ | Van Doan et al. (2022a) |
| BFT | Host-associated probiotic *Bacillus altitudinis* B61-34b | Nile tilapia (*O. niloticus*) (25.50 ± 0.52 g) | 0 (BAA1—Control), $10^6$ (BAA2), $10^7$ (BAA3), $10^8$ (BAA4) and $10^9$ (BAA5) CFU $ml^{-1}$<br>8 weeks | Growth performance ↑<br>FCR ↓ | Van Doan et al. (2021e) |
| BFT | Host-associated probiotic *Lactobacillus paracasei* l61-27b | Nile tilapia (*O. niloticus*) (25.40 ± 0.52 g) | LP1 = 0 (Control), LP2 = $10^6$ CFU $mL^{-1}$, LP3 = $10^7$ CFU $mL^{-1}$, LP4 = $10^8$ CFU $mL^{-1}$, and LP5 = $10^9$ CFU $mL^{-1}$)<br>8 weeks | Growth performance ↑<br>FCR ↓ | Van Doan et al. (2021c) |
| BFT | Grade feeding rates | Nile tilapia (*O. niloticus*) (3.1 ± 0.1 g) | 0%, 2.5%, 5.0%, 7.5%, and 10% of body weight per day<br>70 days | Growth performance ↑ | Oliveira et al. (2021) |

(continued)

**Table 9.1** (continued)

| Studied systems | Studies parameters | Fish species | Doses and supplementations duration | Results | References |
|---|---|---|---|---|---|
| BFT | 17-α-methyltestosterone | Nile tilapia (*O. niloticus*) (Fry) | 60, 90, 120, 150 and 180 mg $kg^{-1}$ | Masculinization rates ↑ | Costa e Silva et al. (2022) |
| BFT | Feeding levels and stocking densities | Nile tilapia (*O. niloticus*) (3.2 ± 0.05 g) | Feeding levels (0, 15, 30, 45 and 100) and 2 stocking densities (500 fish/$m^3$ and 1000fish/$m^3$) | Growth performance ↑ | Sarsangi Aliabad et al. (2022) |
| BFT | Longan seed powder (LS) | Nile tilapia (*O. niloticus*) (13.82 ± 0.06 g) | Control (LS0), 10 (LS10), 20 (LS20), 40 (LS40), and 80 (LS80) g $kg^{-1}$ LS<br>8 weeks | Growth performance ↑<br>FCR ↓ | Wannavijit et al. (2022) |
| BFT | Rambutan seed (RS) | Nile tilapia (*O. niloticus*) (14.77 ± 0.80 g) | 0, 5, 10, 20, and 40 g $kg^{-1}$ of RS<br>8 weeks | Growth performance ↑<br>FCR ↓ | Xuan et al. (2022) |
| BFT | Rambutan peel (RP) | Nile tilapia (*O. niloticus*) (17.14 ± 0.12 g) | 0 g $kg^{-1}$ (control – RP0); 10 g $kg^{-1}$ (RP10); 20 g $kg^{-1}$ (RP20); 40 g $kg^{-1}$ (RP40), and 80 g $kg^{-1}$ (RP80)<br>8 weeks | Growth performance ↑<br>FCR ↓ | Le Xuan et al. (2022) |
| BFT | Chitosan | Nile tilapia (*O. niloticus*) (1.70 ± 0.36 g) | 30, 60 and 90 ppm and 10, 20 and 30 ppm of chitosan | Growth performance ↑<br>Digestive enzymes ↑<br>FCR ↓ | Chutia et al. (2022) |
| RAS | Light intensity and photoperiod | Nile tilapia (*O. niloticus*) (5 ± 0.9 g) | (1000, 2000, and 3000 lx) and photoperiods (12L:12D, 18L:6D, 24L:0D)<br>160 days | Growth performance ↑<br>FCR ↓<br>Stress → | Wang et al. (2020) |

| | | | | | |
|---|---|---|---|---|---|
| RAS | Magnetic field | Nile tilapia (*O. niloticus*) (7.16 ± 0.05 g) | 0.00, 0.10, 0.15 and 0.20 T<br>70 days | Growth performance ↑<br>FCR ↓ | Hassan et al. (2018) |
| RAS | Rearing systems and dietary probiotic | Nile tilapia (*O. niloticus*) (embryos) | FTS + control diet, RAS + control diet and RAS + *B. subtilis* coated diet (RASB)<br>33 days | Survival rate ↑<br>Beneficial bacteria in gut ↑ | Deng et al. (2022) |
| BFT-RAS | Culture systems | Nile tilapia (*O. niloticus*) (0.17 ± 0.00 g) | Clear-water (CW), biofloc (BF), or hybrid (HY)<br>9 weeks | Growth performance ↑<br>FCR ↓ | Fleckenstein et al. (2018) |
| RAS + BFT | Nitrogen and phosphorus budgets | Nile tilapia (*O. niloticus*) (3.54 ± 2.82 g) | (BFT) aquaculture system and a recirculation aquaculture system (RAS) during over-wintering of tilapia<br>64 days | Recovery rate of N in BFTSs ↑<br>P recovery rate →| Cao et al. (2020) |
| BFT-RAS | Protein levels | Nile tilapia (*O. niloticus*) (39.1 ± 2.5 g) | 23, 27, 31 or 35% crude protein<br>9 weeks | Growth performance ↑<br>FCR ↓ | Nguyen et al. (2021) |

performance and feed utilization were observed in Nile tilapia fed dietary inclusion of OPDP and *Lactobacillus plantarum*, chestnut polyphenols (CSP), watermelon rind powder (WMRP), pineapple peel powder (PAPP), watermelon rind powder (WMRP) + *L. plantarum*, pineapple peel powder (PAPP) + *L. plantarum*, amla (*Phyllanthus emblica*) fruit extract, coffee silverskin (CSS), spent coffee grounds (SCG) (Van Doan et al. 2019; 2020a, b; 2021a, b, c, d; 2022a, b). Significant improvement in growth performance and FCR may be attributable to the bioactive compounds of these supplementations, which act not only as a nutrient source for fish but also are carbon sources for microbial protein production in biofloc systems. In studies using host-associated probiotics (*Bacillus altitudinis* B61-34b and *Lactobacillus paracasei* l61-27b), the authors indicated that supplementation of host-associated probiotics in indoor biofloc system resulted in better growth performance and feed utilization compared to the control group. This may be due to the complementary roles of biofloc and *B. altitudinis*. Numerous investigations have demonstrated that biofloc offers an essential nutrient source for tilapia (Ekasari et al. 2014a; Green et al. 2019). The addition of *Bacillus* spp. in cultured water or diets lowers ammonium levels in fish culture systems (Dash et al. 2018; Elsabagh et al. 2018). Furthermore, the presence of favorable microbial flocs and external probiotics will likely boost the number of valuable microbiota in the tilapia's digestive system (Rohani et al. 2022; de Sousa et al. 2019). Increased secretion of digestive enzymes through the colonization of bacteria facilitates the absorption of nutrients by the intestinal epithelial cells (Liu et al. 2017). *Bacillus* produces many biological substances, including cellulase, phytase, tannase, chitinase, xylanase, protease, amylase, and lipase (Ringø 2020). Favorable bacteria also release several nutrients, in particular vitamins, amino acids, and fatty acids, and diminish lethal feedstuffs and infectious bacteria (Zaineldin et al. 2021). Recently, the dietary inclusion of rambutan and long seed powder or rambutan peel in the Nile tilapia diet led to an increase in growth rate and feed utilization (Xuan et al. 2022; Wannavijit et al. 2022). It has been reported that these seeds are known as carbon sources (Yang et al. 2015; Lawtae and Tangsathitkulchai 2021) and has hence been used in biofloc system (Liu et al. 2019). It has been observed that adding carbon to a biofloc system causes heterotrophic bacteria to utilize the inorganic nitrogen by changing the water C: N ratio, resulting in a higher microbic protein source for the host and improved water quality (Guo et al. 2020). In addition, incorporating a carbon source leads to the formation of biofloc, a new protein source for fish (Krummenauer et al. 2020; Tinh et al. 2021). Additionally, these products also act as potential prebiotics or carbohydrate (Estrada-Gil et al. 2022; Jahurul et al. 2020). Similarly, supplementation of pizzeria by-product de Sousa et al. (2019); dietary digestible protein and digestible energy (Durigon et al. 2019); phosphatidylcholine (Sousa et al. 2020); *Tenebrio molitor* meal (TM) (Tubin et al. 2020); symbiotics (Laice et al. 2021); beneficial bacteria (Mohammadi et al. 2021); dietary phytase (Green et al. 2021), and chitosan (Chutia et al. 2022) led to higher growth rate and feed utilization.

Another common study aspect using biofloc technology is the application of different carbon sources and their effects on tilapia growth and feed conversion ratio. (Mirzakhani et al. (2019) reported that fish in a biofloc system with 100% of wheat

flour at a C:N ratio of 15:1 showed the highest growth performance with improved intestine histoarchitecture. Wheat flour as a major source of starch and energy can also provide substantial amounts of other nutrients such as protein, vitamins, and phytochemicals and especially high fiber content (ca. 12%) compared to the lower fiber content in molasses (ca. 0.5%) (Shewry and Hey 2015). These nutrients might enhance the biochemical composition and bioactive compounds of biofloc. In addition, dispersed particles of wheat flour in water may provide a good substrate for the development and growth of microorganisms and bacteria because of which the nutrition value of the produced biofloc increases, ultimately influencing the fish growth and immune response (Mirzakhani et al. (2019). García-Ríos et al. (2019) indicated that the fingerlings obtained in BFT, with corn and sugar as C sources, had a similar growth rate to the control. However, the BFT promotes significant savings in feed (41.1 to 58.9%) and water (67.4 to 75.5%) compared to the traditional method. Similar results were in the study of Zaki et al. (2020), where the authors indicated that Increased growth and feed utilization were recorded in 40 fish per $m^3$ fed with broken rice flour. El-Hawarry et al. (2021) also found that the growth rate was improved in the groups of fish under low stocking density with molasses and glycerol as carbon sources. Carbon source affects the cultured species' growth depending on the formatted biofloc characteristics, such as its "volume, chemical composition, and ability to store bioactive compounds (Wang et al. 2015; Zhao et al. 2016). Additionally, microbial flocs which are formed from different carbon sources act as a supplemental food source that constantly provides additional essential amino acids profile (microbial protein), polyunsaturated fatty acids, minerals, vitamins, and an external source of digestive enzymes (Avnimelech 2007; Azim and Little 2008; Bakhshi et al. 2018; De Schryver and Verstraete 2009). In contrast, the use of biochar as an alternative carbon source for biofloc technology did not affect the growth rate of Nile tilapia (Abakari et al. 2020). Although biochar is regarded as a recalcitrant carbon source, the utilization of biochar-derived carbon by heterotrophic bacteria has been described (Farrell et al. 2013).

Effects of stocking density on Nile tilapia growth raised in biofloc systems have been conducted by several researchers. Liu et al. (2018) showed that low stocking density (166 fish/$m^{-3}$) improved growth performance and FCR of Nile tilapia raised in the biofloc system. Similarly, Manduca et al. (2021) reported that tilapia stocking density in BFT around 33 fish $m^{-3}$ had higher profitability since it produces a large proportion of harvested fish that reach high body weights, and possibly high selling prices, combined with desirable biomass. Recently, Sarsangi Aliabad et al. (2022) also suggested that the stocking density of 1000/$m^3$ for larviculture of tilapia in BFT uses water and equipment more efficiently. Biofloc acts as the natural food that contributes significantly to the nutrition of tilapia fingerlings, allowing the reduction of the feeding rations. Biofloc consumption corresponds to 50% of the daily food of tilapia (Avnimelech 2007). Another study revealed that 25% of the protein requirement of tilapia could be provided by floc consumption (Avnimelech 2015). Besides, significantly improved growth performance, FCR, and digestive enzymes were observed in Nile tilapia raised in biofloc combined with different conditions, such as in-situ and ex-situ biofloc (Menaga et al. 2019), jaggery-based BFT (Elayaraja

et al. 2020); light levels (Khanjani and Sharifinia 2021); salinities (Kumari et al. 2021); grade feeding rates (Oliveira et al. 2021), and 17-α-methyltestosterone (Costa e Silva et al. 2022).

#### 9.2.3.2 Biofloc as Immunostimulants

Bioflocs also offer a lot of MAMPs (microbial-associated molecular patterns), which may be recognized as immunostimulants, resulting in higher resistance to diseases (Ekasari et al. 2014b, 2015a). Additionally, it consists of a wide range of organic compounds, such as carotenoids, chlorophylls, bromophenols, phytosterols, and antibacterials that have a positive effect on immune factors of cultivated aquatic species (Crab et al. 2010; Najdegerami et al. 2016; Bakhshi et al. 2018; Mirzakhani et al. 2019).

The effects of biofloc in combination with different functional feed additives on the immune response of Nile tilapia have been reported in previous studies (Doan et al. 2018; Van Doan et al. 2019, 2020a, b; 2021a, b, c, d; 2022a, b; Xuan et al. 2022; Le Xuan et al. 2022; Wannavijit et al. 2022; Table 9.2). Similar findings were observed in Nile tilapia fed in-situ and ex-situ biofloc (Menaga et al. 2019); phosphatidylcholine (Sousa et al. 2020); symbiotics (Laice et al. 2021); beneficial bacteria (Mohammadi et al. 2021), and probiotics (Bañuelos-Vargas et al. 2021). These substances act as immunostimulants and/or carbon sources for the proliferation of microbial proteins in the biofloc system.

Carbon source applications in the biofloc system could result in better immune response in Nile tilapia. Mirzakhani et al. (2019) indicated that fish reared in a biofloc system based on 100% wheat flour and a C/N ratio of 15 demonstrated the humoral immune response. Similarly, a significant increase in innate and specific immune responses was observed in Nile tilapia raised in biofloc with biochar (Abakari et al. 2020) and jaggery-based BFT (Elayaraja et al. 2020) as carbon sources. Carbon sources play a vital role in the proliferation of microbial protein in biofloc systems, which in turn act as immunostimulants for culture species (Panigrahi et al. 2019). Carbon sources and stocking densities also have a great impact on Nile tilapia's immune response raised under the biofloc system. El-Hawarry et al. (2021) indicated that the growth rate and growth-related genes were improved in the groups of fish under low stocking density (LSD) with molasses and glycerol as carbon sources. Recently, (Sarsangi Aliabad et al. 2022) also reported that the BFT system improved water quality, growth performance, and immune function of Nile tilapia fry.

#### 9.2.3.3 Biofloc as Disease Prevention Techniques

In biofloc systems, aquaculture animals may also benefit from reduced pathogen pressure (Bossier and Ekasari 2017). Some studies demonstrated that the presence of potentially pathogenic bacteria might be reduced in biofloc systems (Gustilatov et al. 2022; de Lima Vieira et al. 2021; Khanjani et al. 2022; Table 9.3). Increase disease

**Table 9.2** Immune responses of tilapia cultured biofloc system

| Studied systems | Studies parameters | Fish species | Doses and supplementations duration | Results | References |
|---|---|---|---|---|---|
| BFT | Stocking density | Tilapias (0.51 ± 0.05 g) | 166 orgs $m^{-3}$ (LD, low density), 333 orgs $m^{-3}$ (MD, middle density) and 600 orgs $m^{-3}$ (HD, high density)<br>120 days | Lysozyme activity ↓<br>Complement 3 activity ↓<br>Glutathione level ↓ | Liu et al. (2018) |
| BFT | Orange peels derived pectin | Nile tilapia (9.09 ± 0.05 g) | 0 (control in clear water), 0 (control in biofloc system), 5, 10, and 20 g $kg^{-1}$ OPDP for 8 weeks | Skin mucus immunity ↑<br>Serum immunity ↑ | Doan et al. (2018) |
| BFT | *in-situ* and *ex-situ* biofloc | Nile tilapia (*O. niloticus*) (5.1 ± 0.05 g/fish) | T1-biofloc developed within the culture systems (*insitu*), T2-biofloc supplementation in fish feed (*exsitu*) and C- Control without biofloc | Immune gene expressions ↑ | Menaga et al. (2019) |
| BFT | Carbon sources | Nile tilapia (*O. niloticus*) 2.7 ± 0.4 g | 100% of MO, 75% of MO+ 25% of WF, 50% of MO+ 50% of WF, 25% of MO+ 75% of WF,and 100% of WF | Humoral immune responses ↑ | Mirzakhani et al. (2019) |
| BFT | OPDP and *L. plantarum* | Nile tilapia (*O. niloticus*) (1.25 ± 0.15 g) 5.92 ± 0.08 g | Diet 1 (0 g $kg^{-1}$ OPDP and 0 CFU $g^{-1}$ *L. plantarum*), diet 2 (10 g $kg^{-1}$ OPDP), diet 3 (108 CFU $g^{-1}$ *L. plantarum*), and diet 4 (10 g $kg^{-1}$ OPDP +108 CFU $g^{-1}$ *L. plantarum*) | Skin mucus immunity ↑<br>Serum immunity ↑ | Van Doan et al., (2019) |
| BFT | Biochar | Nile tilapia (*O. niloticus*) (36.2 g/fish) | B; only biochar, GB; biochar + glucose, while for the control (G) only glucose | Immune parameters ↑ | Abakari et al. (2020) |
| BFT | Jaggery-based BFT | Nile tilapia (*O. niloticus*) (32.2 ± 10.1 g/fish) | 22.5%, 27.7%, and 32.3% digestible protein (DP) and 6% lipid | Innate immunity ↑<br>Immune gene expressions ↑ | Elayaraja et al. (2020) |

(continued)

**Table 9.2** (continued)

| Studied systems | Studies parameters | Fish species | Doses and supplementations duration | Results | References |
|---|---|---|---|---|---|
| BFT | Chestnut polyphenols (CSP) | Nile tilapia (*O. niloticus*) (12.77 ± 0.17 g) | 0, 1, 2, 4, and 8 g $kg^{-1}$ of CSP | Skin mucus immunity ↑ Serum immunity ↑ | Van Doan et al. (2020a) |
| BFT | Watermelon rind powder (WMRP) | Nile tilapia (*O. niloticus*) (17.14 ± 0.12 g) | 0 (Diet 1- control), 20 g $kg^{-1}$ WMRP (Diet 2), 40 g $kg^{-1}$ WMRP (Diet 3), 80 g $kg^{-1}$ WMRP (Diet 4), and 160 g $kg^{-1}$ WMRP (Diet 5) | Immune responses ↑ | Van Doan et al. (2020b) |
| BFT | Phosphatidylcholine | Nile tilapia (*O. niloticus*) | 0, 400, 800 and 1200 mg/kg of feed | Antioxidant enzymes Lipoperoxidation in liver ↓ | Sousa et al. (2020) |
| BFT | Pineapple peel powder | Nile tilapia (*O. niloticus*) (20.91 ± 0.11 g) | 0, 10, 20, 30 and 40 g $kg^{-1}$ PAPP 8 weeks | Skin mucus immunity ↑ Serum immunity ↑ | Van Doan et al. (2021a) |
| BFT | Watermelon rind powder (WMRP) + *L. plantarum* | Nile tilapia (*O. niloticus*) (16.57 ± 0.14 g) | Diet 1 (0 g $kg^{-1}$ WMRP and 0 CFU $g^{-1}$ L. *plantarum*) (control), Diet 2 (40 g $kg^{-1}$ WMRP), Diet 3 ($10^8$ CFU $g^{-1}$ LP), and Diet 4 (40 g $kg^{-1}$ WMRP + $10^8$ CFU $g^{-1}$ LP) 8 weeks | Skin mucus immunity ↑ Serum immunity ↑ | Van Doan, Seyed Hossein Hoseinifar, et al. (2021b) |
| BFT | Pineapple peel powder (PAPP) + *L. plantarum* | Nile tilapia (*O. niloticus*) (20.91 ± 0.11 g) | Diet 1 (0 g $kg^{-1}$ PAPP and 0 CFU $g^{-1}$ L. *plantarum*) (control), Diet 2 (10 g $kg^{-1}$ PAPP), Diet 3 ($10^8$ CFU $g^{-1}$ LP), and Diet 4 (10 g $kg^{-1}$ PAPP + $10^8$ CFU $g^{-1}$ LP) 8 weeks | Skin mucus immunity ↑ Serum immunity ↑ | Van Doan et al. (2021d) |
| BFT | Amla (*Phyllanthus emblica*) fruit extract | Nile tilapia (*O. niloticus*) (10.48 ± 0.56 g) | 0, 5, 10, 20, and 40 mg $kg^{-1}$ AFE 8 weeks | Skin mucus immunity ↑ Serum immunity ↑ | Van Doan et al. (2022b) |

| | | | | | |
|---|---|---|---|---|---|
| BFT | Symbiotics | Nile tilapia (*O. niloticus*) (30–35 g) | BFT with and without symbiotics 40 days | Hematological parameters ↑ | Laice et al. (2021) |
| **BFT** | Beneficial bacteria | Nile tilapia (*O. niloticus*) (8.63 ± 3.35g) | T1, SR control; T2, SR + SSP; T3, SR + MSP; T4, BF + MSP; T5, BF + SSP; T6, BF control 112 days | Innate immune response ↑ | Mohammadi et al. (2021) |
| BFT | Coffee silverskin (CSS) | Nile tilapia (*O. niloticus*) (15.54 ± 0.21 g) | CSS1 (Control), CSS2 (10 g kg−1), CSS3 (20 g kg−1), CSS4 (40 g kg−1), and CSS5 (80 g kg−1) 8 weeks | Skin mucus immunity ↑ Serum immunity ↑ | Hien Van Doan et al. (2021c) |
| BFT | Carbon source and stocking density | Nile tilapia (*O. niloticus*) (5.15 ± 1.12 g) | Low stocking density (LSD), 140 fish /$m^3$ and high stocking density, (HSD), 280/$m^3$ 98 days | Growth-related genes ↑ | El-Hawarry et al. (2021) |
| BFT | Probiotics | Nile tilapia (*O. niloticus*) (6.7 ± 0.2 g) | Stocking densities (D1, 120 fish/$m^3$; D2, 240 fish/$m^3$) with biofloc plus probiotics | Immune response ↑ | Bañuelos-Vargas et al. (2021) |
| BFT | Spent coffee grounds (SCG) | Nile tilapia (*O. niloticus*) (15.25 ± 0.07 g) | SCG1 (control), SCG2 (10 g $kg^{-1}$), SCG3 (20 g $kg^{-1}$), SCG4 (40 g $kg^{-1}$), and SCG5 (80 g $kg^{-1}$) 8 weeks | Skin mucus immunity ↑ Serum immunity ↑ | Van Doan et al. (2022a) |
| BFT | Feeding levels and stocking densities | Nile tilapia (*O. niloticus*) (3.2 ± 0.05 g) | Feeding levels (0, 15, 30, 45 and 100) and 2 stocking densities (500 fish/m3 and 1000fish/m3) | Innate immune response ↑ | Sarsangi Aliabad et al. (2022) |
| BFT | Rambutan seed (RS) | Nile tilapia (*O. niloticus*) (14.77 ± 0.80 g) | 0, 5, 10, 20, and 40 g $kg^{-1}$ of RS 8 weeks | Skin mucus immunity ↑ Serum immunity ↑ Gene expressions ↑ | Xuan et al. (2022) |

(continued)

**Table 9.2** (continued)

| Studied systems | Studies parameters | Fish species | Doses and supplementations duration | Results | References |
|---|---|---|---|---|---|
| BFT | Longan seed powder (LS) | Nile tilapia (*O. niloticus*) (13.82 ± 0.06 g) | Control (LS0), 10 (LS10), 20 (LS20), 40 (LS40), and 80 (LS80) g $kg^{-1}$ LS<br>8 weeks | Skin mucus immunity ↑<br>Serum immunity ↑<br>Gene expressions ↑ | Wannavijit et al. (2022) |
| BFT | Rambutan peel (RP) | Nile tilapia (*O. niloticus*) (17.14 ± 0.12 g) | 0 g $kg^{-1}$ (control – RP0); 10 g $kg^{-1}$ (RP10); 20 g $kg^{-1}$ (RP20); 40 g $kg^{-1}$ (RP40), and 80 g $kg^{-1}$ (RP80)<br>8 weeks | Skin mucus immunity ↑<br>Serum immunity ↑<br>Gene expressions ↑ | Le Xuan et al. (2022) |

**Table 9.3** Increase disease resistance of tilapia cultured under biofloc system

| Studied systems | Studies parameters | Fish species | Doses and supplementations duration | Results | References |
|---|---|---|---|---|---|
| BFT | Orange peels derived pectin | Nile tilapia (9.09 ± 0.05 g) | 0 (control in clear water), 0 (control in biofloc system), 5, 10, and 20 g $kg^{-1}$ OPDP for 8 weeks | Resistance to *S. agalactiae* ↑ | Doan et al. (2018) |
| BFT | Dietary digestible protein and digestible energy | Nile tilapia (*Oreochromis niloticus*) (1.25 ± 0.15 g) | Digestible protein (22, 26 and 30% DP) and digestible energy (3000, 3150 and 3300 kcal $kg^{-1}$) 42 days | Ectoparasite spread ↓ | Durigon et al. (2019) |
| BFT | *in-situ* and *ex-situ* biofloc | Nile tilapia (*O. niloticus*) (5.1 ± 0.05 g/fish) | T1-biofloc developed within the culture systems (*insitu*), T2-biofloc supplementation in fish feed (*exsitu*) and C- Control without biofloc | Resistance to *A. hydrophila* ↑ | Menaga et al. (2019) |
| BFT | OPDP and *L. plantarum* | Nile tilapia (*O. niloticus*) (1.25 ± 0.15 g) 5.92 ± 0.08 g | Diet 1 (0 g $kg^{-1}$ OPDP and 0 CFU $g^{-1}$ *L. plantarum*), diet 2 (10 g $kg^{-1}$ OPDP), diet 3 (108 CFU $g^{-1}$ *L. plantarum*), and diet 4 (10 g $kg^{-1}$ OPDP +108 CFU $g^{-1}$ *L. plantarum*) | Resistance to *S. agalactiae* ↑ | Van Doan et al. (2019) |
| BFT | Jaggery-based BFT | Nile tilapia (*O. niloticus*) (32.2 ± 10.1 g/fish) | 22.5%, 27.7%, and 32.3% digestible protein (DP) and 6% lipid | Resistance to *A. hydrophila* ↑ | Elayaraja et al. (2020) |
| BFT | Chestnut polyphenols (CSP) | Nile tilapia (*O. niloticus*) (12.77 ± 0.17 g) | 0, 1, 2, 4, and 8 g $kg^{-1}$ of CSP | Resistance to *S. agalactiae* ↑ | Van Doan et al. (2020a) |
| BFT | Watermelon rind powder (WMRP) | Nile tilapia (*Oreochromis niloticus*) (17.14 ± 0.12 g) | 0 (Diet 1- control), 20 g $kg^{-1}$ WMRP (Diet 2), 40 g $kg^{-1}$ WMRP (Diet 3), 80 g $kg^{-1}$ WMRP (Diet 4), and 160 g $kg^{-1}$ WMRP (Diet 5) | Resistance to *S. agalactiae* ↑ | Van Doan et al. (2020b) |
| BFT | Pineapple peel powder (PAPP) | Nile tilapia (*O. niloticus*) (20.91 ± 0.11 g) | 0, 10, 20, 30 and 40 g $kg^{-1}$ PAPP 8 weeks | Resistance to *S. agalactiae* ↑ | Van Doan et al. (2021a) |

(continued)

**Table 9.3** (continued)

| Studied systems | Studies parameters | Fish species | Doses and supplementations duration | Results | References |
|---|---|---|---|---|---|
| BFT | Pineapple peel powder (PAPP) + *L. plantarum* | Nile tilapia (*O. niloticus*) (20.91 ± 0.11 g) | Diet 1 (0 g $kg^{-1}$ PAPP and 0 CFU $g^{-1}$ L. *plantarum*) (control), Diet 2 (10 g $kg^{-1}$ PAPP), Diet 3 ($10^8$ CFU $g^{-1}$ LP), and Diet 4 (10 g $kg^{-1}$ PAPP + $10^8$ CFU $g^{-1}$ LP)<br>8 weeks | Resistance to *S. agalactiae* ↑ | Van Doan et al. (2021d) |
| BFT | Coffee silverskin (CSS) | Nile tilapia (*O. niloticus*) (15.54 ± 0.21 g) | CSS1 (Control), CSS2 (10 g kg−1), CSS3 (20 g kg−1), CSS4 (40 g kg−1), and CSS5 (80 g kg−1)<br>8 weeks | Resistance to *S. agalactiae* ↑ | Van Doan et al. (2021c) |
| BFT | Amla (*Phyllanthus emblica*) fruit extract | Nile tilapia (*O. niloticus*) (10.48 ± 0.56 g) | 0, 5, 10, 20, and 40 mg $kg^{-1}$ AFE<br>8 weeks | Resistance to *S. agalactiae* ↑ | Van Doan et al. (2022b) |
| BFT | Beneficial bacteria | Nile tilapia (*O. niloticus*) (8.63 ± 3.35g) | T1, SR control; T2, SR + SSP; T3, SR + MSP; T4, BF + MSP; T5, BF + SSP; T6, BF control<br>112 days | Resistance to *A. hydrophila* ↑ | Mohammadi et al. (2021) |
| BFT | Spent coffee grounds (SCG) | Nile tilapia (*O. niloticus*) (15.25 ± 0.07 g) | SCG1 (control), SCG2 (10 g $kg^{-1}$), SCG3 (20 g $kg^{-1}$), SCG4 (40 g $kg^{-1}$), and SCG5 (80 g $kg^{-1}$)<br>8 weeks | Resistance to *S. agalactiae* ↑ | Van Doan et al. (2022a) |

resistance against *Streptococcus agalactiae* and *Aeromonas hydrophila* have been reported in Nile tilapia-fed orange peels derived pectin (OPDP) (Doan et al. 2018); OPDP and *L. plantarum* (Van Doan et al. 2019); in-situ and ex-situ biofloc (Menaga et al. 2019); jaggery-based BFT (Elayaraja et al. 2020); chestnut polyphenols (CSP) (Van Doan et al. 2020a); watermelon rind powder (WMRP) (Van Doan et al. 2020b); pineapple peel powder (PAPP) (Van Doan et al. 2021a); pineapple peel powder (PAPP) + *L. plantarum* (Van Doan et al. 2021d); coffee silverskin (CSS) (Van Doan et al. 2021c); amla (*Phyllanthus emblica*) fruit extract (Van Doan et al. 2022b); beneficial bacteria (Mohammadi et al. 2021); spent coffee grounds (SCG) (Van Doan et al. 2022a). It has been also reported that a biofloc system could reduce ectoparasite spread Durigon et al. (2019). A significant increase in disease resistance may be attributable to the presence of MAMPs in the biofloc system, which may be recognized as immunostimulants, resulting in higher resistance to diseases (Ekasari et al. 2014b). In addition, it may be due to the prebiotic and probiotic properties of feed additives, which are known to enhance the immune response and disease resistance of Nile tilapia (Cavalcante et al. 2020; Cano-Lozano et al. 2022).

## 9.3 Recirculating Aquaculture Systems (RAS)

### *9.3.1 Brief History of Development*

Though in its infancy and still considered to be a recent innovation, the basic technology of RAS has existed for over 65 years, with the first, pioneering RAS research activity being conducted in Japan in the 1950s (Murray et al. 2014; Saeki 1958). According to Espinal and Matulić (2019), the technology of RAS including aquaponics has been developed over the past 40 years. In the 1970s, a German program demonstrated the feasibility of intensive carp production in RAS, and subsequently, the Danish Aquaculture Institute undertook an innovative effort to develop further technical aspects of RAS (Goldman 2016). The idea for commercial fish production in RAS was first fostered in Denmark in the mid-1970s, and the first commercial RAS was then built in 1980 (Warrer-Hansen 2015). The Danish efforts supported the development of one of the initial commercial RAS industries, specifically for the production of European eel (Anguilla Anguilla) (Goldman 2016). This work inspired the subsequent further development and uptake of RAS in other European countries in the late 1980s and 1990s (Martins et al. 2010). Over the last 25–35 years, a significant and growing experience in designing, building, and operating RAS, particularly in Nordic countries, has been reported (Dalsgaard et al. 2013). The initial success of the RAS-based European eel industry also inspired to development of RAS in North America (Goldman 2016). In China, marine RAS was initiated in the 1980s, and since then China has made considerable progress in RAS (Ying et al. 2015). Since the 2000s, further development of RAS has occurred in Europe, North America, Australia, and other aquaculture-producing countries (Espinal and Matulić 2019; Martins et al. 2010).

A significant acceleration in the development of RAS technology has been observed over the last two decades (Espinal and Matulić 2019), and RAS have become popular in recent years. RAS has been developed to grow fish where inadequate biophysical conditions, water scarcity, poor water quality, and unfavorable environment exist (Murray et al. 2014). According to Malone (2013), RAS provides an alternative production method when environmental regulations, disease, land availability, salinity, temperature, and water supply prevent more cost-effective alternatives. However, other factors stimulated the development and implementation of RAS. For example, RAS are increasingly being used for Mediterranean marine fish and salmonid production cycle, particularly for juvenile stages, before being transferred into outdoor grow-out systems, such as cages or flow-through raceways (Bostock et al. 2016; Clarke and Bostock 2017; Terjesen et al. 2013). In fact, RAS can be used for broodstock and seedstock production, which can support cage and net-pen aquaculture (Malone 2013). In Europe and North America, RAS was developed as an alternative to the cage culture of salmon (Murray et al. 2014). RAS has also been developed to culture exotic fish species, to avoid adverse effects on native species and biodiversity (Malone 2013; Murray et al. 2014).

### *9.3.2 Basic Principles of RAS Operation and Production*

RAS are land-based, indoor fish-rearing facilities, where fish are stocked in tanks within a controlled environment, and where filtration is applied to purify water by removing metabolic wastes of stock, before being recirculated into the system itself. Water purification is achieved through mechanical and/or biological filtration, sterilization, and oxygenation. Different levels of sophistication and efficiency can be achieved, but generally, all RAS have a high degree (>90%) of water reuse (Murray et al. 2014; Badiola et al. 2012). RAS provides opportunities to enhance waste management, reduce water usage, and nutrient recycling (Martins et al. 2010; Murray et al. 2014; van Rijn 2013).

Although RAS have been initially developed and are ideally suited to produce freshwater as well as warm water fish species, RAS is flexible and can be modified and adapted to be operated with brackish and marine water as well as cold water species (Helfrich and Libey 1991). Therefore, by decoupling fish production from the marine environment, RAS may offer an alternative to traditional and net pen aquaculture (O'Shea et al. 2019). RAS can also provide suitable environmental conditions for fish species that are sensitive to water quality (Zhang et al. 2011). Despite RAS the potential to produce diverse seafood products, RAS is generally utilized to culture high-value fish, with high stocking densities and year-round production to offset high operational costs (Dalsgaard et al. 2013; Martins et al. 2010; Murray et al. 2014). Nevertheless, other fish species, including arctic char, clarias, halibut, pangasius, tilapia, and turbot are also commonly produced in RAS (Badiola et al. 2018; Ngoc et al. 2016a; Ngoc et al. 2016b; Summerfelt and Vinci 2008). The selection of fish species can be "market-driven" due to a high return on

investment to keep the RAS profitable (Badiola et al. 2017). The choice of fish also depends on the fast-growing and hardy fish in RAS (Badiola et al. 2018).

RAS can be categorized into five types: (1) hatchery and grow-out, (2) breeding, (3) long-term holding, (4) short-term holding, and (5) display (Yanong 2012). Moreover, RAS can be incorporated into an "integrated agriculture-aquaculture" system, which is known as aquaponics (Martins et al. 2010). Aquaponics is considered a particular type of RAS, where vegetable plants are included with fish to provide water filtration and crop diversification (Goddek et al. 2019). RAS have greater control over production outcomes, and the productivity of RAS depends on culture species, stocking densities, feeding rate, duration of the production cycle, and other management aspects. According to available scientific literature, the stocking densities of RAS range from 70 to 120 kg/m$^3$ with feed conversion ratio (FCR) values from 0.8 to 1.1. RAS can be of various sizes including small, medium, and large (Helfrich and Libey 1991), with a large-scale RAS typically being able to produce 400e500 tons of fish per annum (Murray et al. 2014). However, even higher stocking densities and total production values are currently reported by some commercial producers. According to (Bregnballe 2015), RAS are highly productive intensive farming, which generates vast quantities of fish (500 tons/ha/year) in a comparatively small volume of water. Because of higher production, RAS is often referred to as "hyper" or "super" intensive farming (O'Shea et al. 2019).

### *9.3.3 RAS in Tilapia Culture*

There is limited information regarding the application of RAS in Nile tilapia farming. It has been reported that RAS is a costly engineering approach, with a high initial investment in installation and operation (Murray et al. 2014). The reported annual production cost of RAS (US$2250e8800 per ton) is considerably higher than conventional pond aquaculture (US$2000 per ton) (Waite et al. 2014). Additionally, the Economic viability of RAS requires a long payback period, on average 8 years (Badiola et al. 2012). Wang et al. (2020) indicated that light intensity and photoperiod manipulation did not cause a significant chronic stress response in tilapia. This study demonstrated that light intensity, especially at 2000 lx, and photoperiod manipulation could stimulate the growth of tilapia in the RAS and significantly affect economic profitability. Another study using a different magnetic field (Hassan et al. 2018) showed that based on the growth, water properties, and serum biochemistry, it was concluded that magnetized water at 0.15 T intensity may improve tilapia growth in recirculating aquaculture systems. Recently, Deng et al. (2022) indicated that rearing fish larvae in RAS supports better survival compared to the flow-through system, while dietary probiotic supplementation further modulates the gut bacterial composition and stimulates the presence of beneficial bacteria during early life. It has been reported that RAS has a more stable and diverse microbial community composition, which could result in better growth performance compared to other culture systems (Deng et al. 2022). In addition, RAS could reduce

the ammonium and toxic gas in the culture system (Villar-Navarro et al. 2021; Nguyen et al. 2021).

A comparison between RAS, clear water, and biofloc system has been conducted in Nile tilapia. (Fleckenstein et al. 2018) indicated that clear water or hybrid systems may be a better choice for tilapia nurseries than chemoautotrophic biofloc systems due to the short-term periods in which nurseries operate and the volatility of nitrification in biofloc systems. In another study, Cao et al. (2020) indicated that There was no significant difference between the RASs and BFT aquaculture systems in terms of P recovery rate. The regular backwashing of the drum filter and biological filter in RAS accounted for 41 ± 2% of input N and 39 ± 2% of input P. Approximately 54% of unassimilated nitrogen N was removed by nitrification in the BFT aquaculture systems. The results from the present study suggest that nitrification may be the dominant pathway for ammonia removal in a BFT aquaculture system rather than by heterotrophic bacterial assimilation. RAS is characterized as a closed aquaculture and water reuse system; however, without an efficient and effective system for the treatment of discharged water and solids, this characterization only seems to indicate potential. Significantly, the treatment of the solids and water discharged from RASs has been suggested by (Luo et al. 2013). In BFT systems, most unused N and P are retained in biofloc and nitrate in tanks. The biofloc can be used for shrimp feed (Ray et al. 2017) or for feeding Artemia (Luo et al. 2017). Nitrate may be reduced by denitrification and dissimilatory nitrate reduction to ammonium (DNRA) activities in the BFT systems (Chutivisut et al. 2014). In these respects, the production activity in BFT systems may be more closed than that of RAS (Cao et al. 2020).

## References

Abakari G, Luo G, Meng H, Yang Z, Owusu-Afriyie G, Kombat EO, Alhassan EH (2020) The use of biochar in the production of tilapia (Oreochromis niloticus) in a biofloc technology system–BFT. Aquac Eng 91:102123. https://doi.org/10.1016/j.aquaeng.2020.102123

Adegbeye MJ, Elghandour MMMY, Monroy JC, Abegunde TO, Salem AZM, Barbabosa-Pliego A, Faniyi TO (2019) Potential influence of yucca extract as feed additive on greenhouse gases emission for a cleaner livestock and aquaculture farming–a review. J Clean Prod 239:118074. https://doi.org/10.1016/j.jclepro.2019.118074

Ahmad AL, Chin JY, Mohd Harun MHZ, Low SC (2022) Environmental impacts and imperative technologies towards sustainable treatment of aquaculture wastewater: a review. J Water Process Eng 46:102553. https://doi.org/10.1016/j.jwpe.2021.102553

Ahmad I, Babitha Rani AM, Verma AK, Maqsood M (2017) Biofloc technology: an emerging avenue in aquatic animal healthcare and nutrition. Aquac Int 25(3):1215–1226. https://doi.org/10.1007/s10499-016-0108-8

Ahmed N, Thompson S, Glaser M (2019) Global aquaculture productivity, environmental sustainability, and climate change adaptability. Environ Manag 63(2):159–172. https://doi.org/10.1007/s00267-018-1117-3

Ahmed N, Turchini GM (2021) Recirculating aquaculture systems (RAS): environmental solution and climate change adaptation. J Clean Prod 297:126604. https://doi.org/10.1016/j.jclepro.2021.126604

Anand PSS, Kohli MPS, Kumar S, Sundaray JK, Roy SD, Venkateshwarlu G, Sinha A, Pailan GH (2014) Effect of dietary supplementation of biofloc on growth performance and digestive enzyme activities in *Penaeus monodon*. Aquaculture 418-419:108–115. https://doi.org/10.1016/j.aquaculture.2013.09.051

Avnimelech Y (2007) Feeding with microbial flocs by tilapia in minimal discharge bio-flocs technology ponds. Aquaculture 264(1–4):140–147. https://doi.org/10.1016/j.aquaculture.2006.11.025

Avnimelech Y (2015) Biofloc technology: a practical guide book. World Aquaculture Society

Azim ME, Little DC (2008) The biofloc technology (BFT) in indoor tanks: water quality, biofloc composition, and growth and welfare of Nile tilapia (Oreochromis niloticus). Aquaculture 283(1–4):29–35. https://doi.org/10.1016/j.aquaculture.2008.06.036

Baag S, Mandal S (2022) Combined effects of ocean warming and acidification on marine fish and shellfish: a molecule to ecosystem perspective. Sci Total Environ 802:149807. https://doi.org/10.1016/j.scitotenv.2021.149807

Badiola M, Basurko OC, Gabiña G, Mendiola D (2017) Integration of energy audits in the life cycle assessment methodology to improve the environmental performance assessment of recirculating aquaculture systems. J Clean Prod 157:155–166. https://doi.org/10.1016/j.jclepro.2017.04.139

Badiola M, Basurko OC, Piedrahita R, Hundley P, Mendiola D (2018) Energy use in recirculating aquaculture systems (RAS): a review. Aquac Eng 81:57–70. https://doi.org/10.1016/j.aquaeng.2018.03.003

Badiola M, Mendiola D, Bostock J (2012) Recirculating aquaculture systems (RAS) analysis: main issues on management and future challenges. Aquac Eng 51:26–35. https://doi.org/10.1016/j.aquaeng.2012.07.004

Bahar NHA, Lo M, Sanjaya M, Van Vianen J, Alexander P, Ickowitz A, Sunderland T (2020) Meeting the food security challenge for nine billion people in 2050: what impact on forests? Glob Environ Chang 62:102056. https://doi.org/10.1016/j.gloenvcha.2020.102056

Bakhshi FH, Najdegerami E, Manaffar R, Tokmechi A, Rahmani Farah K, Shalizar Jalali A (2018) Growth performance, haematology, antioxidant status, immune response and histology of common carp (Cyprinus carpio L.) fed biofloc grown on different carbon sources. Aquac Res 49(1):393–403

Banha F, Diniz AM, Olivo del Amo R, Oliva-Paterna FJ, Anastácio PM (2022) Perceptions and risk behaviors regarding biological invasions in inland aquatic ecosystems. J Environ Manag 308:114632. https://doi.org/10.1016/j.jenvman.2022.114632

Bañuelos-Vargas I, Rodríguez-Montes de Oca GA, Martínez-Montaño E, Pérez-Jiménez A, Mendoza-Gamboa OA, Estrada-Godínez JA, Hernández C (2021) Antioxidant and immune response of juvenile red tilapia (Oreochromis sp) cultured at different densities in sea water with biofloc plus probiotics. Aquaculture 544:737112. https://doi.org/10.1016/j.aquaculture.2021.737112

Bashir I, Lone FA, Bhat RA, Mir SA, Dar ZA, Dar SA (2020) Concerns and threats of contamination on aquatic ecosystems. Bioremed Biotechnol:1–26. https://doi.org/10.1007/978-3-030-35691-0_1

Berners-Lee M, Kennelly C, Watson R, Hewitt CN (2018) Current global food production is sufficient to meet human nutritional needs in 2050 provided there is radical societal adaptation. Elementa 6. https://doi.org/10.1525/elementa.310

Bossier P, Ekasari J (2017) Biofloc technology application in aquaculture to support sustainable development goals. Microb Biotechnol 10(5):1012–1016. https://doi.org/10.1111/1751-7915.12836

Bostock J, Lane A, Hough C, Yamamoto K (2016) An assessment of the economic contribution of EU aquaculture production and the influence of policies for its sustainable development. Aquacult Int 24(3):699–733. https://doi.org/10.1007/s10499-016-9992-1

Boyd CE, D'Abramo LR, Glencross BD, Huyben DC, Juarez LM, Lockwood GS, McNevin AA, Tacon AGJ, Teletchea F, Tomasso JR Jr, Tucker CS, Valenti WC (2020) Achieving sustainable

aquaculture: historical and current perspectives and future needs and challenges. J World Aquacult Soc 51(3):578–633. https://doi.org/10.1111/jwas.12714
Bregnballe J (2015) A guide to recirculation aquaculture. FAO Eurofish Rep 100
Cano-Lozano JA, Villamil Diaz LM, Melo Bolivar JF, Hume ME, Ruiz Pardo RY (2022) Probiotics in tilapia (Oreochromis niloticus) culture: Potential probiotic Lactococcus lactis culture conditions. J Biosci Bioeng 133(3):187–194. https://doi.org/10.1016/j.jbiosc.2021.11.004
Cao B, Abakari G, Luo G, Tan H, Xia W (2020) Comparative analysis of nitrogen and phosphorus budgets in a bioflocs aquaculture system and recirculation aquaculture system during overwintering of tilapia (GIFT, Oreochromis niloticus). Aquac Eng 89:102026. https://doi.org/10.1016/j.aquaeng.2019.102026
Carballeira Braña CB, Cerbule K, Senff P, Stolz IK (2021) Towards environmental sustainability in marine finfish aquaculture. Front Mar Sci 8(343). https://doi.org/10.3389/fmars.2021.666662
Cavalcante RB, Telli GS, Tachibana L, Dias DC, Oshiro E, Natori MM, Silva WF, Ranzani-Paiva MJ (2020) Probiotics, prebiotics and Synbiotics for Nile tilapia: growth performance and protection against Aeromonas hydrophila infection. Aquacult Rep 17:100343. https://doi.org/10.1016/j.aqrep.2020.100343
Chutia A, Xavier KAM, Shamna N, Rani AMB (2022) Application of bioflocculating agent in inoculum enhances quality of biofloc and influences growth, feed utilization and stress responses of GIFT tilapia reared in-situ. Aquaculture 553:738050. https://doi.org/10.1016/j.aquaculture.2022.738050
Chutivisut P, Pungrasmi W, Powtongsook S (2014) Denitrification and dissimilatory nitrate reduction to ammonium (DNRA) activities in freshwater sludge and biofloc from Nile tilapia aquaculture systems. J Water Environ Technol 12(4):347–356
Clarke R, Bostock J (2017) Regional review on status and trends in aquaculture development in Europe-2015. Food and Agriculture Organisation of the United Nations
Costa e Silva RZ, Alvarenga ÉR, Matta SV, Alves GFO, Manduca LG, Silva MA, Yoshinaga TT, Fernandes AFA, Turra EM (2022) Masculinization protocol for Nile tilapia (O. niloticus) in biofloc technology using 17-α-methyltestosterone in the diet. Aquaculture 547:737470. https://doi.org/10.1016/j.aquaculture.2021.737470
Crab R, Chielens B, Wille M, Bossier P, Verstraete W (2010) The effect of different carbon sources on the nutritional value of bioflocs, a feed for *Macrobrachium rosenbergii* postlarvae. Aquac Res 41(4):559–567. https://doi.org/10.1111/j.1365-2109.2009.02353.x
Dalsgaard J, Lund I, Thorarinsdottir R, Drengstig A, Arvonen K, Pedersen PB (2013) Farming different species in RAS in Nordic countries: current status and future perspectives. Aquac Eng 53:2–13. https://doi.org/10.1016/j.aquaeng.2012.11.008
Dash P, Tandel RS, Bhat RAH, Mallik S, Pandey NN, Singh AK, Sarma D (2018) The addition of probiotic bacteria to microbial floc: water quality, growth, non-specific immune response and disease resistance of *Cyprinus carpio* in mid-Himalayan altitude. Aquaculture 495:961–969. https://doi.org/10.1016/j.aquaculture.2018.06.056
Dauda AB, Ajadi A, Tola-Fabunmi AS, Akinwole AO (2019) Waste production in aquaculture: sources, components and managements in different culture systems. Aquac Fish 4(3):81–88. https://doi.org/10.1016/j.aaf.2018.10.002
de Lima Vieira J, dos Santos NL, Rodrigues de Menezes FG, Vieira de Mendonça K, Viana de Sousa O (2021) An integrated approach to analyzing the effect of biofloc and probiotic technologies on sustainability and food safety in shrimp farming systems. J Clean Prod 318:128618. https://doi.org/10.1016/j.jclepro.2021.128618
De Schryver P, Verstraete W (2009) Nitrogen removal from aquaculture pond water by heterotrophic nitrogen assimilation in lab-scale sequencing batch reactors. Bioresour Technol 100(3):1162–1167. https://doi.org/10.1016/j.biortech.2008.08.043
de Sousa AA, Pinho SM, Rombenso AN, de Mello GL, Emerenciano MGC (2019) Pizzeria by-product: a complementary feed source for Nile tilapia (*Oreochromis niloticus*) raised in biofloc technology? Aquaculture 501:359–367. https://doi.org/10.1016/j.aquaculture.2018.11.055

Deng Y, Verdegem MCJ, Eding E, Kokou F (2022) Effect of rearing systems and dietary probiotic supplementation on the growth and gut microbiota of Nile tilapia (Oreochromis niloticus) larvae. Aquaculture 546:737297. https://doi.org/10.1016/j.aquaculture.2021.737297

Devi A, Kurup BM (2015) Biofloc technology: an overview and its application in animal food industry. Int J Fish Aquac Sci 5(1):1–20

Doan HV, Hoseinifar SH, Elumalai P, Tongsiri S, Chitmanat C, Jaturasitha S, Doolgindachbaporn S (2018) Effects of orange peels derived pectin on innate immune response, disease resistance and growth performance of Nile tilapia (*Oreochromis niloticus*) cultured under indoor biofloc system. Fish Shellfish Immunol 80:56–62. https://doi.org/10.1016/j.fsi.2018.05.049

Durigon EG, Almeida APG, Jerônimo GT, Baldisserotto B, Emerenciano MGC (2019) Digestive enzymes and parasitology of Nile tilapia juveniles raised in brackish biofloc water and fed with different digestible protein and digestible energy levels. Aquaculture 506:35–41. https://doi.org/10.1016/j.aquaculture.2019.03.022

Durigon EG, Lazzari R, Uczay J, Lopes DLA, Jerônimo GT, Sgnaulin T, Emerenciano MGC (2020) Biofloc technology (BFT): adjusting the levels of digestible protein and digestible energy in diets of Nile tilapia juveniles raised in brackish water. Aquac Fish 5(1):42–51. https://doi.org/10.1016/j.aaf.2019.07.001

Eding EH, Kamstra A, Verreth JAJ, Huisman EA, Klapwijk A (2006) Design and operation of nitrifying trickling filters in recirculating aquaculture: a review. Aquac Eng 34(3):234–260. https://doi.org/10.1016/j.aquaeng.2005.09.007

Ekasari J, Angela D, Waluyo SH, Bachtiar T, Surawidjaja EH, Bossier P, De Schryver P (2014a) The size of biofloc determines the nutritional composition and the nitrogen recovery by aquaculture animals. Aquaculture 426:105–111

Ekasari J, Hanif Azhar M, Surawidjaja EH, Nuryati S, De Schryver P, Bossier P (2014b) Immune response and disease resistance of shrimp fed biofloc grown on different carbon sources. Fish Shellfish Immunol 41(2):332–339. https://doi.org/10.1016/j.fsi.2014.09.004

Ekasari J, Rivandi DR, Firdausi AP, Surawidjaja EH, Zairin M Jr, Bossier P, De Schryver P (2015a) Biofloc technology positively affects Nile tilapia (Oreochromis niloticus) larvae performance. Aquaculture 441(0):72–77. https://doi.org/10.1016/j.aquaculture.2015.02.019

Ekasari J, Zairin M Jr, Putri DU, Sari NP, Surawidjaja EH, Bossier P (2015b) Biofloc-based reproductive performance of Nile tilapia Oreochromis niloticus L. broodstock. Aquac Res 46(2):509–512

El-Hawarry WN, Shourbela RM, Haraz YG, Khatab SA, Dawood MAO (2021) The influence of carbon source on growth, feed efficiency, and growth-related genes in Nile tilapia (Oreochromis niloticus) reared under biofloc conditions and high stocking density. Aquaculture 542:736919. https://doi.org/10.1016/j.aquaculture.2021.736919

El-Sayed AFM (2021) Use of biofloc technology in shrimp aquaculture: a comprehensive review, with emphasis on the last decade. Rev Aquac 13(1):676–705

Elayaraja S, Mabrok M, Algammal A, Sabitha E, Rajeswari MV, Zágoršek K, Ye Z, Zhu S, Rodkhum C (2020) Potential influence of jaggery-based biofloc technology at different C:N ratios on water quality, growth performance, innate immunity, immune-related genes expression profiles, and disease resistance against Aeromonas hydrophila in Nile tilapia (Oreochromis niloticus). Fish Shellfish Immunol 107:118–128. https://doi.org/10.1016/j.fsi.2020.09.023

Elsabagh M, Mohamed R, Moustafa EM, Hamza A, Farrag F, Decamp O, Dawood MA, Eltholth M (2018) Assessing the impact of *bacillus strains* mixture probiotic on water quality, growth performance, blood profile and intestinal morphology of Nile tilapia, *Oreochromis niloticus*. Aquac Nutri 24(6):1613–1622

Emerenciano M, Cuzon G, Goguenheim J, Gaxiola G, Aquacop (2012) Floc contribution on spawning performance of blue shrimp Litopenaeus stylirostris. Aquac Res 44(1):75–85. https://doi.org/10.1111/j.1365-2109.2011.03012.x

Emerenciano M, Gaxiola G, Cuzon G (2013) Biofloc technology (BFT): a review for aquaculture application and animal food industry. In: Biomass now-cultivation and utilization, pp 301–328

Emerenciano MGC, Miranda-Baeza A, Martínez-Porchas M, Poli MA, Vieira FN (2021) Biofloc technology (BFT) in shrimp farming: past and present shaping the future. Front Mar Sci 8. https://doi.org/10.3389/fmars.2021.813091

Espinal CA, Matulić D (2019) Recirculating aquaculture technologies. In: Aquaponics food production systems, pp 35–76

Estrada-Gil L, Contreras-Esquivel JC, Flores-Gallegos C, Zugasti-Cruz A, Govea-Salas M, Mata-Gómez MA, Rodríguez-Herrera R, Ascacio-Valdés JA (2022) Recovery of bioactive Ellagitannins by ultrasound/microwave-assisted extraction from Mexican Rambutan Peel (Nephelium lappaceum L.). Molecules 27(5):1592

FAO (2020a) Cultured Aquatic Species Information Programme *Labeo rohita* (Hamilton, 1822)

FAO (2020b) The state of World fisheries and aquaculture (SOFIA). FAO, Rome, Italy

Farrell M, Kuhn TK, Macdonald LM, Maddern TM, Murphy DV, Hall PA, Singh BP, Baumann K, Krull ES, Baldock JA (2013) Microbial utilisation of biochar-derived carbon. Sci Total Environ 465:288–297. https://doi.org/10.1016/j.scitotenv.2013.03.090

Felix S, Menaga M (2021) Applied aquaculture biofloc technology. CRC Press

Fleckenstein LJ, Tierney TW, Ray AJ (2018) Comparing biofloc, clear-water, and hybrid recirculating nursery systems (part II): tilapia (Oreochromis niloticus) production and water quality dynamics. Aquac Eng 82:80–85. https://doi.org/10.1016/j.aquaeng.2018.06.006

García-Ríos L, Miranda-Baeza A, Coelho-Emerenciano MG, Huerta-Rábago JA, Osuna-Amarillas P (2019) Biofloc technology (BFT) applied to tilapia fingerlings production using different carbon sources: emphasis on commercial applications. Aquaculture 502:26–31. https://doi.org/10.1016/j.aquaculture.2018.11.057

Goddek S, Joyce A, Kotzen B, Burnell GM (2019) Aquaponics food production systems: combined aquaculture and hydroponic production technologies for the future. Springer Nature

Goldman J (2016) So you want to be a fish farmer. World Aquaculture 25

Green BW, Rawles SD, Schrader KK, Gaylord TG, McEntire ME (2019) Effects of dietary protein content on hybrid tilapia (Oreochromis aureus× O. niloticus) performance, common microbial off-flavor compounds, and water quality dynamics in an outdoor biofloc technology production system. Aquaculture 503:571–582

Green BW, Rawles SD, Schrader KK, McEntire ME, Abernathy J, Ray CL, Gaylord TG, Lange MD, Webster CD (2021) Impact of dietary phytase on tilapia performance and biofloc water quality. Aquaculture 541:736845. https://doi.org/10.1016/j.aquaculture.2021.736845

Guo H, Huang L, Hu S, Chen C, Huang X, Liu W, Wang S, Zhu Y, Zhao Y, Zhang D (2020) Effects of carbon/nitrogen ratio on growth, intestinal microbiota and metabolome of shrimp (Litopenaeus vannamei). Front Microbiol 11:652–652. https://doi.org/10.3389/fmicb.2020.00652

Gustilatov M, Widanarni EJ, Pande GSJ (2022) Protective effects of the biofloc system in Pacific white shrimp (Penaeus vannamei) culture against pathogenic Vibrio parahaemolyticus infection. Fish Shellfish Immunol 124:66–73. https://doi.org/10.1016/j.fsi.2022.03.037

Hassan SM, Sulaiman MA, Rahman RA, Kamaruddin R (2018) Effects of long term and continuous magnetic field exposure on the water properties, growth performance, plasma biochemistry and body composition of tilapia in a recirculating aquaculture system. Aquac Eng 83:76–84. https://doi.org/10.1016/j.aquaeng.2018.09.003

Helfrich LA, Libey GS (1991) Fish farming in recirculating aquaculture systems (RAS). Virginia Cooperative Extension,

Jahurul MHA, Azzatul FS, Sharifudin MS, Norliza MJ, Hasmadi M, Lee JS, Patricia M, Jinap S, Ramlah George MR, Firoz Khan M, Zaidul ISM (2020) Functional and nutritional properties of rambutan (*Nephelium lappaceum* L.) seed and its industrial application: a review. Trends Food Sci Technol 99:367–374. https://doi.org/10.1016/j.tifs.2020.03.016

Jamal MT, Broom M, Al-Mur BA, Al Harbi M, Ghandourah M, Al Otaibi A, Haque MF (2020) Biofloc technology: emerging microbial biotechnology for the improvement of aquaculture productivity. Pol J Microbiol 69(4):401–409. https://doi.org/10.33073/pjm-2020-049

Kaleem O, Bio Singou Sabi A-F (2021) Overview of aquaculture systems in Egypt and Nigeria, prospects, potentials, and constraints. Aquac Fish 6(6):535–547. https://doi.org/10.1016/j.aaf.2020.07.017

Khanjani MH, Alizadeh M, Mohammadi M, Aliabad HS (2021) The effect of adding molasses in different times on performance of Nile tilapia (Oreochromis niloticus) raised in a Low-salinity biofloc system. Ann Anim Sci 21(4):1435–1454. https://doi.org/10.2478/aoas-2021-0011

Khanjani MH, Sharifinia M (2020) Biofloc technology as a promising tool to improve aquaculture production. Rev Aquac n/a (n/a) https://doi.org/10.1111/raq.12412

Khanjani MH, Sharifinia M (2021) Production of Nile tilapia Oreochromis niloticus reared in a limited water exchange system: the effect of different light levels. Aquaculture 542:736912. https://doi.org/10.1016/j.aquaculture.2021.736912

Khanjani MH, Sharifinia M, Hajirezaee S (2022) Recent progress towards the application of biofloc technology for tilapia farming. Aquaculture 552:738021. https://doi.org/10.1016/j.aquaculture.2022.738021

Kiruba-Sankar R, Praveen Raj J, Saravanan K, Lohith Kumar K, Raymond Jani Angel J, Velmurugan A, Dam Roy S (2018) Chapter 9–invasive species in freshwater ecosystems–threats to ecosystem services. In: Sivaperuman C, Velmurugan A, Singh AK, Jaisankar I (eds) Biodiversity and climate change adaptation in tropical Islands. Academic Press, pp 257–296. https://doi.org/10.1016/B978-0-12-813064-3.00009-0

Kosten S, Almeida RM, Barbosa I, Mendonça R, Santos Muzitano I, Sobreira Oliveira-Junior E, Vroom RJE, Wang H-J, Barros N (2020) Better assessments of greenhouse gas emissions from global fish ponds needed to adequately evaluate aquaculture footprint. Sci Total Environ 748:141247. https://doi.org/10.1016/j.scitotenv.2020.141247

Krummenauer D, Abreu PC, Poersch L, Reis PACP, Suita SM, dos Reis WG, Wasielesky W (2020) The relationship between shrimp (Litopenaeus vannamei) size and biofloc consumption determined by the stable isotope technique. Aquaculture 529:735635. https://doi.org/10.1016/j.aquaculture.2020.735635

Kuhn DD, Boardman GD, Lawrence AL, Marsh L, Flick GJ Jr (2009) Microbial floc meal as a replacement ingredient for fish meal and soybean protein in shrimp feed. Aquaculture 296(1–2):51–57

Kuhn DD, Lawrence AL, Boardman GD, Patnaik S, Marsh L, Flick GJ (2010) Evaluation of two types of bioflocs derived from biological treatment of fish effluent as feed ingredients for Pacific white shrimp, Litopenaeus vannamei. Aquaculture 303(1):28–33. https://doi.org/10.1016/j.aquaculture.2010.03.001

Kumari S, Harikrishna V, Surasani VKR, Balange AK, Babitha Rani AM (2021) Growth, biochemical indices and carcass quality of red tilapia reared in zero water discharge based biofloc system in various salinities using inland saline ground water. Aquaculture 540:736730. https://doi.org/10.1016/j.aquaculture.2021.736730

Laice LM, Corrêa Filho RAC, Ventura AS, Farias KNN, Silva ALN, Fernandes CE, Silva ACF, Barbosa PTL, de Souza AI, Emerenciano MGC, Povh JA (2021) Use of symbiotics in biofloc (BFT)-based Nile tilapia culture: production performance, intestinal morphometry and hematological parameters. Aquaculture 530:735715. https://doi.org/10.1016/j.aquaculture.2020.735715

Lawtae P, Tangsathitkulchai C (2021) The use of high surface area mesoporous-activated carbon from Longan seed biomass for increasing capacity and kinetics of methylene blue adsorption from aqueous solution. Molecules 26(21):6521

Le Xuan C, Wannavijit S, Outama P, Montha N, Lumsangkul C, Tongsiri S, Chitmanat C, Hoseinifar SH, Van Doan H (2022) Effects of dietary rambutan (Nephelium lappaceum L.) peel powder on growth performance, immune response and immune-related gene expressions of striped catfish (Pangasianodon hypophthalmus) raised in biofloc system. Fish Shellfish Immunol 124:134. https://doi.org/10.1016/j.fsi.2022.03.039

Liu G, Deng Y, Verdegem M, Ye Z, Zhu S (2019) Using poly(-β-hydroxybutyrate-β-hydroxyvalerate) as carbon source in biofloc-systems: nitrogen dynamics

and shift of Oreochromis niloticus gut microbiota. Sci Total Environ 694:133664. https://doi.org/10.1016/j.scitotenv.2019.133664

Liu G, Ye Z, Liu D, Zhao J, Sivaramasamy E, Deng Y, Zhu S (2018) Influence of stocking density on growth, digestive enzyme activities, immune responses, antioxidant of Oreochromis niloticus fingerlings in biofloc systems. Fish Shellfish Immunol 81:416–422. https://doi.org/10.1016/j.fsi.2018.07.047

Liu H, Wang S, Cai Y, Guo X, Cao Z, Zhang Y, Liu S, Yuan W, Zhu W, Zheng Y, Xie Z, Guo W, Zhou Y (2017) Dietary administration of *Bacillus subtilis* HAINUP40 enhances growth, digestive enzyme activities, innate immune responses and disease resistance of tilapia, *Oreochromis niloticus*. Fish Shellfish Immunol 60:326–333. https://doi.org/10.1016/j.fsi.2016.12.003

Luo G, Liu G, Hx T (2013) Effects of stocking density and food deprivation-related stress on the physiology and growth in adult Scortum barcoo (McCulloch & Waite). Aquac Res 44(6):885–894

Luo G, Zhang N, Cai S, Tan H, Liu Z (2017) Nitrogen dynamics, bacterial community composition and biofloc quality in biofloc-based systems cultured Oreochromis niloticus with poly-β-hydroxybutyric and polycaprolactone as external carbohydrates. Aquaculture 479:732–741. https://doi.org/10.1016/j.aquaculture.2017.07.017

Malone R (2013) Recirculating aquaculture tank production systems: a review of current design practice (453)

Manduca LG, Silva MA, Alvarenga ÉR, Alves GFO, Ferreira NH, Teixeira EA, Fernandes AFA, MdAe S, Turra EM (2021) Effects of different stocking densities on Nile tilapia performance and profitability of a biofloc system with a minimum water exchange. Aquaculture 530:735814. https://doi.org/10.1016/j.aquaculture.2020.735814

Martins CIM, Eding EH, Verdegem MCJ, Heinsbroek LTN, Schneider O, Blancheton JP, d'Orbcastel ER, Verreth JAJ (2010) New developments in recirculating aquaculture systems in Europe: a perspective on environmental sustainability. Aquac Eng 43(3):83–93. https://doi.org/10.1016/j.aquaeng.2010.09.002

Maulu S, Hasimuna OJ, Haambiya LH, Monde C, Musuka CG, Makorwa TH, Munganga BP, Phiri KJ, Nsekanabo JD (2021) Climate change effects on aquaculture production: sustainability implications, mitigation, and adaptations. Front Sustain Food Sys 5(70). https://doi.org/10.3389/fsufs.2021.609097

Menaga M, Felix S, Charulatha M, Gopalakannan A, Panigrahi A (2019) Effect of in-situ and ex-situ biofloc on immune response of genetically improved farmed tilapia. Fish Shellfish Immunol 92:698–705. https://doi.org/10.1016/j.fsi.2019.06.031

Mirzakhani N, Ebrahimi E, Jalali SAH, Ekasari J (2019) Growth performance, intestinal morphology and nonspecific immunity response of Nile tilapia (Oreochromis niloticus) fry cultured in biofloc systems with different carbon sources and input C:N ratios. Aquaculture 512:734235. https://doi.org/10.1016/j.aquaculture.2019.734235

Mohammadi G, Rafiee G, Tavabe KR, Abdel-Latif HMR, Dawood MAO (2021) The enrichment of diet with beneficial bacteria (single- or multi- strain) in biofloc system enhanced the water quality, growth performance, immune responses, and disease resistance of Nile tilapia (Oreochromis niloticus). Aquaculture 539:736640. https://doi.org/10.1016/j.aquaculture.2021.736640

Moyo NAG, Rapatsa MM (2021) A review of the factors affecting tilapia aquaculture production in southern Africa. Aquaculture 535:736386. https://doi.org/10.1016/j.aquaculture.2021.736386

Murray F, Bostock J, Fletcher D (2014) Review of recirculation aquaculture system technologies and their commercial application

Najdegerami EH, Bakhshi F, Lakani FB (2016) Effects of biofloc on growth performance, digestive enzyme activities and liver histology of common carp (*Cyprinus carpio* L.) fingerlings in zero-water exchange system. Fish Physiol Biochem 42(2):457–465

Ngoc PTA, Meuwissen MPM, Cong Tru L, Bosma RH, Verreth J, Lansink AO (2016a) Economic feasibility of recirculating aquaculture systems in pangasius farming. Aquac Econ Manag 20(2): 185–200. https://doi.org/10.1080/13657305.2016.1156190

Ngoc PTA, Meuwissen MPM, Le TC, Bosma RH, Verreth J, Lansink AO (2016b) Adoption of recirculating aquaculture systems in large pangasius farms: a choice experiment. Aquaculture 460:90–97. https://doi.org/10.1016/j.aquaculture.2016.03.055

Nguyen HYN, Trinh TL, Baruah K, Lundh T, Kiessling A (2021) Growth and feed utilisation of Nile tilapia (Oreochromis niloticus) fed different protein levels in a clear-water or biofloc-RAS system. Aquaculture 536:736404. https://doi.org/10.1016/j.aquaculture.2021.736404

Nisar U, Peng D, Mu Y, Sun Y (2022) A solution for sustainable utilization of aquaculture waste: a comprehensive review of biofloc technology and Aquamimicry. Front Nutr 8. https://doi.org/10.3389/fnut.2021.791738

O'Shea T, Jones R, Markham A, Norell E, Scott J, Theuerkauf S, Waters T (2019) Towards a blue revolution: catalyzing private investment in sustainable aquaculture production systems. The Nature Conservancy and Encourage Capital, Arlington, VA

Ogello EO, Outa NO, Obiero KO, Kyule DN, Munguti JM (2021) The prospects of biofloc technology (BFT) for sustainable aquaculture development. Scientific African 14:e01053. https://doi.org/10.1016/j.sciaf.2021.e01053

Oliveira LK, Pilz L, Furtado PS, Ballester ELC, Bicudo ÁJA (2021) Growth, nutritional efficiency, and profitability of juvenile GIFT strain of Nile tilapia (Oreochromis niloticus) reared in biofloc system on graded feeding rates. Aquaculture 541:736830. https://doi.org/10.1016/j.aquaculture.2021.736830

Panigrahi A, Sundaram M, Saranya C, Swain S, Dash RR, Dayal JS (2019) Carbohydrate sources deferentially influence growth performances, microbial dynamics and immunomodulation in Pacific white shrimp (*Litopenaeus vannamei*) under biofloc system. Fish Shellfish Immunol 86: 1207–1216. https://doi.org/10.1016/j.fsi.2018.12.040

Prabu E, Rajagopalsamy C, Ahilan B, Jeevagan IJMA, Renuhadevi M (2019) Tilapia–an excellent candidate species for World aquaculture: a review. Ann Res Rev Biol:1–14

Pradeepkiran JA (2019) Aquaculture role in global food security with nutritional value: a review. Transl Anim Sci 3(2):903–910. https://doi.org/10.1093/tas/txz012

Ray AJ, Drury TH, Cecil A (2017) Comparing clear-water RAS and biofloc systems: shrimp (Litopenaeus vannamei) production, water quality, and biofloc nutritional contributions estimated using stable isotopes. Aquac Eng 77:9–14

Ringø E (2020) Probiotics in shellfish aquaculture. Aquac Fish 5(1):1–27. https://doi.org/10.1016/j.aaf.2019.12.001

Rohani MF, Islam SMM, Hossain MK, Ferdous Z, Siddik MAB, Nuruzzaman M, Padeniya U, Brown C, Shahjahan M (2022) Probiotics, prebiotics and synbiotics improved the functionality of aquafeed: upgrading growth, reproduction, immunity and disease resistance in fish. Fish Shellfish Immunol 120:569–589. https://doi.org/10.1016/j.fsi.2021.12.037

Saeki A (1958) Studies on fish culture in aquarium of closed-circulating system. Its fundamental theory and standard plan. Nippon Suisan Gakkaishi 23(11):684–695

Samocha TM, Prangnell DI, Castro LF (2019) Chapter 3–Biofloc. In: Samocha TM (ed) Sustainable biofloc systems for marine shrimp. Academic Press, pp 29–36. https://doi.org/10.1016/B978-0-12-818040-2.00003-4

Sarsangi Aliabad H, Naji A, Mortezaei SRS, Sourinejad I, Akbarzadeh A (2022) Effects of restricted feeding levels and stocking densities on water quality, growth performance, body composition and mucosal innate immunity of Nile tilapia (Oreochromis niloticus) fry in a biofloc system. Aquaculture 546:737320. https://doi.org/10.1016/j.aquaculture.2021.737320

Shaaban NA, Tawfik S, El-Tarras W, El-Sayed Ali T (2021) Potential health risk assessment of some bioaccumulated metals in Nile tilapia (Oreochromis niloticus) cultured in Kafr El-Shaikh farms, Egypt. Environ Res 200:111358. https://doi.org/10.1016/j.envres.2021.111358

Shewry PR, Hey SJ (2015) The contribution of wheat to human diet and health. Food Energy Security 4(3):178–202

Sousa AA, Lopes DLA, Emerenciano MGC, Nora L, Souza CF, Baldissera MD, Baldisserotto B, Alba DF, Da Silva AS (2020) Phosphatidylcholine in diets of juvenile Nile tilapia in a biofloc technology system: effects on performance, energy metabolism and the antioxidant system. Aquaculture 515:734574. https://doi.org/10.1016/j.aquaculture.2019.734574

Summerfelt ST, Vinci BJ (2008) Better management practices for recirculating aquaculture systems. In: Environmental best management practices for aquaculture, pp 389–426. https://doi.org/10.1002/9780813818672.ch10

Terjesen BF, Summerfelt ST, Nerland S, Ulgenes Y, Fjæra SO, Megård Reiten BK, Selset R, Kolarevic J, Brunsvik P, Bæverfjord G, Takle H, Kittelsen AH, Åsgård T (2013) Design, dimensioning, and performance of a research facility for studies on the requirements of fish in RAS environments. Aquac Eng 54:49–63. https://doi.org/10.1016/j.aquaeng.2012.11.002

Thong PY (2014) Biofloc technology in shrimp farming: success and failure. Aquacult Asia Pac 10: 13–16

Tinh TH, Momoh TA, Kokou F, Hai TN, Schrama JW, Verreth JAJ, Verdegem MCJ (2021) Effects of carbohydrate addition methods on Pacific white shrimp (Litopenaeus vannamei). Aquaculture 543:736890. https://doi.org/10.1016/j.aquaculture.2021.736890

Tom AP, Jayakumar JS, Biju M, Somarajan J, Ibrahim MA (2021) Aquaculture wastewater treatment technologies and their sustainability: a review. Energy Nexus 4:100022. https://doi.org/10.1016/j.nexus.2021.100022

Tubin JSB, Paiano D, Hashimoto GSO, Furtado WE, Martins ML, Durigon E, Emerenciano MGC (2020) Tenebrio molitor meal in diets for Nile tilapia juveniles reared in biofloc system. Aquaculture 519:734763. https://doi.org/10.1016/j.aquaculture.2019.734763

Ulloa Walker DA, Morales Suazo MC, Emerenciano MGC (2020) Biofloc technology: principles focused on potential species and the case study of Chilean river shrimp Cryphiops caementarius. Rev Aquac 12(3):1759–1782

Van Doan H, Hoseinifar SH, Harikrishnan R, Khamlor T, Punyatong M, Tapingkae W, Yousefi M, Palma J, El-Haroun E (2021a) Impacts of pineapple peel powder on growth performance, innate immunity, disease resistance, and relative immune gene expression of Nile tilapia, Oreochromis niloticus. Fish Shellfish Immunol 114:311–319. https://doi.org/10.1016/j.fsi.2021.04.002

Van Doan H, Hoseinifar SH, Hung TQ, Lumsangkul C, Jaturasitha S, Ehab E-H, Paolucci M (2020a) Dietary inclusion of chestnut (Castanea sativa) polyphenols to Nile tilapia reared in biofloc technology: impacts on growth, immunity, and disease resistance against Streptococcus agalactiae. Fish Shellfish Immunol 105:319–326. https://doi.org/10.1016/j.fsi.2020.07.010

Van Doan H, Hoseinifar SH, Naraballobh W, Jaturasitha S, Tongsiri S, Chitmanat C, Ringø E (2019) Dietary inclusion of Orange peels derived pectin and lactobacillus plantarum for Nile tilapia (Oreochromis niloticus) cultured under indoor biofloc systems. Aquaculture 508:98–105

Van Doan H, Hoseinifar SH, Naraballobh W, Paolucci M, Wongmaneeprateep S, Charoenwattanasak S, Dawood MAO, Abdel-Tawwab M (2021b) Dietary inclusion of watermelon rind powder and lactobacillus plantarum: effects on Nile tilapia's growth, skin mucus and serum immunities, and disease resistance. Fish Shellfish Immunol 116:107–114. https://doi.org/10.1016/j.fsi.2021.07.003

Van Doan H, Lumsangkul C, Hoseinifar SH, Harikrishnan R, Balasundaram C, Jaturasitha S (2021c) Effects of coffee silverskin on growth performance, immune response, and disease resistance of Nile tilapia culture under biofloc system. Aquaculture 543:736995

Van Doan H, Lumsangkul C, Hoseinifar SH, Hung TQ, Stejskal V, Ringø E, Dawood MAO, Esteban MÁ (2020b) Administration of watermelon rind powder to Nile tilapia (*Oreochromis niloticus*) culture under biofloc system: effect on growth performance, innate immune response, and disease resistance. Aquaculture 528:735574. https://doi.org/10.1016/j.aquaculture.2020.735574

Van Doan H, Lumsangkul C, Hoseinifar SH, Jaturasitha S, Tran HQ, Chanbang Y, Ringø E, Stejskal V (2022a) Influences of spent coffee grounds on skin mucosal and serum immunities, disease resistance, and growth rate of Nile tilapia (Oreochromis niloticus) reared under biofloc system. Fish Shellfish Immunol 120:67–74

Van Doan H, Lumsangkul C, Hoseinifar SH, Tongsiri S, Chitmanat C, Musthafa MS, El-Haroun E, Ringo E (2021d) Modulation of growth, innate immunity, and disease resistance of Nile tilapia (Oreochromis niloticus) culture under biofloc system by supplementing pineapple peel powder and lactobacillus plantarum. Fish Shellfish Immunol 115:212–220

Van Doan H, Lumsangkul C, Ruangwong OU, Meidong R, Hoseinifar SH, Dawood MA, Carnevali O (2021e) Effects of host-associated probiotic Bacillus altitudinis B61-34b on growth performance, immune response and disease resistance of Nile tilapia (Oreochromis niloticus) raised under biofloc system. Aquaculture Nutrition 27:61–72

Van Doan H, Lumsangkul C, Sringarm K, Hoseinifar SH, Dawood MAO, El-Haroun E, Harikrishnan R, Jaturasitha S, Paolucci M (2022b) Impacts of Amla (Phyllanthus emblica) fruit extract on growth, skin mucosal and serum immunities, and disease resistance of Nile tilapia (Oreochromis niloticus) raised under biofloc system. Aquac Rep 22:100953. https://doi.org/10.1016/j.aqrep.2021.100953

van Rijn J (2013) Waste treatment in recirculating aquaculture systems. Aquac Eng 53:49–56. https://doi.org/10.1016/j.aquaeng.2012.11.010

Villar-Navarro E, Garrido-Pérez C, Perales JA (2021) Recycling "waste" nutrients back into RAS and FTS marine aquaculture facilities from the perspective of the circular economy. Sci Total Environ 762:143057. https://doi.org/10.1016/j.scitotenv.2020.143057

Vyas A (2020) Chapter 3–Biofloc systems in aquaculture: global status and trends. In: Rastegari AA, Yadav AN, Yadav N (eds) New and future developments in microbial biotechnology and bioengineering. Elsevier, pp 31–42. https://doi.org/10.1016/B978-0-12-820528-0.00004-1

Waite R, Beveridge M, Brummett R, Castine S, Chaiyawannakarn N, Kaushik S, Mungkung R, Nawapakpilai S, Phillips M (2014) Improving productivity and environmental performance of aquaculture. World Fish

Wang G, Yu E, Xie J, Yu D, Li Z, Luo W, Qiu L, Zheng Z (2015) Effect of C/N ratio on water quality in zero-water exchange tanks and the biofloc supplementation in feed on the growth performance of crucian carp, Carassius auratus. Aquaculture 443:98–104. https://doi.org/10.1016/j.aquaculture.2015.03.015

Wang K, Li K, Liu L, Tanase C, Mols R, van der Meer M (2020) Effects of light intensity and photoperiod on the growth and stress response of juvenile Nile tilapia (*Oreochromis niloticus*) in a recirculating aquaculture system. Aquac Fish 8:85. https://doi.org/10.1016/j.aaf.2020.03.001

Wannavijit S, Outama P, Le Xuan C, Lumsangkul C, Lengkidworraphiphat P, Tongsiri S, Chitmanat C, Doan HV (2022) Modulatory effects of longan seed powder on growth performance, immune response, and immune-antioxidant related gene expression in Nile tilapia (Oreochromis niloticus) raised under biofloc system. Fish Shellfish Immunol 123:460–468. https://doi.org/10.1016/j.fsi.2022.03.029

Warrer-Hansen I (2015) Potential for land based salmon grow-out in recirculating aquaculture systems (RAS) in Ireland. IFA Aquaculture, Netherlands

Xuan CL, Wannavijit S, Outama P, Lumsangkul C, Tongsiri S, Chitmanat C, Doan HV (2022) Dietary inclusion of rambutan (Nephelium lappaceum L.) seed to Nile tilapia (Oreochromis niloticus) reared in biofloc system: impacts on growth, immunity, and immune-antioxidant gene expression. Fish Shellfish Immunol 122:215–224. https://doi.org/10.1016/j.fsi.2022.01.020

Yang J, Yu M, Chen W (2015) Adsorption of hexavalent chromium from aqueous solution by activated carbon prepared from longan seed: kinetics, equilibrium and thermodynamics. J Ind Eng Chem 21:414–422. https://doi.org/10.1016/j.jiec.2014.02.054

Yanong RP (2012) Biosecurity in aquaculture, Part 2: Recirculating aquaculture systems. Retrieved November 29:2018

Ying L, Baoliang L, Ce S, Guoxiang S (2015) Recirculating aquaculture systems in China-current application and prospects. Fish Aquac J 6(3):1

Zaineldin AI, Hegazi S, Koshio S, Ishikawa M, Dawood MA, Dossou S, Yukun Z, Mzengereza K (2021) Singular effects of Bacillus subtilis C-3102 or Saccharomyces cerevisiae type 1 on the growth, gut morphology, immunity, and stress resistance of red sea bream (Pagrus major). Ann Anim Sci 21(2):589–608

Zaki MAA, Alabssawy AN, Nour AE-AM, El Basuini MF, Dawood MAO, Alkahtani S, Abdel-Daim MM (2020) The impact of stocking density and dietary carbon sources on the growth, oxidative status and stress markers of Nile tilapia (*Oreochromis niloticus*) reared under biofloc conditions. Aquac Rep 16:100282. https://doi.org/10.1016/j.aqrep.2020.100282

Zhang S-Y, Li G, Wu H-B, Liu X-G, Yao Y-H, Tao L, Liu H (2011) An integrated recirculating aquaculture system (RAS) for land-based fish farming: the effects on water quality and fish production. Aquac Eng 45(3):93–102. https://doi.org/10.1016/j.aquaeng.2011.08.001

Zhao D, Pan L, Huang F, Wang C, Xu W (2016) Effects of different carbon sources on bioactive compound production of biofloc, immune response, antioxidant level, and growth performance of Litopenaeus vannamei in zero-water exchange culture tanks. J World Aquacult Soc 47(4): 566–576