Review on the progress in the role of herbal extracts in tilapia culture

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Abstract: Tilapia is one of the most important fish in freshwater aquaculture. However, increased intensification of aquaculture has led to many constraints including, poor growth, and poor health. This has made it hard for fish farmers to turn the biological benefits associated with intensive farming systems into economical gain. Moreover, the wide adoption use of chemotherapeutic drugs to maintain health and sex reversal hormones to control reproduction appears to be merely production-oriented, thus unsustainable. Hence, improvement of productions in aquaculture should also focus on environmentally friendly, and sustainable methods. Today, huge attention is focused on the use of medicinal herbal extracts to improve yield in aquaculture as alternatives to chemical agents. Accordingly, the aim of this work was to critically review the effectiveness of herbal extracts in tilapia farming, and further highlight gaps in the existing knowledge and the way forward in using medicinal herbal extracts in tilapia aquaculture. A wide range of medicinal herbal products were reported to enhance growth, appetite, immune responses, antioxidation, hepatoprotective activity, and control reproduction in tilapia species; attributed by their abundant bio-actives such as saponin, phenols, flavonoids and polysaccharides. However, the lack of sufficient knowledge on herbal extracts limits the cost-effective use of herbal extracts in tilapia aquaculture. Little knowledge still

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PUBLIC INTEREST STATEMENT

In aquaculture, the maintenance of good health of fish is achieved by using pharmaceutical drugs. These drugs are unaffordable, unavailable to poor farmers in the rural areas, some pathogenic bacteria develop resistance (i.e. antibiotics), their residues end up in the final products, affecting humans’ health and polluting the environment. Thus, the use of these drugs is unsustainable. Alternatively, several medicinal herbs have been reported to possess the potential to reduce or eliminate the use of pharmaceutical drugs. Studies have reported beneficial growth, health, and disease resistance promoting effects of several herbs in aquaculture including tilapia culture. In tilapia culture, herbs such as aloe vera, garlic, ginger lemon oils, among others have been reported to promote their growth and health. However, before herbs are fully implemented in aquaculture studies are still needed to validate their allied growth, health, toxicity effects, as well as preparation methods, and optimum dosages, among others.
exists on herbal extract concentration, types of extracts, and their potential negative impacts on fish, consumers, and environment, just to mention but a few. More researches are therefore deemed necessary to optimize the use of herbal extracts in tilapia culture.

Subjects: Aquaculture; Laboratory Animal Science; Nutrition; Pharmaceutical Science; Pharmacology

Keywords: Tilapia; herbal extracts; growth promoting effects; immunestimulants; sex reversal effects

1. Introduction

Globally, aquaculture (marine and freshwater) remains one of the fast growing food-producing sectors, with the highest potential to assist marine and inland capture fisheries meet global demand for aquatic food (FAO, 2016). In freshwater aquaculture, tilapias (til ah pe ah) are reported to be the second most important group of farmed fin fish just after carps (Waite et al., 2014). An impressive global production performance by aquaculture is a result of wide adoption of intensive production systems, which are associated with higher productivity per unit area as a result of higher stocking density (Basha et al., 2013). However, higher stocking density in intensive farming systems coupled with other general aquaculture activities such as fish handling, transportation and harvesting may be stressful to fish. This may consequently lead to a number of conditions including poor metabolism capacity (Santos, Schrama, Mamaug, Rombout, & Verreth, 2010), poor meat quality (Jittinandana et al., 2003), increased susceptibility to diseases (Wu et al., 2013a), and in extreme cases lead to deaths (Mckenzie et al., 2012). All these constraints have made it hard for fish farmers to convert the benefits of higher production yield associated with intensive production systems into economical gains. Thus, aquaculture is yet to reach its maximum potential.

In an effort for fish farmers to economically benefit from intensive farming systems, they started using synthetic antibiotics and other chemotherapeutic drugs to maintain good health of farmed fish. The adoption of these drugs in aquaculture appears to be only profit-driven and unsustainable, as they cause several other constraints such as fish pathogen drug resistance, immunosuppression, environmental pollution, and accumulation of chemical residues, which can be potentially hazardous to the public health (Bulfon, Volpatti, & Galeotti, 2013; WHO, 2006). Thus, many nations across the globe such as the United States, European Union (Bulfon et al., 2013), and Asian countries (Ji et al., 2007) have strict demand for aquatic products free from chemical/drugs. Today, the need of replacing antibiotics and other synthetic chemicals with dietary supplements or ingredients that is capable of strengthening fish health, and enhance their growth, feed utilization ability, and ultimately ensure safety and good quality products from aquaculture are becoming increasingly vital.

Over the past two decades, there have been an increase in the number of research with common conclusions that indeed medicinal herbal extracts have the potential to eradicate the use of synthetic chemicals such as antibiotics and other chemotherapeutic drugs in aquaculture. Medicinal herbal extracts stand out as potential alternatives to synthetic drugs in aquaculture as they provide useful biologically active metabolites with various benefits such as immune modulating (Zanuzzo et al., 2015; Yang, Guo, Ye, Zang, & Wang, 2015; Yilmaz, & Ergün, 2018; Yilmaz, 2019b), growth promoting, antioxidant enhancing, antidepressant, digestive enhancing, appetite-stimulating effects (Zhang, Zhang, Li, & Gao, 2010; Mahdavi, Hajimoradloo, & Ghorbani, 2013; Gabriel, Qiang, Ma, et al. 2015), and hepatoprotective effects (Gurkan, Yilmaz, Kaya, Ergün, & Alkan, 2015; Yilmaz, Ergün, Kaya, & Gürkan, 2014), if properly administered. Another reasons are that medicinal herbal extracts are easily available, inexpensive, and tend to be more biodegradable in nature compared to synthetic drugs (Olusola, Emikpe, & Olaifa, 2013; Reverter, Bontemps, Lecchini, Banaigs, & Sasal, 2014).
Lately, there have been numerous reviews about the potential use of medicinal herbal extracts in aquaculture (Bulfon et al., 2013; Reverter et al., 2014; Van Hai, 2015). However, to the best of my knowledge, there are very few studies that reviewed the effectiveness of herbal extracts with focus on a specific fish species. Reviews that focused on specific fish species include studies on prebiotic effectiveness in carp (Dawood & Koshio, 2016), Sparus aurata and Dicentrarchus labrax (Carbone & Faggio, 2016). Up to date, no study specifically reviewed the studies on medicinal herbal extracts in tilapia species (one of the most important fish in freshwater aquaculture), despite numerous experimental studies (Yilmaz, Ergün, Türk, 2012; Bulfon et al., 2013; Yilmaz, Ergün, & Soytaş, 2013a; 2013b; Güllü et al., 2016; Gültepe, Bilen, Yilmaz, Gürroy, & Aydin, 2014; Gurkan et al., 2015; Acar, Kesbiç, Yilmaz, Gültepe, & Türker, 2015; Baba, Acar, Öntaş, Kesbiç, & Yilmaz, 2016; Mo, Lun, Choi, Man, & Wong, 2016), except by (Gabriel, Qiang, Kpundeh, & Xu, 2015). However, the later was limited to sex reversal effects of herbal extracts in tilapia production systems. Therefore, this is the first study to critically review the effectiveness of herbal extracts as growth promoters, appetizers, antioxidant, antidepressants, immunostimulants, and sex reversal agents in tilapia farming. This study further discussed gaps in the existing knowledge and the way forward in using medicinal herbal extracts in tilapia aquaculture, as their use can be a sustainable and feasible strategy for the success of tilapia culture in particular and aquaculture in general.

2. Some medicinal herbs investigated

Medicinal herbs are as old as civilization and throughout history they have been used as popular folk medicine because of their broad-spectrum medicinal properties. The attempt to adopt them in aquaculture is a novel development that got huge attention virtually in every part of the globe, with Asia having the most researched herbs (Bulfon et al., 2013). Furthermore, among aquaculture species, effects of herbal extracts are widely researched in tilapia species (Reverter et al., 2014). A wide range of medicinal herbs used in tilapia aquaculture is shown in Table 1. These herbs could be used as a whole or parts (i.e. leaves, flowers, roots, seeds, or barks) in a crude form or as extracts/compounds from whole plant or parts (Table 1). For instance, crude extract in the form of powder from Aloe vera (Gabriel, Qiang, He, Yu, et al., 2015), and Camellia sinensis (Abdel-Tawwab, Ahmad, Seden, & Sakr, 2010) was incorporated in feed to investigate their effects on growth and resistance of Nile tilapia, Oreochromis niloticus against pathogenic bacteria, respectively. Similarly, dietary blackberry syrup was studied for growth, antioxidation, immune response, and resistance against Pleiromonas shigelloides in O. niloticus (Yilmaz, 2019a). Meanwhile, essential oil extracted from Citrus sinensis (Acar et al., 2015), and Citrus limon peels (Baba et al., 2016) were investigated for growth, health parameters, and resistance against Streptococcus iniae, and Edwardsiella tarda in Oreochromis mossambicus, respectively. In the same fish, dietary Pimenta dioica powder was investigated for haemato-immunological and serum biochemical responses (Güllü et al., 2016; Yilmaz, Acar, Kesbiç, Gültepe, & Ergün, 2015), and dietary red pepper for growth and pigmentation (Yilmaz et al., 2013a). Other compounds such as saponins extracted from Trigonella foenum-graecum (Stadtlander et al., 2013) were mixed with feed to study their sex ratio and gonadal histology effects in O. niloticus, while polysaccharides from Astragalus membranaceus (Abuelsaad, 2014; Ardó et al., 2008) were incorporated with feed to investigate their effects on O. niloticus immune responses. Moreover, herbal extracted Caffeic acid was also reported in O. niloticus for antioxidation, immunological and liver gene expression responses, and resistance against Aeromonas veronii (Yilmaz, 2019b).

Herbal extracts differ and depend on plant species, i.e. the experiments by Yin et al. (2009); Abuelsaad (2014); Ardó et al. (2008) used Astragalus extracts containing 40%, >65%, and 90% commercial polysaccharides, respectively, while with Ganoderma extracts, 30% commercial polysaccharides were used (Yin et al., 2009). Besides crude extracts, extraction of phytochemicals/plant compounds is not complicated. Extracts can be extracted using solvents with different polarities such as water, petroleum ether, toluene, acetone, ethanol, or ethly acetate (Susmitha, Vidyamol, Ranganayaki, & Vijayaragavan, 2013). In tilapia culture, these solvents were either used alone (Mo, Lun, Choi, Man, & Wong, 2016; Arenal et al., 2012; Park & Choi, 2012; Nagarajan, Benjakul, Prodpran, & Songtippy, 2015; Wu et al., 2013), or in series (i.e. order of increasing polarity such
Table 1. A list of some medicinal herbs and types of extracts used in tilapia aquaculture

| Medicinal herbs                | Types of extracts                                      | References                                                                 |
|--------------------------------|--------------------------------------------------------|----------------------------------------------------------------------------|
| Citrus sinensis                | Essential oil                                          | (Acar et al., 2015)                                                       |
| Caraway                        | Crude powder                                           | (Ahmad & Abdel-Tawwab, 2011)                                              |
| Moringa oleifera               | Seed powder, Leaves powder, Methanol extracts          | (Ampofo-Yeboah, 2013)                                                     |
|                                |                                                        | (Hlophe & Moyo, 2014)                                                     |
|                                |                                                        | (Dongmezeta et al., 2006)                                                 |
|                                |                                                        | (Madalla et al., 2013)                                                    |
| Carica papaya                  | Seed powder                                            | (Ampofo-Yeboah, 2013); (Kareem et al., 2016)                              |
| Astragalus membranaceus        | Polysaccharides, Aqueous extracts, Crude powder        | (Ardo et al., 2008; Zahran et al., 2014)                                  |
|                                |                                                        | (Mo, Lun, Choi, Man, & Wong, 2016)                                        |
|                                |                                                        | (Tang, Cai, Liu, Wang, & Lu, 2014)                                        |
| Ocimum tenuiflorum             | Aqueous extracts                                       | (Arenal et al., 2012)                                                     |
| Citrus limon                   | Essential oil                                          | (Baba et al., 2016)                                                       |
| Allium sativum                 | Crude extracts                                         | (Chitmanat, Tongdonmuan, & Nunsong, 2005; Sholaby et al., 2006)           |
| Terminalia catappa             | Crude extracts                                         | (Chitmanat et al., 2005)                                                  |
| Ulva clathrata                 | Lyophilized extracts                                   | (Quezada-Rodriguez & Fajer-Avila, 2016)                                  |
| Aloe barbadensis               | Crude extracts                                         | (Dotta et al., 2014; Gabriel, Qiang, Ma, et al., 2015)                    |
| Rosmarinus officinalis         | Leaves powder (ethyl acetate extracts), Crude powder   | (Zilberg et al., 2010)                                                    |
|                                |                                                        | (Gültepe et al., 2014); (Yilmaz, Ergün, & Soytaş, 2013a)                  |
| Thymus vulgaris                | Crude powder                                           | (Gültepe et al., 2014; Zaki et al., 2012)                                 |
| Trigonella foenum graecum      | Crude powder                                           | (Gültepe et al., 2014; Zaki et al., 2012; Gurkan et al., 2015)            |
| Pennisetum clandestinum        | Leaf meal                                              | (Hiophé & Moya, 2014)                                                     |
| Tribulus terrestris            | 40% saponin, Aqueous seed extracts, Ethanolic-aqueous extracts | (Gültepe et al., 2014); (Ghosal & Chakraborty, 2014); (Yilmaz et al., 2014) |
| Cinnamomum camphora            | Bark powder                                            | (Kareem et al., 2016)                                                     |
| Euphorbia hirta                | Leaves                                                 | (Kareem et al., 2016)                                                     |
| Azadirachta indica             | Leaves                                                 | (Kareem et al., 2016)                                                     |
| Nyctanthes arbortristis        | Petroleum ether, chloroform, ethyl acetate, methanol, and water extracts | (Kirubakaran et al., 2010)                                               |
| Lycium barbarum               | Aqueous extracts                                       | (Mo, Lun, Choi, Man, & Wong, 2016)                                        |
| Coconut husk                  | Ethanolic extract                                      | (Nagarajan et al., 2015)                                                  |
| Prunella vulgaris              | Mixture of stems, leaves, and flower aqueous extracts   | (Park & Choi, 2014)                                                       |
| Andrographis paniculata        | Aqueous, methanol, & ethanoic extracts                 | (Rottanachaikunssonop & Phumkhachorn, 2009)                               |
| Angelica Honeysuckle           | Crude powder                                           | (Tang et al., 2014)                                                       |
| Sophora flavescens            | Ethanolic extracts                                     | (Wu et al., 2013)                                                         |
| Cuminum cyminum               | Seed meal                                              | (Yilmaz et al., 2012)                                                     |
|                                |                                                        | (Yilmaz, Ergün, Soytaş, 2013b)                                            |
| Pimenta dioica                 | Powder                                                 | (Yilmaz & Ergün, 2014; Yilmaz, Acar, Kesbic, Gültepe, Ergün, 2015; Gülü et al., 2016) |
| Red pepper extracts            | Powder                                                 | (Yilmaz et al., 2013a)                                                    |
| Blackberry                     | Syrup                                                  | (Yilmaz, 2019a)                                                           |

(Continued)
as, petroleum ether, chloroform, ethyl acetate, methanol, and aromatic water) (Kirubakaran, Alexander, & Michael, 2010; Yilmaz et al., 2014), or as mixture (Rattanachaikunsopon & Phumkhachorn, 2009; Gobi et al., 2016). Furthermore, among several solvents combination, a mixture of methanol/water/HCl (70: 29: 1, v/v/v) is reported to be the best at extracting phytochemicals (Xu, Zhang, Wang, & Lu, 2010). Hence, the types of medicinal plants, extracts (i.e. crude from whole or parts, or compounds from whole or parts of the plant), and extraction methods remain crucial aspects to consider in phytomedicinal studies in aquaculture.

3. Administration of herbal extracts

In general, herbal extracts in aquaculture may be delivered in three ways including oral, injection and immersion administration method. The selection of these methods is mainly dictated by the purpose of administration, size and type of the fish species, types of extract, and farming system as explained in (Gabriel et al., 2015). In addition, injection and immersion methods may be effective in delivering herbal extracts (Harikrishnan, Balasundaram, & Heo, 2010); however, they may not be feasible at all levels of aquaculture operation as they tend to be labor intensive, stressful to fish, and require highly skilled personnel. Today, oral administration tend to be the widely used method in aquaculture including tilapia farming, especially for fish growth and health parameters improvement (Tables 2 and 3). However, immersion as a method of extract delivery may also be useful in tilapia farming particularly for the purpose of sex reversal (Mukherjee, Ghosal, & Chakraborty, 2015a), which uses fish larvae that are not fully developed to consume artificial feed. It is therefore clear that more research are still deemed necessary to homogenize herbal extract administration methods for different purposes (i.e. fish growth, health, disease resistance, meat quality, sex reversal), types of extracts, fish species, and fish size.

4. Effects on growth and feed utilization indices

Numerous medicinal herbal extracts (i.e. crude, semi-purified and purified extracts) have been reported to promote growth and feed utilization parameters as well as survival rate among tilapia species. Crude extracts from Aloe vera (Gabriel, Qiang, He, Yu, et al., 2015), caraway (Ahmad & Abdel-Tawwab, 2011), Cinnamomum camphora, Euphorbia hirta, Azadirachta indica, and Carica papaya (Kareem, Abdelhadi, Christianus, Karim, & Romano, 2016), Allium sativum (Shalaby, Khattab, & Abdel Rahman, 2006) as well as those from Camellia sinensis (Abdel-Tawwab et al., 2010) were reported to have significantly increased weight gain (WG), specific growth rate (SGR), feed intake (FI), feed conversion ratio (FCR) among others, in Nile tilapia (Table 2). Similarly, growth performance parameters and feed utilization indices were improved in Nile tilapia fed diet supplemented with Astragalus polysaccharides (Zahran, Risha, Abdelhamid, & Allah, 2014; Mo, Lun, Choi, Man, & Wong, 2016), blackberry syrup (Yilmaz et al., 2019a), and in Oreochromis mossambicus fed...
Table 2. Effects of some herbal extracts on growth performance and feed utilization indices of tilapia species under culture

| Herbs                 | Parts/Products | Delivery | Conc.     | Optimum conc. | Duration | Growth performance/ feed utilization indices | Tilapia sp. | Initial size | References                           |
|-----------------------|----------------|----------|-----------|---------------|----------|-----------------------------------------------|-------------|--------------|--------------------------------------|
| Citrus sinensis       | Essential oil  | Oral     | 1, 3, 5 g kg⁻¹ diet | 3 g kg⁻¹ diet | 90 days  | SGR (>), WG (>), FCR (<)                      | O. mossambicus | 0.91g        | (Acar et al., 2015)                   |
| Citrus limon          | Essential oil  | Oral     | 0.5, 0.75, 1% kg⁻¹ | N/A        | 60 days  | SGR (=), WG (=), FCR (=)                      | O. mossambicus | 12.87       | (Baba et al., 2016)                   |
| Caraway               | Crude powder   | Oral     | 5, 10, 15, 20 g kg⁻¹ | 12.5 kg⁻¹  | 84 days  | FW (>), WG (>), FI (>), PER (>), FCR (<), APU (>), EU (>)| O. niloticus     | 3.60 g       | (Ahmad & Abdel-Tawwab, 2011)          |
| Blackberry            | Syrup          | Oral     | 7.5, 15, 30 g kg⁻¹ | 15 g kg⁻¹  | 90 days  | FW (>), RGR (>), SGR (>), FCR (=)             | O. niloticus     | 26.75g      | Yilmaz, 2019a                         |
| Tribulus terrestris   | Crude powder   | Oral     | 0.2, 0.4, 0.6, 0.8 g kg⁻¹ | 0.4 g kg⁻¹  | 45 days  | FW (>), SGR (>), WG (>), FCR (<)              | O. mossambicus     | fry          | Yilmaz et al., 2014                   |
| *Aloe vera*           | Powder         | Oral     | 0.5, 1, 2, 4% kg⁻¹ | 2% kg⁻¹    | 60 days  | WG (>), SGR (>), AGR (>), FCR (<), FI (>), PER (>), FER (>)| (GIFT-strain) | O. niloticus     | 4.83 g                               |
| (Gabriel, Qiang, Ma, et al., 2015) |                |          |           |               |          |                                               |             |             |                                      |
| *Camellia sinensis*   | Crude powder   | Oral     | 0.125, 0.25, 0.5, 1, 2 g kg⁻¹ | 0.5 g kg⁻¹  | 84 days  | FW (>), WG (>), SGR (>), FI (>), PER (>), EU (>)| O. niloticus     | Fingerlings  | (Abdel-Tawwab et al., 2010)           |
| *Allium sativum*      | Crude extracts | Oral     | 10, 20, 30, 40 g kg⁻¹ | 30 g kg⁻¹  | 90 days  | FW (>), WG (>), SGR (>), FI (>), FCR (<), PER (>)| O. niloticus     | 7.06 g       | (Shalaby, Khattab, & Abdel- Rahman, 2006) |
| *Ulva clathrata*      | Lyophilized Extracts | Oral     | 0.1, 0.5, 1% kg⁻¹ | N/A        | 60 days  | WG (=), SGR (=), FI (=), FCR (=)              | O. niloticus     | 25 g         | (Quezada-Rodriguez & Fajer-Avila, 2016) |

(Continued)
| Herbs                                      | Parts/Products | Delivery | Conc.       | Optimumconc. | Duration | Growth performance/ feed utilization indices | Tilapia ssp.   | Initial size | References                                |
|-------------------------------------------|----------------|----------|-------------|--------------|----------|---------------------------------------------|----------------|--------------|-------------------------------------------|
| Cynodon dactylon                         | Acetone extracts | Oral     | 1 g kg\(^{-1}\) | N/A          | 45       | PW (=)                                       | O. mossambicus | 7.46 g       | (Immanuel et al., 2009)                   |
| Aegle marmelos                           |                |          |             |              |          |                                             |                 |              |                                           |
| Withania somnifera                       |                |          |             |              |          |                                             |                 |              |                                           |
| Zingiber officinale                      |                |          |             |              |          |                                             |                 |              |                                           |
| Trigonella foenum-graecum                | Crude extracts | Oral     | 1, 2% kg\(^{-1}\) | 1% kg\(^{-1}\) | 112 days | TWG (>), SGR (>), FCR (<), PPV (>), EU (>), TWG (<), SGR (<), FCR (>), PPV (<), EU (<) | O. niloticus    | Fingerlings | (Zaki et al., 2012)                       |
| Capsicum frutescens                      |                |          |             | N/A          |          |                                             |                 |              |                                           |
| Eucalyptus citrodora                     |                |          |             | N/A          |          |                                             |                 |              |                                           |
| Matricaria recutit                       |                |          |             | N/A          |          |                                             |                 |              |                                           |
| Thymus vulgaris                          |                |          |             | N/A          |          |                                             |                 |              |                                           |
| Moringa oleifera                         | Crude extracts | Oral     | 10, 20 30% TD P | N/A          | 49 days  | SGR (<)                                      | O. niloticus    | 9-11 g       | (Richter, Siddhuraju, & Becker, 2003)     |

Notes: SGR, specific growth rate; WG, weight gain; FW, final weight; RGR, relative growth rate; AGR, absolute growth rate; TWG, total weight gain; PPV, protein productive value; PER, protein efficiency ratio; APU, apparent protein utilization; EU, energy utilization; FCR, feed conversion ratio; FI, feed intake; TDP, total dietary protein; N/A, not available; (>), significantly increased; (<), significantly decreased; (=) not affected.
Table 3. Effects of some herbal extracts on hematological and other immunological indices of tilapia species under culture

| Herbs               | Parts/Products | Delivery | Conc. | Duration | haematological/immunological indices | Tilapia ssp. | References                  |
|---------------------|----------------|----------|-------|----------|--------------------------------------|--------------|-----------------------------|
| Citrus sinensis     | Essential oil  | Oral     | 1, 3, 5 g kg\(^{-1}\) diet | 90 days | Hct (>), Hb (>), RBC (<), MCV (<), MCH (<), MCHC (>), Lyz. Act. (>), MPO (>), Glu (<), Trig (<), Chol (<), TP (>), Alb (>), Glob. (>). | O. mossambicus | (Acar et al., 2015)          |
| Tribulus terrestris | Crude powder   | Oral     | 0.2, 0.4, 0.6, 0.8 g kg\(^{-1}\) | 45 days | Hepatoprotective (>). | O. mossambicus | (Yilmaz et al., 2014)       |
| Citrus limon        | Essential oil  | Oral     | 0.5, 0.75, 1% kg\(^{-1}\) | 60 days | Hct (>), WBC (>), Lyz. Act. (>), MPO (>). | O. mossambicus | (Baba et al., 2016)         |
| Aloe vera           | Crude powder   | Oral     | 0.5, 1, 2, 4% kg\(^{-1}\) | 60 days | RBC (>), Hct (>), Hb (>), MCV (>), MCH (>), MCHC (>), WBC (>), Neutr. (>), Lymp. (>), Mono. (>), Eosin. (>), Neutr./Lymp. (>), Glu (>), TP (>), Lyz. Act. (>), Cort. (>). | O. niloticus (GIFT-strain) | (Gabriel et al., 2015)      |
| Blackberry          | Syrup          | Oral     | 7.5, 15, 30 g kg\(^{-1}\) | 90 days | RBC (=), Hb (=), Hct (=), RBA (>), Phagoc. act (>), Lyz. (>), T. immunoglob. (>), MPO (>), SOD (>), CAT (>). | O. niloticus | (Yilmaz, 2019a)             |
| Pimenta dioica      | Crude powder   | Oral     | 5, 10, 15, 20 g kg\(^{-1}\) | 60 days | RBC (<), Hct (<), Hb (<), MCV (<), MCH (<), MCHC (<), Glu. (<), TP (>), Alb. (>), Glob. (>), RBA (<), Lyz. (<), MPO (>). | O. mossambicus | (Güllü et al., 2016)        |
| P. dioica           | Crude powder   | Oral     | 5, 10, 15, 20 g kg\(^{-1}\) | 60 days | RBC (>), Hb (>), Hct (>), MCV (<), MCH (<), MCHC (>), Glu. (=), TP (>), Alb. (=), Glob. (>), RBA (>), Lyz. (>), MPO (>). | O. mossambicus | (Yilmaz et al., 2015)       |
| Camellia sinensis   | Crude powder   | Oral     | 0.125, 0.25, 0.5, 1, 2 g kg\(^{-1}\) | 84 days | RBC (>), WBC (>), Lymp. (>), Mono. (<), Lymp. (>), Granzn. (<), Glu. (>), T. (>), TP (<), Alb. (>), Glb. (>), NBT (>). | O. niloticus | (Abdel-Tawwab et al., 2010) |
| Allium sativum      | Crude extracts | Oral     | 10, 20, 30, 40 g kg\(^{-1}\) | 90 days | Eryt. (>), Hb (>), Hct (<), MCV (=), MCH (=), MCHC (>), Glu (<), TP (>), TL (>), AST (<), ALT (<). | O. niloticus | (Sholoby et al., 2006)       |

(Continued)
| Herbs                              | Parts/Products          | Delivery | Conc.            | Duration | haematological/immunological indices                                                                 | Tilapia ssp. | References                                      |
|------------------------------------|-------------------------|----------|------------------|----------|-------------------------------------------------------------------------------------------------------|--------------|-------------------------------------------------|
| Ulva clathrata                     | Lyophilized Extracts    | Oral     | 0.1, 0.5, 1% kg\(^{-1}\) | 60 days  | Hct (>), Hb (=), RBC (=), WBC (>), TP (>), Alb. (=), Glob. (=), Phagoc. act. (>).                  | O. niloticus | (Quezada-Rodríguez & Fajer-Avila, 2016)        |
| Cynodon dactylon                   | Acetone extracts        | Oral     | 1g kg\(^{-1}\)   | 45 days  | Hct (>), TP (>), Alb. (>), Trig. (<), Glob. (>), Glu. (<), Chol. (<), Leuco. (>), Phagoc.act. (>), Lyz. Act. (>), Cal. (=). | O. mossambicus | (Immanuel et al., 2009)                        |
| Aegle marmelos                     | Acetone extracts        | Oral     | 1g kg\(^{-1}\)   | 45 days  | Hct (>), TP (>), Alb. (>), Trig. (<), Glob. (=), Glu. (<), Chol. (<), Leuco. (=), Phagoc.act. (=), Lyz (>). | O. mossambicus | (Immanuel et al., 2009)                        |
| Withania somnifera                 | Acetone extracts        | Oral     | 1g kg\(^{-1}\)   | 45 days  | Hct (>), TP (>), Alb. (>), Trig. (<), Glob. (=), Glu. (<), Chol. (<), Leuco. Lyz (=), Cal. (=), Phagoc.act. (>). | O. mossambicus | (Immanuel et al., 2009)                        |
| Andrographis paniculata            | Methanolic extracts     | Oral     | 500, 1000, 2000, 3000 mg/kg | 45 days  | RBC (>), WBC (>), Thromb. (>), Hb (>), MCV (>), MCH (>), MCHC (>).                               | O. mossambicus | (Prosad & Mukthiraj, 2011)                      |
| Prunella vulgaris                  | Aqueous extracts        | Injection| 100, 300, 500 μg  | 4 days   | RBA (>), Ant. (>), Leuco. (>), Lzy. Act. (>), Phagocact. (>).                                      | O. niloticus | (Park & Choi, 2014)                            |
| Ginseng                            | Commercial Product (Ginsana, G115) | Oral     | 50, 100, 200, 250 mg/kg | 119 days | RBC (>), Hct (>), Hb (>), MCV (>), MCH (>), MCHC (=), Mono. (=), Granu. (=), TP (>), Alb. (>), Glob. (>). | O. niloticus | (Goda, 2008)                                   |

(Continued)
Table 3. (Continued)

| Herbs                        | Parts/Products | Delivery | Conc.  | Duration | haematological/immunological indices | Tilapia ssp. | References                          |
|------------------------------|----------------|----------|--------|----------|-------------------------------------|--------------|-------------------------------------|
| Rosmarinus officinalis       | Crude powder   | Oral     | 1% kg^{-1} | 45 days  | WBC (>), RBC (>), Hb (=), Hct (>), Mono. (>), Phagoc. act. (>), NBT (=), Lzy.Act. (=), MPO (=), Hepatoprotective (>) | O. mossambicus | (Gültepe et al., 2014) (Gurkan et al., 2015) |
| Trigonella foenum graecum    | Crude powder   | Oral     | 1% kg^{-1} | 45 days  | WBC (>), RBC (>), Hb (=), Hct (>), Mono. (>), Phagoc. act. (>), NBT (=), Lzy. Act. (>), MPO (>), Hepatoprotective (>) | O. mossambicus | (Gültepe et al., 2014) (Gurkan et al., 2015) |
| Thymus vulgaris              | Crude powder   | Oral     | 1% kg^{-1} | 45 days  | WBC (>), RBC (>), Hb (=), Hct (>), Mono. (>), Phagoc. act. (>), NBT (=), Lzy. Act. (>), MPO (>), Hepatoprotective (>) | O. mossambicus | (Gültepe et al., 2014) (Gurkan et al., 2015) |
| Nigella sativum              | Crude seed Extracts | Oral | 3 % kg^{-1} | 30 days  | WBC (>), Glob. (=), Phago.Act. (>), Phagoc. index. | O. niloticus | (Elkamel & Mosaad, 2012) |
| Caffeic acid                 | Oral           |          | 1.0, 5.0, 10.0 g kg^{-1} | 60 days  | RBC (=), Hb (=), Hct (=), Glu (=), TP (>, Alb (=), Trig. (>, Chol. (>, AST (<), ALT (=), LDH (=), ALP (>), RBA (>), Phagoc. act. (>), Lzy. Act. (=), MPO (>), SOD (>), CAT (>)) | O. niloticus | Yilmaz et al. 2019b |
| Echinacea purpurea           | Capsule        | Oral     | 0.75 g/kg^{-1} | 30 days  | Leuco. (>), NBT (>), Lzy. Act. (>), Bactericidal act. (<), Glob. (>), Lymph. stim. index (>), IgM (>), | O. niloticus | (El-Sayed et al., 2014) |
| Lacinera japonica            | Chlorogenic acid| Oral     | 1, 0.5 kg^{-1} | 21 days  | Phagoc. act. (>), RBA (=), Lzy. Act. (>), TP (=), T.mmonoglob.v. (=). | O. niloticus | (Yin et al., 2008) |
| Ganoderma lucidum            | Polysaccharide | Oral     | 1, 0.5% kg^{-1} | 21 days  | Phagoc. act. (>), RBA (=), Lzy. Act. (>), TP (=), T.mmonoglob.v. (=). | O. niloticus | (Yin et al., 2008) |

Notes: Hct = Hematocrits; Hb = Hemoglobin; WBC = White blood cells; MCV = Mean corpuscular volume; Lzy. Act. = Lysosome activity; MPO = Myeloperoxidase; Glu. = Glucose; Trig. = Triglycerides; TP = Total protein; Alb. = Albumin; Glob. = Globulin; Chol. = Cholesterol; RBC = Red blood cells; MCH = Mean corpuscular hemoglobin; MCHC = mean corpuscular hemoglobin concentrate; Neutr. = Neutrophils; Lymp. = Lymphocytes; Cort. = Cortisol; TL = Total lipids; NBT = Nitro blue tetrazolium; Eryt. = Erythrocytes; AST = Aspartate aminotransferase; ALT = Alanine aminotransferase; Phagoc. Act. = Phagocytic activity; Calc. = calcium; Leuco. = Leucocytes; Thromb. = Thrombocytes; RBA = Respiratory burst activity; Mono. = Monocytes; Granu. = Granulocytes; Phagoc. index = Phagocytic index; Bactericidal act. = Bactericidal activity; IgM = Immunoglobulin M; Lymph. stim. index = Lymphocytes stimulation index; T. Immunoglobulin v. = Total immunoglobulin value. (> =) Significantly increased; (< =) significantly decreased; (= =) not affected; phagocytic ratio = Phagoc. ratio; phagocytic index = Phagoc. index; Basophils = Baso.; LDH = Lactate dehydrogenase; ALP = Alkaline phosphatase.
diet enriched with *Cynodon dactylon*, *Aegle marmelos*, *Withania somnifera*, and *Zingiber officinale* acetone extracts (Immanuel et al., 2009), *Tribulus terrestris* (Yilmaz et al., 2014). Improvement in growth performance and feed utilization indices in fish following medicinal herbal extracts is recited to be attributed by their wide range of immuno-nutritional constituents including complex sugars such as polysaccharides (Zahran et al., 2014). Polysaccharides are believed to possess prebiotic properties (Kumar, Auroshree, & Mishra, 2016), which can increase nutrient digestibility, absorption, and assimilation capacity of an animal through an improved gastrointestinal morphology or digestive systems (Heidarieh et al., 2013; Gabriel, Qiang, He, Ma, et al., 2015), 30g/kg diet of *Allium sativum* (Shalaby et al., 2006), 1%/kg diet of *Ulva clathrata* (Quezada-Rodriguez & Fajer-Ávila, 2016), and 0.5g/kg diet of *Camellia sinensis* (Abdel-Tawwab et al., 2010) were, respectively, recommended to be the optimum dietary inclusion levels that can enhance better growth in tilapia (Table 2). Moreover, poor fish growth or no growth effect that is mostly observed at higher herbal extract dietary inclusion level has been reported to be attributed by a higher concentration of anti-nutritional factors (i.e. saponin, tannin), toxic constituents, excessive doses, and allergic reactions (Irkin, Yigit, Yilmaz, & Maita, 2014; Madalla, Agbo, & Jauncey, 2013, 2018). This is one of the main reasons, why some herbal extracts negatively affect or have no effect on growth and feed utilization indices of fish, such as those extracted from *Moringa oleifera* (Madalla et al., 2013; Dongmeza, Siddhuraju, Francis, & Becker, 2006; Richter, Siddhuraju, & Becker, 2003), *Eucalyptus citrodora*, *Capsicum frutescens*, *Matricaria recutita*, *Thymus vulgaris*, and fenugreek sprouts (Zaki, Labib, Nour, Tonsy, & Mahmoud, 2012), *Cynodon dactylon*, *Aegle marmelos*, *Withania somnifera*, and *Zingiber officinale* (Immanuel et al., 2009) (Table 2). Thus, the need to research effective medicinal herbal extracts purification/extraction methods, that do not affect the final required composition of the extracts is deemed necessary in aquaculture.

5. Effects on health parameters/indices

5.1. Hematological indices

In vertebrates including fish, blood is the most frequently examined tissue in efforts to establish their health status or physiological status. Accordingly, health status such as oxygen carrying capacity has been directly determined by reference to main hematological indices including red blood cell (RBC), hemoglobin concentration (Hb), percentage of blood volume consisting of red cells, and hematocrit (Hct) (Houston, 1997). Secondary indices, sometimes called Wintrobe indices (Urrechaga, Izquierdo, & Esconero, 2014) can be derived from these indices for the classification of anemia condition such as mean corpuscular volume (MCV) = (Hct x 10/RBC), mean corpuscular hemoglobin (MCH) = (Hb x 10/RBC), and mean corpuscular hemoglobin concentration (MCHC) = (Hb x 100/Hct) as demonstrated in (Gabriel et al., 2015a). Furthermore, other hematological indices such as white blood cell (WBC), and a number of their differential counts (i.e. leucocyte counts such as lymphocytes, neutrophils, eosinophils, monocytes, and basophils) have been assessed to take account of innate immune status of animals especially during stressful conditions (Roberts & Rodger, 1978). In addition, neutrophils to lymphocytes ratio has been proven to be a useful tool to estimate stress level in vertebrates (Van Rijn & Reina, 2010).
Several studies in aquaculture have adequately demonstrated that numerous medicinal plants have the capacity to enhance some of the aforementioned hematological parameters. In tilapia culture for instance, A. vera supplemented diet was reported to have significantly increased RBC, Hct, Hb, WBC, and some differential leukocyte counts of O. niloticus (GIFT-strain) before and after Streptococcus iniae challenge (Gabriel et al., 2015). Similarly, administration of Rosmarinus officinalis, Trigonella foenum graecum, Thymus vulgaris administration in O. mossambicus (Gültepe et al., 2014), Camellia sinensis in O. niloticus (Abdel-Tawwab et al., 2010), Citrus sinensis in O. mossambicus (Acar et al., 2015), Citrus limon in O. mossambicus (Baba et al., 2016), ginseng in O. niloticus (God, 2008), Ulva clathrata in O. niloticus (Quezada-Rodriguez & Fajer-Ávila, 2016), Cynodon dactylon, Aegle marmelos, Withania somnifera, Zingiber officinal (Immanuel et al., 2009), Lonicera japonica and Ganoderma lucidum (Yin, Ardó, Jeney, Xu, & Jeney, 2008), P. dioca (Güllü et al., 2016; Yilmaz et al., 2015) reportedly improved some hematological parameters. The observed improvement of hematological indices signify the ability of herbal extracts to stimulate erythropoiesis, thus increasing the capability of oxygen transport and strengthening of defense mechanisms against physiological stress. This is suggested to have been attributed by their rich nutritional properties especially polysaccharides, essential vitamins (i.e. riboflavin, thiamine, folic acid), and nonessential amino acids, which are primarily required for hemoglobin synthesis (Latona, Oyeleke, & Olayiwola, 2012; Hamman, 2008).

Furthermore, some medicinal herbal extracts have been reported to have no effects on hematological parameters in tilapia species. For instance, Cinnamomum camphora, Euphorbia hirta, Azadirachta indica, or Carica papaya crude extracts were reported to impose no effects on RBC, Hb, MCV, MCHC, Hct, and WBC of O. niloticus (Kareem et al., 2016). It appears that, the capacity or effects of a medicinal herb on hematological indices can only be well established if an animal is exposed to some stressful conditions as demonstrated in (Gabriel et al., 2015), of which several studies did not perform (Zaki et al., 2012; Shalaby et al., 2006; Quezada-Rodriguez & Fajer-Ávila, 2016; Prasad & Priyanka, 2011; Park & Choi, 2014; Elkamel & Mosad, 2012). Moreover, several studies in tilapia culture (Baba et al., 2016; Gabriel, Qiang, He, Yu, et al., 2015a; Goda, 2008), and in other fish species such as Labeo rohita (Andrews, Sahu, Pal, Mukherjee, & Kumar, 2011), Cyprinus carpio (Pakravan, Hajar Moradlou, & Ghorbani, 2011), and Oncorhynchus mykiss (Haghighi, Rohani, Samadi, & Tavoli, 2014) reported that herbal extracts presented lower hematological indices and to a certain extent cause anemia in fish (Gabriel et al., 2015a), especially at higher dosage. The causes and mechanisms of this are barely known. However, they are assumed to do this by interfering with erythropoiesis, hemosynthesis, and osmoregulatory functions or increasing erythrocyte destruction in hematopoietic organs (Jenkins, Smith, Rajanna, & Rokkam, 2003). Therefore, optimization of herbal extracts based not only on growth, and feed utilization parameters but also on blood parameters such as hematocrit is essential for aquaculture.

5.2. Immunological and biochemical indices

In addition to hematological parameters, blood serum contains numerous elements that can be used to monitor health status of fish. For example, serum total protein (product of WBC) (Misra, Das, Mukherjee, & Meher, 2006), and globulins (source of immunoglobulins or antibodies) (Goda, 2008) levels in the blood reflect immune system activation (Siwicki, Anderson, & Rumsey, 1994). While lysozyme, antimicrobial peptides, phagocytes, complement factors content in the blood indicate pathogens entry inhibiting activity through pathogen cell wall lysis (i.e. lysozyme, antimicrobial peptides), phagocytosis (i.e. phagocytes), and neutralization (complement factors) (Uribe, Folch, Enriquez, & Moran, 2011). Furthermore, several endogenous antioxidant enzymes such as myeloperoxidase (MDA), catalase (CAT), superoxide dismutase (SOD), and glutathione peroxide GSH-Px have been used to indicate cell damage from reactive oxygen species (ROS) (Wu, Xu, Shan, & Tan, 2006). Moreover, hepatoprotective activity is mainly determined by aspartate aminotransferase (AST), and alanine aminotransferase (ALT) (Cui et al., 2014), while stress can be reflected by glucose and cortisol blood content (He et al., 2015).
It has been established that several medicinal herbal extracts have potent ability to improve a range of biochemical indices in fish including tilapia species. Accordingly, essential oil extracted from *C. sinensis* (Acar et al., 2015), and *C. limon* (Baba, Acar, Öntaş, et al., 2016) was reported to have enhanced innate immune biochemical parameters (total protein, and lysozyme), and even resistance against *Edwardsiella tarda* and *Streptococcus iniae* bacterial pathogen in *O. mossambicus*, respectively. Similarly, improvement of innate immune biochemical parameters following dietary administration of *A. vera* (Gabriel, Qiang, He, Yu, et al., 2015a), *A. sativum* (Shalaby et al., 2006), *Echinacea purpurea* (El-Sayed, El-Galil, & Rashied, 2014), *G. lucidum* (Yin et al., 2008), ginseng (Goda, 2008), blackberry syrup (Yilmaz, 2019a), and Caffeic acid (Yilmaz, 2019b) was reported in *O. niloticus*, respectively. In addition, dietary *E. purpurea* extracts (capsules) were reported to trigger immunoglobulin M activity in *O. niloticus* (El-Sayed et al., 2014), which is an indication of specific immune response activation.

Furthermore, *A. vera* crude extracts were reported to have enhanced antioxidant enzymes (CAT, SOD, GSH-Px), reduced stress (lower level of glucose and cortisol) (Gabriel et al., 2015a) and improved hepatoprotective activity (lower level of AST) (Gabriel et al., 2015b) in GIFT-tilapia, pre and post *Streptococcus iniae* challenge. The same results were obtained by Metwally (2009) in *O. niloticus* after been fed a diet supplemented with *A. sativum* extracts, however without these animals being challenged. In the same line, unchallenged animals (*O. niloticus*) fed diet incorporated with *A. sativum* acetone extracts presented improved hepatoprotective activity (Shalaby et al., 2006). Meanwhile, acetone extracts from *C. dactylon, A. marmelos, W. somnifera*, and *Z. officinale* were reported to have reduced stress in *O. mossambicus* (Immanuel et al., 2009).

The enhancement of antioxidant and hepatoprotective activity in fish by herbal extract is fairly understood, and often times is correlated with certain phytochemicals. Phytochemicals such as phenol/polyphenols (gallic acid, tannins, and ellagic acid), enzymes (SOD, CAT, GSH-Px), vitamins (C, E, and carotenoids), flavonoids (flavones, isoflavone, flavone, anthocynins and catechins) (Gupta & Sharma, 2014) present in herbal extracts are known to support the inhibition or suppression of oxidation process (Kenari, Mohsenzadeh, & Amiri, 2014). They can inhibit or suppress oxidation process by increasing the amount and activity of the body’s natural antioxidant enzymes such as liver CAT, SOD, and glucose-6-phosphate dehydrogenase (Rajasekaran, Ravi, Sivagananam, & Subramanian, 2006) or by increasing the bioavailability of vitamin E and C (important antioxidant agents) (Vinson, Al Kharrat, & Andreoli, 2005). Furthermore, antioxidation and hepatoprotective properties of herbal extracts cannot be emphasized; however, their optimization in aquaculture requires more research including quantification of extracts’ beneficial phytochemicals (i.e. flavonoids and phenols) and their correlation to different immune biochemical indices. The extend of possible negative impacts of these phytochemicals on fish species, environment, and consumers also needs to be established, as they are known to be toxic at higher dosages (Taiwo, Olukunle, Ozor, & Oyejobi, 2005; Gabriel et al., 2015a).

### 5.3. Herbal extract as reproduction controlling agent in tilapia culture

In intensive production systems, tilapias are associated with precocious maturity and prolific breeding behaviors, which affects their production parameters and ultimately economic return (Budd, Banh, Domingos, & Jerry, 2015). Farming with monosex tilapia population is therefore highly recommended. Today, there are several methods used to produce monosex tilapia population including manual separation of sex, hybridization, genetic manipulation and sex reversal hormone (Gabriel et al., 2015c). The later is acknowledged as the most effective and widely used method responsible with mass production of male tilapias in commercial production systems (El-Greisy & El-Gamal, 2012). Hence, the current global tilapia production success owes it to this method. While hormonal sex reversal method is believed to offer practical and economical solution to control reproduction in tilapia, this method is associated with a number of shortcomings including potential health risk to workers, consumers and environment (Phelps & Popma, 2000). Thus, more
studies on the safety of sex reversal hormones in fish are needed, and exploration of affordable, environmental and appropriate technology is deemed necessary.

Early studies have revealed that several medicinal herbs contain phytochemicals (phytoestrogen or phytoandrogens) that are structurally similar to steroid hormones, i.e. 17-β estradiol (E2) in animals (Glazier & Bowman, 2001). Recently, these phytochemicals have been reported to induce masculinization, feminization or impair fertility in tilapia species (Gabriel et al., 2017; Jegede, 2010). For instance, saponin extracts from Quillaja saponins (QS) (Francis, Levavi-Sivan, Avitan, & Becker, 2002), fenugreek (Trigonella foenum-graecum) and soapbark tree (Quillaja saponaria) (Stadtlander et al., 2008), and Tribulus terrestris (Omitoyin, Ajani, & Sadiq, 2013), reportedly produced a significant number of males Nile tilapia when were incorporated in their diet, and high percentage of males was recorded at high concentrations. Masculinization effects of saponin extracts on tilapia larvae may be explained by the fact that saponin is able to elevate testosterone hormone production (Ganzera, Bedir, & Khan, 2001) and as a result, plants that contain saponin compounds, especially Tribulus terrestris have been used to treat impotence in human (Akram et al., 2011). Similarly, masculinization effects were also reported in Nile tilapia fed dietary Aloe vera (Gabriel et al., 2017), Mucuna pruriens (Mukherjee, Ghosal, & Chakraborty, 2015b), Butea superb (Kiriyakit, 2014), and in other tilapia species such O. mossambicus fed dietary moringa and paw paw crude extracts, respectively (Ampofo-Yeboah, 2013). In addition, a study by (El-Sayed, Abdel-Aziz, & Abdel-Ghani, 2012) revealed that soybean meal significantly reduced the number of males in Nile tilapia culture, and further advised tilapia farmers to avoid using soybean as a source of protein during sex reversal. Considering these findings, herbal extracts therefore present potent potential to eradicate the use of synthetic sex reversal hormones in tilapia culture. Because, compared to sex reversal hormones, herbal extracts are believed to be easily accessible, simple to apply, and may be safe to the environment and human as they tend to be more biodegradable (Reverter et al., 2014).

Furthermore, as mentioned early in this paper, another way herbal extracts could control reproduction in tilapia is by impairing fertility through gonads (testes and ovaries) destruction. A study by Jegede and Fagbenro (2008) reported swollen spermatids nuclei, increased interstitial cells and focal necrosis in testes; and hydroptic degeneration, ruptured follicles, granulomatous inflammation in the interstitium and necrosis ovaries when neem (Azadirachta indica) leaves were incorporated in Tilapia zilli basal diet at 2.0 g kg⁻¹. Similar findings were reported in O. niloticus fed Carica papaya (Abdelhak et al., 2013), Hibiscus rosa-sinensis (Jegede, 2010), and Aloe vera (Jegede, 2011) as well as in O. mossambicus fed dietary Carica papaya and Moringa oleifera respectively (Ampofo-Yeboah, 2013). This is an indication that indeed herbal extracts may be used to control reproduction in tilapias by delaying maturing, and producing monosex population as mentioned earlier. However, optimization of herbal extracts as sex reversal and fertility controlling agents in tilapia requires extensive research.

5.4. Gaps in the existing knowledge and way forward
Constraints associated with the wide adoption of intensive aquaculture farming systems such as increased susceptibility to diseases and poor meat quality among others, can not be overemphasized. And the consequent use of chemotherapeutic drugs (i.e. antibiotics and sex reversal hormones) to improve production appears to be more production-oriented, while ignoring the potential impacts these chemicals might have on the environment, humans, and animals. The findings of this review paper give an impression that there are several medicinal herbs that indeed possess ability to enhance growth, feed utilization, immune response (both innate and specific), antioxidation, hepatoprotective activity, resistance against disease, and control reproduction in tilapia culture. However, the pace of implementation of this innovation is slow, despite numerous advantages associated with it, as mentioned earlier.

Effective application of herbal extract in tilapia culture and aquaculture in general is limited in many ways. These limitations include lack of sufficient knowledge on effective herbal extraction methods for different purposes/functions (i.e. growth, immune, antioxidation, sex
reversal among others), types of effective extracts (i.e. raw, aqueous, methanolic, ethanolic), optimum dosage for different purpose, potential herbal extracts harmful effects in fish, environment, and consumers, mode of actions, effect on fish meat quality, effects of herbal extracts between different physiological process (i.e. growth optimum herbal extract dosage on fish reproduction. For example, saponin compound found in most medicinal plants that is believed to be a promising tilapia masculinizing agent Francis et al., 2002; Omitoyin et al., 2013; Stadtlander et al., 2008), and anti-inflammatory properties (Zhang et al., 1990), it also believed to act as feed deterrent, reducing feed intake in fish, and consequently growth (Dongmeza et al., 2006). Method of extraction and types of extracts are among the factors that indeed determine the beneficial properties and efficacy of herbal extracts on the health of cultured fish. For instance, fish fed with diet containing methanol extracted moringa leaf have been reported to present a better feed intake and growth performance than those fed with diet containing raw moringa leaf meal extract (Afuang et al., 2003). In addition to the limitations, effects of herbal extracts in fish at different life stages (i.e. fries, fingerlings, juveniles, pre-adults and adults) are unknown, and another is lack of quantitative estimation of beneficial phytochemicals (i.e. phenols & flavonoids) of herbal extraction and correlations to their effects in fish. Therefore, the need to research more and standardize every aspect around the use of herbal extracts in tilapia culture is overwhelming. Moreover, exploration and implementation of herbs in tilapia culture and aquaculture in general has to be done in a sustainable manner, as adopting them in aquaculture may double the pressure already exerted by agricultural sectors and humans.

In conclusion, this review reveals that there are numerous medicinal plants with potential to enhance growth, several physiological parameters, control early maturity and prolific breeding in tilapia aquaculture. However, the lack of sufficient knowledge on herbal extracts limits the cost-effective use of herbal extracts in tilapia aquaculture. Therefore, more research is required to further validate herbal extracts with their allied growth-promoting effects, immune-stimulating effects, sex reversal effect, toxicity effects, extraction methods, and extract concentration, among others.

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References
Abdelhak, E. M., Madkour, F. F., Ibrahim, A. M., Sharaf, S. M., Sharaf, M. M., & Mohammed, D. A. (2013). Effect of pawpaw (Carica papaya) seeds meal on the reproductive performance and histological characters of gonads in Nile tilapia (Oreochromis niloticus). Ijar, 4, 34–37.
Abdel-Tawwab, M., Ahmad, M., Seden, M. E. A., & Sakr, S. F. M. (2010). Use of green tea, Camellia sinensis L., in practical diet for growth and protection Nile tilapia, Oreochromis niloticus (L.), against Aeromons hydrophila infection. Journal of the World Aquaculture Society, 41, 203–2013. doi:10.1111/jwas.2010.41.issue-s2
Abuelsaad, A. S. A. (2014). Supplementation with Astragalus polysaccharides alters Aeromonas induced tissue-specific cellular immune response. Microbial Pathogenesis, 66, 48–56. doi:10.1016/j.micpath.2013.12.005
Acar, Ü., Kesbic, O. S., Yilmaz, S., Gültepe, N., & Türker, A. (2015). Evaluation of the effects of essential oil extracted from sweet orange peel (Citrus sinensis) on growth rate of tilapia (Oreochromis mossambicus) and possible disease resistance against Streptococcus iniae. Aquaculture, 437, 282–286. doi:10.1016/j.aquaculture.2014.12.015
Afuang, W., Siddhuraju, P., & Becker, K. (2003). Comparative nutritional evaluation of raw, methanol extracted residues and methanol extracts of moringa (Moringa oleifera lam.), leaves on growth performance and feed utilization in Nile tilapia, Oreochromis niloticus. Aquaculture Research, 34, 1147–1159. doi:10.1046/j.1365-2109.2003.00920.x
Ahmad, M. H., & Abdel-Tawwab, M. (2011). The use of caraway seed meal as a feed additive in fish diets: Growth performance, feed utilization, and whole-body composition of Nile tilapia, Oreochromis niloticus (L.) fingerlings. Aquaculture, 314, 110–114. doi:10.1016/j.aquaculture.2011.01.030
Akram, M., Asif, H. M., Akhtar, N., Shah, P. A., Uzair, M., Shaheen, G., ... Ahmad, K. (2013). Tribulus terrestris Linn.: A review article. The Journal of Medicinal Plants Research, 5, 1601–1605.
Ampofo-Yeboah, A. (2013). Effect of phytogenic feed additives on gonadal development in Mozambique tilapia (Oreochromis mossambicus). (PhD Agric) thesis, University of Stellenbosch, South Africa.

Andrew, S. R., Saha, N. P., Pal, A. K., Mukherjee, S. C., & Kumar, S. (2011). Yeast extract, brewer’s yeast extract, brewer’s yeast and spirulina in diets for Labeo rohita fingerlings affect haemato-immunological responses and survival following Aeromonas hydrophila challenge. Research in Veterinary Science, 91, 103–109. doi:10.1016/j. rvsc.2010.08.009

Ardo, L., Yin, G., Xu, P., Vörösi, L., Szigeti, G., Jeney, Z., & Jeney, G. (2008). Chinese herbs (Astragalus membranaceus and Lonicera japonica) and boron enhance the non-specific immune response of Nile tilapia (Oreochromis niloticus) and resistance against Aeromonas hydrophila. Aquaculture, 275, 26–33. doi:10.1016/j.aquaculture.2007.12.022

Arenol, A., Martin, L., Castillo, N. M., de la Torre, D., Torres, U., & González, R. (2012). Aqueous extract of Ocimum tenuiflorum decreases levels of blood glucose in induced hyperglycemic tilapia (Oreochromis niloticus). Asian Pacific Journal of Tropical Medicine, 5(8), 634–637.

Baba, E., Acar, U., Ontas, K. P., Kumar, K., Nilavan, E., & Kumar, S. (2013). Effect of dietary supplemented androgrophiol on growth, non-specific immune parameters and resistance against Aeromonas hydrophila in Labeo rohita (Hamilton). Fish & Shellfish Immunology, 35, 1433–1441. doi:10.1016/j.fsi.2013.08.005

Budd, A., Banh, Q., Domingis, J., & Jerry, D. (2015). Sex control in fish: Approaches, challenges and opportunities for aquaculture. Journal of Marine Science and Engineering, 3, 329–355. doi:10.3390/jmse3020329

Bulfon, C., Volpatti, D., & Galeotti, M. (2013). Current research on the use of plant-derived products on farmed fish. Journal of Aquaculture Research, 46, 1–39.

Carbone, D., & Faggio, C. (2018). Importance of probiotics in aquaculture as immunostimulants. Effects on immune system of Sparus aurata and Dicentrarchus labrax. Fish & Shellfish Immunology, 54, 172–178. doi:10.1016/j.fsi.2016.04.011

Chitmanat, C., Tongdonmuan, K., & Nunsong, W. (2005). The use of crude extracts from traditional medicinal plants to eliminate Trichodina sp. in tilapia (Oreochromis niloticus) fingerlings. Journal of Science and Technology, 27(Suppl 1), 359–364.

Christybpita, D., Divyagnaneswari, M., & Michael, R. D. (2007). Oral administration of Eclipta alba leaf aqueous extract enhances the non-specific immune responses and disease resistance of Oreochromis mossambicus. Fish & Shellfish Immunology, 23(4), 840–852. doi:10.1016/j.fsi.2007.03.010

Cui, Y., Ye, Q., Wang, H., Li, Y., Yao, W., & Qian, H. (2014). Hepatoprotective potential of Aloe vera polysaccharides against chronic alcohol-induced hepatotoxicity in mice. Journal of the Science of Food and Agriculture, 94(9), 1766–1771. doi:10.1002/jsfa.6489

Dawood, M. A. O., & Koshibo, S. (2016). Recent advances in the role of probiotics and prebiotics in carp aquaculture: A review. Aquaculture, 454, 243–251. doi:10.1016/j.aquaculture.2015.12.033

Dongmeza, E., Sidduraju, P., Francis, G., & Becker, K. (2006). Effects of dehydrated methanol extracts of Moringa (Moringa oleifera Lam.) leaves and three of its fractions on growth and feed nutrient assimilation in Nile tilapia (Oreochromis niloticus L.). Aquaculture, 261, 407–422. doi:10.1016/j.aquaculture.2006.08.006

Dotta, G., de Andrade, J. J. A., Gonçalves, E. L. T., Brum, A., Mattos, J. J., Maraschin, M., & Martins, M. L. (2014). Leukocyte phagocytosis and lysozyme activity in Nile tilapia fed supplemented diet with natural extracts of propolis and Aloe barbadensis. Fish & Shellfish Immunology, 39(2), 280–284. doi:10.1016/j.fsi.2014.05.020

El-Greisy, Z. A., & El-Gamal, A. E. (2012). Monosex production of tilapia, Oreochromis niloticus using different doses of 17α-Methyltestosterone with respect to the degree of sex stability after one year of treatment. The Egyptian Journal of Aquatic Research, 38, 59–66. doi:10.1016/j.ejaq.2012.08.005

Elkammel, A. A., & Mosaad, G. M. (2012). Immunomodulation of Nile Tilapia, Oreochromis niloticus, by Nigella sativa and Bacillus subtilis. Journal of Aquaculture & Research Development, 3(6). doi:10.4172/2155-9546.1000147

El-Sayed, A. F. M., Abdel-Aziz, E. S. H., & Abdel-Ghani, H. M. (2012). Effects of phytoestrogens on sex reversal of Nile tilapia (Oreochromis niloticus) larvae fed diets treated with 17α-Methyltestosterone. Aquaculture, 360–361, 58–63. doi:10.1016/j.aquaculture.2012.07.010

El-Sayed, S. A. A., El-Galil, S. Y. A., & Rashied, N. A. (2014). Effects of Some herbal plants as natural feed additives in comparison with antibiotic on growth performance and immune status of Nile tilapia (Oreochromis niloticus). Urp, 4, 22–30.

FAO. (2016). The state of world fisheries and aquaculture 2016 (Vol. 160). Rome: Food and Agriculture Organization.

Francis, G., Levavi-Sivan, B., Avitan, A., & Becker, K. (2002). Effects of long term feeding of Quillaja saponins on sex ratio, muscle and serum cholesterol and LH levels in Nile tilapia (Oreochromis niloticus (L.)). Comparative Biochemistry & Physiology Part C, 133, 593–603.

Gabriel, N. N., Qiang, J., He, J., Mo, X. Y., Kpundeh, M. D., & Xu, P. (2015a). Dietary Aloe vera supplementation on growth performance, some haemato-biochemical parameters and disease resistance against Streptococcus iniae in tilapia (GIFT). Fish & Shellfish Immunology, 44, 504–514. doi:10.1016/j.fsi.2015.03.002

Gabriel, N. N., Qiang, J., Kpundeh, M. D., & Xu, P. (2015). Use of herbal extracts for controlling reproduction in tilapia culture: Trends and prospects – A review. Israeli Journal of Aquaculture-Bamidgeh, 67, 1–22.

Gabriel, N. N., Qiang, J., Mo, X. Y., He, J., Xu, P., & Liu, K. (2015). Dietary Aloe vera improves plasma lipid profile, antioxidant, and hepatoprotective enzyme activities in GIFT-tilapia (Oreochromis niloticus) after Streptococcus iniae challenge. Fish Physiology and Biochemistry, 41(5), 1321–1332. doi:10.1007/s10695-015-0088-z

Gabriel, N. N., Qiang, J., Mo, X. Y., He, J., Xu, P., & Omorogie, E. (2017). Sex-reversal effect of dietary Aloe vera (Lilaceae) on genetically improved farmed Nile tilapia fry. North American Journal of Aquaculture, 79(1), 100–105. doi:10.1080/15222055.2016.1236064
Ganzer, M., Bedir, E., & Khan, I. A. (2001). Determination of steroidal saponins in Tribulus terrestris by reversed-phase high-performance liquid chromatography and evaporation liquid detection scattering. *Journal of Pharmaceutical Sciences, 90*, 1752–1758. doi:10.1002/jps.1124

Ghosal, I., & Chakraborty, B. S. (2014). Effects of the aqueous leaf extract of Basella alba on sex reversal Nile tilapia, *Oreochromis niloticus* L. *Journal of Pharmacy and Biological Sciences, 9*, 162–164. doi:10.9790/2008

Glazier, M. G., & Bowman, M. A. (2001). A review of the evidence for the use of phytoestrogens as a replacement for traditional estrogen replacement therapy. *Archives of Internal Medicine, 161*, 1161–1172. doi:10.1001/archinte.161.9.1161

Gobi, N., Ramya, C., Vaseeharan, B., Malalkathundan, B., Vignayakumar, S., Murugan, V., & Benelli, G. (2016). *Oreochromis mossambicus* diet supplementation with *Psidium guajava* leaf extracts enhance growth, immune, antioxidant response and resistance to *Aeromonas hydrophila*. *Fish & Shellfish Immunology, 58*, 572–583.

Godo, A. M. A. S. (2008). Effect of dietary ginseng herb (Ginsana @ G115) supplementation on growth, feed utilization, and hematological indices of Nile tilapia, *Oreochromis niloticus* (L.), fingerlings. *Journal of the World Aquaculture Society, 39*(2), 205–214. doi:10.1111/j.1749-7345.2008.00153.x

Gullu, K., Acar, Ü., Kesbiç, O. S., Yilmaz, S., Ağıltay, S., Ergün, S., & Türker, A. (2016). Beneficial effects of Oral Allspice, *Pimenta dioica* powder supplementation on the hematomo-immunological and serum biochemical responses of *Oreochromis mossambicus*. *Aquaculture Research, 47*(9), 2697–2704. doi:10.1111/are.12717

Gultepe, N., Acar, Ü., Kesbiç, O. S., Yılmaz, S., Yıldırım, O., & Türker, A. (2016). Effects of dietary Tribulus terrestris extract supplementation on growth, feed utilization, hematological, immunological and biochemical variables of Nile tilapia *Oreochromis niloticus*. *Journal of Aquaculture-Bamidgeh, 66*, 1–8.

Gultepe, N., Bilen, S., Yılmaz, S., Güroy, D., & Aydin, S. (2016). Effects of herbs and spice on health status of tilapia (*Oreochromis mossambicus*) challenged with *Streptococcus iniae*. *Acta Veterinaria Brno, 83*, 129–135. doi:10.17559/avb201483020125

Gupta, V. K., & Sharma, S. K. (2014). Plants as natural antioxidants. *Injpr, 5*, 326–334.

Gurkan, M., Yilmaz, S., Kaya, H., Ergun, S., & Alkan, S. (2015). Influence of three spice powders on the survival and histopathology of *Oreochromis mossambicus* before and after *Streptococcus iniae* infection. *The Marine Science and Technology Bulletin, 4*(1), 1–5.

Haghighi, M., Rohani, M. S., Samadi, M., & Tavoli, M. (2016). Study of effects Aloe vera extract supplemented feed on hematological and immunological indices of rainbow trout (*Oncorhynchus mykiss*). *Ijnpr, 2*, 2143–2154.

Hamman, J. (2008). Composition and applications of Aloe vera leaf gel. *Molecules, 13*(8), 1599–1616.

Hankirishnan, R., Balasundaram, C., & Heo, M. S. (2010). Effect of chemotherapy, vaccines and immunostimulants on innate immunity of golden fish infected with *Aeromonas hydrophila*. *Diseases of Aquatic Organisms, 88*(1), 45–54. doi:10.3354/dao02143

He, J., Zhang, J., Gabriel, N. N., Xu, P., & Yang, R. (2015). Effect of Feeding-Intensive Stress on Biochemical and Hematological Indices of GIFT Tilapia (*Oreochromis niloticus*). *Turkish Journal of Fisheries and Aquatic Sciences, 15*, 305–312.

Heidari, M., Mirvaghefi, A. R., Sepahi, A., Sheikhzadeh, N., Ali, A., Akbari, M., & Shahbazfar, A. A. (2013). Effects of dietary Aloe vera on growth performance, skin and gastrointestinal morphology in rainbow trout (*Oncorhynchus mykiss*). *Turkish Journal of Fisheries and Aquatic Sciences, 13*, 881–896.

Hlopete, S. N., & Moyo, N. A. G. (2016). A comparative study on the use of Pennisetum clandestinum and *Moringa oleifera* as protein sources in the diet of the herbivorous Tilapia rendalli. *Aquaculture International, 22*(4), 1245–1262. doi:10.1007/s10499-013-9744-4

Houston, A. H. (1997). Review: Are the classical hematological variables acceptable indicators of fish health? *Transactions of the American Fisheries Society, 126*(6), 879–894. doi:10.1577/1548-8659(1997)126<879:RACRHA>2.3.CO;2

Immanuel, G., Umno, R. P., Jayaparaj, P., Citarasu, T., Punitha Peter, S. M., Michael Babu, M., & Palavesam, A. (2009). Dietary medicinal plant extracts improve growth, immune activity and survival of tilapia *Oreochromis mossambicus*. *Journal of Fish Biology, 74*(7), 1462–1475. doi:10.1111/j.1095-8641.2009.01911.x

Irkin, L. C., Yigit, M., Yılmaz, S., & Maita, M. (2014). Toxicological evaluation of dietary garlic (Allium sativum) powder in European sea bass *Dicentrarchus labrax* juveniles. *Food and Nutrition Sciences, 5*(11), 989. doi:10.4236/fns.2014.511109

Jegede, T., & Fagbenro, O. (2008). Effect of sub-lethal concentrations of endosulfan on *Oreochromis niloticus* (Linneus 1758) using *Hibiscus rosa-sinensis* (Linn.) leaf meal as reproduction inhibitor. *Journal of Agricultural Sciences, 2*, 149–154.

Jegede, T. (2011). Effects of Aloe vera (Liliceae) on the gonad development in Nile tilapia (*Oreochromis niloticus*) (Linneus 1758). In *Proceedings of the 9th International symposiums on tilapia aquaculture*. Eds K. Fitzsimmons & L. Leping, Shanghai, China. Pp. 222–227.

Jegede, T., & Fagbenro, O. (2008). Histology of gonads in Tilapia zillii (Gervais) fed Neem (Azadirachta indica) leaf meal diets. *8th International symposium on tilapia aquaculture. Cairo, Egypt.*

Jenkins, F., Smith, J., Rajanna, B., & Rokkam, M. (2003). Effect of sub-lethal concentrations of endosulfan on hematological and serum biochemical parameters in the carp *Cyprinus carpio*. *Bulletin of Environmental Contamination and Toxicology, 70*, 993–997. doi:10.1007/s00212-003-0880-7

Ji, S. C., Jeong, G. S., Im, G. S., Lee, S. W., Yoo, J. H., & Takii, K. (2007). Dietary medicinal herbs improve growth performance, fatty acid utilization, and stress recovery of Japanese flounder. *Fisheries Science, 73*(1), 70–76. doi:10.1111/j.1745-7870.2007.73.issue-1

Jkitintondaud, J., Kenney, P., Slider, S., Masik, P., Bébak-Williams, J., & Hankins, J. A. (2003). Effect of fish attributes and handling stress. *Journal of Food Science, 68*(1), 57–63. doi:10.1111/j.1399-6039.2003.00814.x

Kareem, Z. H., Abdelhadi, Y. M., Christianus, A., Karim, M., & Romano, N. (2016). Effects of some dietary crude plant extracts on the growth and gonadal maturity of Nile tilapia (*Oreochromis niloticus*) and their resistance to *Streptococcus agalactiae* infection. *Fish Physiology and Biochemistry, 42*(2), 757–769. doi:10.1007/s10695-015-0173-3

Kenari, R. E., Mohsenzadeh, F., & Amir, Z. R. (2014). Antioxidant activity and total phenolic compounds of deezul sesame cake extracts obtained by classical and ultrasound-assisted extraction methods. *Food Science & Nutrition, 2*, 426–435. doi:10.1002/fsn3.110
Kiriyotk, A. (2014). Efficacy of red kwoa krua (Butea superb Roxb) crude extract for all male production of Nile tilapia (Oreochromis niloticus). Aatsea, 10(2), 391–398.

Kirubakaran, C. J. W., Alexander, C. P., & Michael, R. D. (2010). Enhancement of non-specific immune responses and disease resistance on oral administration of Nytontales abartoristis seed extract in Oreochromis mossambicus (Peters). Aquaculture Research, 41(11), 1630–1639. doi:10.1111/are.2010.41.issue-11

Kumar, S., Auroshree, P., & Mishra, J. (2016). Mushroom polysaccharides as potential prebiotics with their antitumor and immunomodulating properties: A review. Bioactive Carbohydrates and Dietary Fibre, 7, 1–14. doi:10.1016/j.bcdf.2015.11.001

Latona, D. F., Oyeleke, G., & Olayiwola, O. (2012). Chemical analysis of ginger root. Journal of Applied Chemistry, 1(1), 47–48.

Madalla, N., Agbo, N. W., & Jouncey, K. (2013). Evaluation of aqueous extracted moringa leaf meal as a protein source for Nile tilapia juveniles. Tajas, 12(1), 53–64.

Mahdavi, M., Hojimaradloo, A., & Ghorbani, R. (2015). Effect of Aloe vera extract on growth parameters of common carp (Cyprinus carpio). World Journal of Medical Sciences, 9(1), 55–60.

Mckenzie, D. J., Höglund, E., Dupont-Prinet, A., Larsen, B. K., Skov, P. V., Pedersen, P. B., & Jokumsen, A. (2012). Effects of stocking density and sustained aerobic exercise on growth, energetics and welfare of rainbow trout. Aquaculture, 341, 216–222. doi:10.1016/j.aquaculture.2012.01.020

Metwally, M. A. A. (2009). Effects of garlic (Allium sativum) on some antioxidant activities in tilapia nilotica (Oreochromis niloticus). Wijfins, 1, 56–64.

Misra, C. K., Das, B. K., Mukherjee, S. C., & Meher, P. K. (2006). The immunomodulatory effects of tufins on the non-specific immune system of Indian major carp, Labeo rohita. Fish & Shellfish Immunology, 20, 728–738. doi:10.1016/j.fsi.2005.09.004

Mo, W. Y., Lun, C. H. I., Choi, W. M., Man, Y. B., & Wong, M. H. (2016). Enhancing growth and non-specific immunity of grass carp and Nile tilapia by incorporating Chinese herbs (Astragalus membranaceus and Lycium barbarum) into food waste based pellets. Environmental Pollution, 219, 475–482. doi:10.1016/j.envpol.2016.05.055

Mukherjee, D., Ghosal, I., & Chakraborty, S. B. (2015a). Application of asparagus racemosus root extract for production of monosex Nile tilapia, Oreochromis niloticus. IAAR, 3, 828–833.

Mukherjee, D., Ghosal, I., & Chakraborty, S. B. (2015b). Production of monosex Nile tilapia, Oreochromis niloticus using seed of Mucuna pruriens. IOSR-JPS, 10(1), 2319–7676.

Nagorjan, M., Benjakul, S., Propran, T., & Songtippa, P. (2015). Properties and characteristics of nanocomposite films from tilapia skin gelatin incorporated with ethanolic extract from coconut husk. The Journal of Food Science and Technology, 52, 7699–7682. doi:10.1007/s13197-015-1905-1

Olusola, S. E., Emeike, B. O., & Olafio, F. E. (2013). The potentials of medicinal plant extracts as bio-antimicrobials in aquaculture. International Journal of Medicinal and Aromatic Plants, 3(3), 404–412.

Olumi, B. O., Ajani, E. K., & Sodiq, H. O. (2013). Preliminary investigation of Tribulus terrestris (linn., 1753) extracts as natural sex reversal agent in Oreochromis niloticus (linn., 1758) larvae. International Journal of Aquaculture, 3, 133–137.

Pokravan, S., Højimoradloo, A., & Ghorbani, R. (2011). Effect of dietary willow herb, Epilobium hirsutum extract on growth performance, body composition, haematological parameters and Aeromonas hydrophila challenge on common carp, Cyprinus carpio. Journal of Aquaculture Research, 43, 1–9.

Park, K. H., & Choi, S. H. (2012). The effect of mistletoe, Viscum album coloratum, extract on innate immune response of Nile tilapia (Oreochromis niloticus). Fish & Shellfish Immunology, 32, 1016–1021.

Phipps, P. R., & Popma, J. T. (2000). Sex reversal of tilapia. In A. B. Costa-Pierce & E. K. Rakocy. (Eds.), Tilapia aquaculture in the Americas (pp. 39–59). Louisiana: Baton Rouge.

Prosad, G., & Priyanka, G. L. (2011). Effect of fruit rind extract of Garcinia gummi-gutta on haematology and plasma biochemistry of catfish Pangasianodon hypophthalmus. Asian Journal of Biochemistry, 6, 240–12.

Quezada-Rodríguez, D. R. P., & Fajer-Ávila, E. J. (2016). The dietary effect of ultr from Ulva clathrata on hematological-immunological parameters and growth of tilapia (Oreochromis niloticus). Journal of Applied Aquatic Physiology, 1–9. doi:10.1007/s10811-016-0093-7

Rajasekaran, S., Ravi, K., Sivagnanam, K., & Subramanian, S. (2006). Beneficial effects of Aloe vera leaf gel extract on lipid, Clinical and Experimental Pharmacology & Physiology, 33, 232–237. doi:10.1111/j.1440-1681.2006.04315.x

Rattanachaikunsopon, P., & Phumkhachorn, P. (2009). Prophylactic effect of Andrographis paniculata extracts against Streptococcus agalactiae infection in Nile tilapia (Oreochromis niloticus). Journal of Bioscience and Bioengineering, 107, 579–582. doi:10.1016/j.jbiosc.2009.01.010

Reverter, M., Bontemps, N., Lecchini, D., Banaigs, B., & Sasal, P. (2014). Use of plant extracts in fish aquaculture as an alternative to chemotherapy: Current status and future perspectives. Aquaculture, 433, 50–61. doi:10.1016/j.aquaculture.2014.05.048

Reverter, M., Bontemps, N., Lecchini, D., Banaigs, B., & Sasal, P. (2014). Use of plant extracts in fish aquaculture as an alternative to chemotherapy: current status and future perspectives. Aquaculture, 433, 50–61.

Richter, N, Siddhuraju, P, & Becker, K. (2003). Evaluation of nutritional quality of moringa (Moringa oleifera Lam.) leaves as an alternative protein source for Nile tilapia (Oreochromis niloticus L.). Aquaculture, 217(1–4), 599–611.

Roberts, R. J., & Rodger, H. D. (1978). The pathophysiology and systematic pathology of teleost fish pathology. In R. J. Roberts (Ed.), Fish pathology (4th ed., pp. 55–91). London: Bailliere Tindall.

Santos, G. A., Schrama, J. W., Mamaoaq, R. E. P., Rombout, J. H. W. M., & Verreth, J. A. J. A. (2010). Chronic stress impairs performance, energy metabolism and welfare indicators in European seabass (Dicentrarchus labrax): The combined effects of fish crowding and water quality deterioration. Aquaculture, 299, 73–80. doi:10.1016/j.aquaculture.2009.11.018

Shalaby, A. M., Khatib, Y. A., & Abdel Rahman, A. M. (2006). Effects of Garlic (Allium sativum) and chlorophenolic on growth performance, physiological parameters and survival of Nile tilapia (Oreochromis niloticus). The Journal of Venomous Animals and Toxins Including Tropical Diseases, 12(2), 172–201.

Siwicki, A. K., Anderson, D. P., & Rumsey, G. L. (1994). Dietary intake of immunostimulants by rainbow trout.
affects non-specific immunity and protection against furunculosis. Veterinary Immunology and Immunopathology, 41(1–2), 125–139. doi:10.1016/0165-2427(94)90062-0

Stadtlander, T., Focken, U., Levavi-Sivan, B., Dweik, H., Qutob, M., Abu-Lafi, S., ... Becker, K. (2008). Treatment with saponins from Trigonella foenum-graecum and Quillaja saponaria influences sex ratio in Nile tilapia (Oreochromis niloticus) larvae. In: 8th International Symposium on Tilapia in Aquaculture 2008. Eds K. Fitzsimmons & L. Liping, Cairo, Egypt. Pp 355–364.

Stadtlander, T., Levavi-Sivan, B., Kerem, Z., Dweik, H., Qutob, M., Abu-Lafi, S., ... Becker, K. (2013). Effects of a saponin fraction extracted from Trigonella foenum-graecum L. and two commercially available saponins on sex ratio and gonad histology of Nile tilapia fry, Oreochromis niloticus (L.). Journal of Applied Ichthyology, 29, 265–287. doi:10.1111/jal.2012.29.issue-1

Susmitha, S., Vidyarom, K. K., Ranganayaki, P., & Vijayaragavan, R. (2013). Phytochemical extraction and antimicrobial properties of azadirachta indica (neem). Global Journal of Pharmacology, 7(3), 316–320.

Taiwo, V. O., Olukunle, O. A., Ozor, I. C., & Oyebaji, A. T. (2005). Consumption of aqueous extract of raw aloe vera leaves : Histopathological and biochemical studies in rat and tilapia. African Journal of Biomedical Research : AJBR, 8, 169–178.

Tang, J., Cai, J., Liu, R., Wang, J., Lu, Y., Wu, Z., & Jian, J. (2014). Immunostimulatory effects of artificial feed supplemented with a Chinese herbal mixture on Oreochromis niloticus against Aeromonas hydrophila. Fish & Shellfish Immunology, 39(2), 401–406. doi:10.1016/j.fsi.2014.05.028

Uribé, C., Folch, H., Enriquez, R., & Moran, G. (2011). Innate and adaptive immunity in teleost fish: A review. Vetmed, 56, 486–503.

Urrechaga, E., Izquierdo, S., & Escanero, J. F. (2014). Looking back to our roots : 80 years of Wintrobe’s indices. Emerg. 1, 7–9.

Van Hai, N. (2015). The use of medicinal plants as immunostimulants in aquaculture: A review. Aquaculture, 446, 88–96. doi:10.1016/j.aquaculture.2015.03.014

Van Rijn, J. A., & Reina, R. D. (2010). Distribution of leukocytes as indicators of stress in the Australian swallowfish, Cethaloscyllium laticeps. Fish & Shellfish Immunology, 29(3), 534–538. doi:10.1016/j.fsi.2010.04.016

Vinson, J., Al Kharrat, H., & Andreoli, L. (2005). Effect of Aloe vera preparations on the human bioavailability of vitamins C and E. Phytomedicine, 12, 760–765. doi:10.1016/j.phymed.2003.07.010

Walata, R., Beveridge, M., Brummett, R., Castine, S., Chaiyawannakorn, N., Kaushik, S., ... Phillips, M. (2014). Improving productivity and environmental performance of aquaculture. Creating a Sustainable Food Future, (June), 1–60. doi:10.5657/FAS.2014.0001

World Health Organization (WHO). (2006). Antimicrobial use in aquaculture and antimicrobial resistance (Report of a Joint FAO/OIE/WHO Expert Consultation on Antimicrobial Use in Aquaculture and Antimicrobial Resistance). Seoul, Republic of Korea, 13–16.

Wu, J. H., Xu, C., Shan, C. Y., & Tan, R. X. (2006). Antioxidant properties and PC12 cell protective effects of APS-1, a polysaccharide from Aloe vera var. chinensis. Life Sciences, 78(6), 622–630. doi:10.1016/j.lfs.2005.05.097

Wu, Y., Gong, Q., Fong, H., Liang, W., Chen, M., & He, R. (2013). Effect of Sophora flavescens on non-specific immune response of tilapia (GIFT Oreochromis niloticus) and disease resistance against Streptococcus agalactiae. Fish & Shellfish Immunology, 34(3), 220–227. doi:10.1016/j.fsi.2012.10.020

Xu, C., Zhang, Y., Wang, J., & Lu, J. (2010). Extraction, distribution and characterisation of phenolic compounds and oil in grapeseed. Food Chemistry, 122, 688–694. doi:10.1016/j.foodchem.2010.03.037

Yang, X., Guo, J. L., Ye, J. Y., Zhang, X. Y., & Wang, W. (2015). The effects of Ficus carica polysaccharide on immune response and expression of some immunorelated genes in grass carp, Ctenopharyngodon idella. Fish & Shellfish Immunology, 42(1), 132–137. doi:10.1016/j.fsi.2014.10.037

Yilmaz, S. (2015). Effects of dietary blackberry syrup supplement on growth performance, antioxidant, and immunological responses, and resistance of Nile tilapia, Oreochromis niloticus to Plesiomonas shigelloides. Fish & Shellfish Immunology, 84, 1125–1133. doi:10.1016/j.fsi.2018.11.012

Yilmaz, S. (2015b). Effects of dietary caffeic acid supplement on antioxidant, immunological and liver gene expression responses, and resistance of Nile tilapia, Oreochromis niloticus to Aeromonas veroni. Fish & Shellfish Immunology, 86, 384–392. doi:10.1016/j.fsi.2018.11.068

Yilmaz, S., Arcar, U., Kesbiç, O. S., Gültepe, N., & Ergün, S. (2015). Effects of dietary allspice, Pimenta dioica powder on physiological responses of Oreochromis mossambicus under low pH stress. SpringerPlus, 4(1), 719. doi:10.1186/s40064-015-1520-7

Yilmaz, S., & Ergün, S. (2012). Effects of garlic and ginger oils on hematological and biochemical variables of sea bass Dicentrarchus labrax. Journal of Aquatic Animal Health, 24(4), 219–224. doi:10.1080/08997659.2012.711266

Yilmaz, S., & Ergün, S. (2014). Dietary supplementation with allspice Pimenta dioica reduces the occurrence of streptococcal disease during first feeding of Mozambique tilapia fry. Journal of Aquatic Animal Health, 26(3), 144–148. doi:10.1080/08997659.2014.893459

Yilmaz, S., & Ergün, S. (2018). Trans-cinnamic acid application for rainbow trout (Oncorhynchus mykiss): 1. Effects on hematological, serum biochemical, non-specific immune and head kidney gene expression responses. Fish & Shellfish Immunology, 78, 140–157. doi:10.1016/j.fsi.2018.04.034

Yilmaz, S., Ergun, S., & Celik, E. S. (2012). Effects of herbal supplements on growth performance of sea bass (Dicentrarchus labrax). Change in body composition and some blood parameters. Journal of Bioscience and Biotechnology, 1, 217–222.

Yilmaz, S., Ergun, S., & Celik, E. S. (2013). Effect of dietary herbal supplements on some physiological conditions of sea bass Dicentrarchus labrax. Journal of Aquatic Animal Health, 25, 98–103. doi:10.1080/08997659.2013.768561

Yilmaz, S., Ergün, S., Kaya, H., & Gürkan, M. (2014). Influence of Tribulus terrestris extract on the survival and histopathology of Oreochromis mossambicus (Peters, 1852) fly before and after Streptococcus iniae infection. Journal of Applied Ichthyology, 30(S), 996–1000. doi:10.1111/j.1439-0426.2014.03014.x

Yilmaz, S., Ergün, S., & Soytaş, N. (2013b). Enhancement of growth performance and pigmentation in red Oreochromis mossambicus associated with dietary

Page 20 of 21
https://doi.org/10.1080/23311932.2019.1619651
intake of astaxanthin, paprika, or capsicum. Israeli Journal of Aquaculture-Bamidgeh, 65
Yilmaz, S., Ergün, S., & Soytaş, N. (2013b). Dietary supplementation of cumin Cuminum cyminum preventing streptococcal disease during first feeding of Mozambique tilapia Oreochromis mossambicus. Journal of Bioscience and Biotechnology Discovery, 2(2), 117–124.
Yilmaz, S., Ergün, S., & Türk, N. (2012). Effects of cumin-supplemented diets on growth and disease (Streptococcus Iniae) resistance of tilapia (Oreochromis mossambicus). Isr. Israeli Journal of Aquaculture-Ramidreh, 64, 1–5.
Yin, G., Ardo, L., Jeney, Z., Xu, P., & Jeney, G. (2008). Chinese herbs (Lonicera japonica and Ganoderma lucidum) enhance non-specific immune response of tilapia, Oreochromis niloticus, and protection against Aeromonas hydrophila. Disease in Asian Aquaculture, VI, 269–282.
Yin, G., Ardo, L., Thompson, K. D., Adams, A., Jeney, Z., & Jeney, G. (2009). Chinese herbs (Astragalus radix and Ganoderma lucidum) enhance immune response of carp, Cyprinus carpio, and protection against Aeromonas hydrophila. Fish & Shellfish Immunology, 26(1), 140–145. doi:10.1016/j.fsi.2008.08.015
Zohran, E., Bisho, E., Abdelhamid, F., & Allah, H. (2014). Effects of dietary Astragalus polysaccharides (APS) on growth performance, immunological parameters, digestive enzymes, and intestinal morphology of Nile tilapia (Oreochromis niloticus). Fish & Shellfish Immunology, 38(1), 149–157. doi:10.1016/j.fsi.2014.03.002
Zok, M. A., Labib, E. M., Nour, A. M., Tonsy, H. D., & Mahmoud, S. H. (2012). Effect some medicinal plants diets on mono sex Nile tilapia (Oreochromis niloticus), growth performance, feed utilization and physiological parameters. APCBEE Procedia, 4, 220–227. doi:10.1016/j.apcbee.2012.11.037
Zanuzzo, F. Z., Urbinati, E. C., Rise, M. L., Hall, J. R., Nash, G. W., & Gamperi, A. K. (2013). Aeromonas salmonicida induced immune gene expression in aloe vera fed steelhead trout, Oncorhynchus mykiss (Walbaum). Aquaculture, 435, 1–9. doi:10.1016/j.aquaculture.2014.09.010
Zhang, P., Zhang, X., Li, J., & Gao, T. (2010). Effect of refeeding on the growth and digestive enzyme activities of Fenneropenaeus chinensis juveniles exposed to different periods of food deprivation. Aquaculture International, 18(6), 1191–1203. doi:10.1007/s10499-010-9333-8
Zhang, Y. H., Yoshida, T., Isobe, K., Rahman, S. M., Nagase, F., Ding, L., & Nakashima, I. (1990). Modulation by glycyrrhizin of the cell-surface expression of H-2 class 1 antigens on murine tumor cell lines and normal cell populations. Journal of Immunology (Baltimore, Md: 1950), 145, 405–410.
Zilberg, D., Tal, A., Froymo, N., Abutbul, S., Dudai, N., & Golan-Goldhirsh, A. (2010). Dried leaves of Rosmarinus officinalis as a treatment for streptococcosis in tilapia. Journal of Fish Diseases, 33(4), 381–389. doi:10.1111/j.1365-2111.2010.00924.x

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