The use of plant extracts to control tilapia reproduction: Current status and future perspectives

Ivan Abaho1,2 | Charles Masembe3 | Peter Akoll3 | Clifford L. W. Jones1

1Department of Ichthyology and Fisheries Science, Rhodes University, Grahamstown, South Africa
2Bulindi Zonal Agricultural Research and Development Institute, National Agricultural Research Organization, Hoima, Uganda
3Department of Zoology, Entomology and Fisheries Science, Makerere University, Kampala, Uganda

Correspondence
Ivan Abaho, Bulindi Zonal Agricultural Research and Development Institute, National Agricultural Research Organization, Hoima, Uganda.
Email: ivomillo@gmail.com

Funding information
European Union, Grant/Award Number: EACEA/05/2017

Abstract
Control of prolific reproduction is vital for a profitable tilapia aquaculture enterprise. All-male tilapia culture is a popular method used to control prolific breeding, because the male individuals grow faster than female and mixed-sex populations. Presently, most farmers use 17α-methyl testosterone (MT) to produce all-male tilapia individuals, although synthetic hormones are linked to human health and environmental risks. Recently, considerable attention has focused on plant-based products as alternatives to MT, because they are affordable, safe, and eco-friendly. Despite the growing interest in using plant extracts to prevent frequent spawning in tilapia production, the available information is not collated to standardize application guidelines. Accordingly, this review article consolidates existing knowledge on the use of plant extracts to control prolific breeding in tilapia culture systems. In addition, limitations to commercial application of the extracts are identified. To date, seed, root, and leaf extracts of 20 plant species, most notably, Tribulus terrestris, Mucuna pruriens, and Carica papaya, exhibit potential for controlling unwanted breeding in tilapia production systems. The extracts are mainly administered orally, incorporated in fish feeds. Saponins and flavanoids are the main bioactive compounds in the phytoextracts,
which induce sex inversion and fertility impairment in tilapia. The commercialization of plant extracts is, however, hampered by lack of standardized information on extract preparation, optimal dosages, and mechanism of action. Thus, future studies should address these technical limitations and highlight economic incentives for commercial use of plant extracts in tilapia aquaculture.

KEYWORDS
all-male tilapia, aquaculture, phytochemicals, synthetic hormones, 17α-methyl testosterone

INTRODUCTION

Tilapia is the second most farmed food fish after carps globally. According to the Food and Agriculture Organization of the United Nations (FAO), the global production of tilapia has continued to grow, rising from 3.1 million tonnes in 2010 to 5.6 million tonnes in 2018 (FAO, 2020). This has highlighted the significant contribution of the tilapia industry to the global economy as one of the world's primary sources of proteins for human consumption (FAO, 2020). The exponential increase in tilapia production is related to the suitable aquacultural attributes: (a) ease to breed in captivity; (b) having a short production cycle because of fast growth rate; (c) acceptability of artificial feeds after yolk-sac absorption; and (d) marketability (El-Sayed, 2006; Mair, 2001). Technology advancements, including control of early maturity and prolific breeding, have also contributed to the expansion of tilapia's global production (Beardmore, Mair, & Lewis, 2001; FAO, 2017; Toguyeni, Fauconncau, Fostier, & Abucay, 2002). Prolific breeding results in excessive fingerling recruitment in grow-out systems causing overpopulation, and competition for resources, and consequently stunted and small-sized fish, which fail to attract good market prices (Teichert-Coddington, Manning, Eya, & Brock, 2000). Therefore, periodic harvesting of fry and fingerlings, high-density culture, cage culture, polyculture with predator fish, sterilization by application of heat shock, and all-male culture, are applied to minimize unwanted reproduction in tilapia production systems (Fortes, 2005; Guerrero, 1982; Mair & Little, 1991). Currently, the culture of all-male tilapia individuals is commonly practiced because, in addition to control of prolific spawning, males grow faster and larger than females, resulting in a shortened production cycle (Baroiller & D’Cotta, 2001; El-Greisy & El-Gamal, 2012; Megbowon & Mojekwu, 2014).

All-male tilapia populations are achieved through: (a) sex-sorting by hand; (b) hormonal sex inversion using androgens; (c) environmental manipulation (such as temperature treatment); and (d) genetic/chromosomal manipulation (Angienda, Aketch, & Waindi, 2010; Beardmore et al., 2001; Dauda, Yakubu, & Oke, 2014; Desprez et al., 2003; Green, Veverica, & Fitzpatrick, 1997; Olufeagba & Okomoda, 2015). Among these methods, hormonal sex reversal using exogenous steroids, mainly 17α-methyl testosterone (MT), yields high success of masculinization (Gale, Fitzpatrick, Lucero, Contreras-Sanchez, & Schreck, 1999; Homklin, Ong, & Limpiyakorn, 2011; Phelps, 2006; Phelps & Popma, 2000). The high sex inversion potency of MT is associated with the hormone’s ability to inhibit aromatase activity, thereby obstructing estrogen biosynthesis while promoting androgenesis in the differentiating gonads (Golan & Levavi-Sivan, 2014). Consequently, MT is the most widely used method for the production of all-male individuals in tilapia culture. However, the carcinogenicity of MT and the associated adverse effects on human health and aquatic ecosystems continue to raise public concerns (Baroiller & D’Cotta, 2001; Biswas, Morita, Yoshizaki, Maita, & Takeuchi, 2005; Dabrowski, Rodriguez, Abiado, Sanchez, & de Jesus, 2005; Haitham, 2018; Jegede, 2010; Leet, Gall, & Sepulveda, 2011; Mlalila, Mahika, Kalombo, Swai, & Hilonga, 2015). Prolonged exposure to MT during
the application process can cause hepatotoxicity and fetotoxicity (Hartleb & Nowak, 1990; Schardein, 1980; Velazquez & Alter, 2004; Vick & Hayton, 2001; Wilkins, 1960). As such, MT poses a health risk to hatchery personnel involved in tilapia seed production (Megbowon & Mojekwu, 2014). Besides, 30% of the administered hormone-treated diet is unavailable to the fish during feeding (Ramirez-Godinez et al., 2013; Vick & Hayton, 2001). Meanwhile, only 10% of the hormone in the consumed diet is utilized for sex inversion (de Ziegler & Fanchin, 2000; Ong, Chotisukarn, & Limpiyakorn, 2012). As a result, hormone residues build-up in the closed environments as either active metabolites excreted by the treated fish or leachates from uneaten food. The accumulation of hormonal residues is facilitated by the hydrophobic nature of MT that allows it to rapidly adsorb onto sediments (Mlalila et al., 2015). The leakages of MT and its metabolites into the aquatic environment from uneaten or un-metabolized food have the potential to disrupt endocrine and reproductive systems of nontarget aquatic organisms (Abucay & Mair, 1997; Gomelsky, Cherfas, Peretz, Ben-Don, & Hulata, 1994; Hulak et al., 2008; Nian, Tumbokon, & Serrano-Jr, 2017; Ramirez-Godinez et al., 2013; Rivero-Wendt, Miranda-Vilela, Ferreira, Borges, & Grisolia, 2013). Further, fish treated with synthetic chemicals are not readily accepted by consumers because of safety concerns (Biswas et al., 2005; Reverter, Bontemps, Lechini, Banaigs, & Sasal, 2014). In view of the above negative consequences, several countries prohibit use of synthetic hormones for fish food production (Chakraborty, Horn, & Hancz, 2013). As such, there is need for research efforts to identify and develop environmentally friendly, economically viable, and socially acceptable alternatives to the synthetic steroids.

Various interventions have demonstrated the possibility of utilizing plant extracts as possible options to synthetic steroids in aquaculture in response to the increasing consumer demand for organically produced agricultural products, including safer for the environment and humans, than synthetic hormones (Chakraborty et al., 2013; Logambal, Venkatalakshmi, & Michael, 2000; Olusola, Emike, & Olaifa, 2013; Reverter et al., 2014). To date, several plant extracts are predominantly used to improve fish growth, enhance innate immune responses, and control disease in aquaculture, as compared to reproduction control (Baluran, Quiazon, Garcia, Fernando, & Velasco, 2018; Logambal et al., 2000; Olusola et al., 2013; Reverter et al., 2014). Nevertheless, the androgenic compounds present in some plant extracts could be used to control unwanted reproduction in tilapia production systems (Chakraborty et al., 2013; Gabriel et al., 2017; Ghosal, Mukherjee, & Chakraborty, 2021). The phytoandrogens, for example, testosterone, androstenedione, and dehydroepiandrosterone, have been implicated in sex reversal of fish (Godwin, Luckenbach, & Borski, 2003).

In this review, an account of the current state of knowledge on the plant extracts used to control unwanted reproduction in tilapia culture is provided. The literature review strategy involved searching from Web of Science, Science Direct, Google Scholar, and Scopus using “tilapia reproduction control” and “plant extracts” as keywords. Conference proceedings and doctoral theses were also collected from various libraries using the online catalogue. The search results were screened and selected by title relevance to the present review, concerning plant extracts for tilapia reproduction control. This search strategy yielded 47 scientific publications, whose findings are reported in this review. The effectiveness of extracts from different plants and the corresponding dosages inducing sex change are documented. Further, the information gaps and the future research directions are highlighted. The review contributes to a better understanding of plant extracts’ application in controlling unwanted spawning in tilapia aquaculture, as an alternative to the currently, most used synthetic hormones.

2 | PLANT EXTRACTS USED IN THE CONTROL OF TILAPIA REPRODUCTION

Plant extracts are becoming an integral part of fish culture, as alternatives to chemicals, drugs, and hormones, in response to the increasing pressure to reduce adverse impacts associated with aquaculture on human and environmental health. The organic plant products are relatively safe, inexpensive and easy to prepare, and are thus viewed as a means to achieving sustainable fish production (Chakraborty et al., 2013; Hoseini, Mirghaed, & Yousef, 2019;
Makkar, Francis, & Becker, 2007; Reverter et al., 2014). Moreover, consumers are increasingly demanding good quality and safe fish products, which are free of pollutants (Chakraborty et al., 2013). Therefore, adopting safe and environmentally clean fish production practices will promote tilapia to meet new market requirements. Accordingly, efforts are required to identify and develop novel plant-based products for tilapia production to replace synthetic hormones and chemicals (Ahmed, Fathy, Fayek, & Mohamed, 2019; Citarasu, 2010; Turan & Akyurt, 2005).

Natural compounds found in plants such as; flavonoids, tannins, terpenoids, alkaloids, and steroids promote androgenic and anabolic processes as well as stimulation of digestion, appetite, and immunity (Chakraborty et al., 2013; Chakraborty & Hancz, 2011; Citarasu, 2010; Gabriel, Qiang, Kpundeh, & Xu, 2015; Ugoala, Ndukwe, Ayo, & Mustapha, 2014). The phytochemicals, including steroidal saponins (Golan et al., 2008) and flavonoids (Miyahara et al., 2003; Tarigan, Nasution, & Widjaja, 2016), attenuate estrogen production by inhibiting the action of aromatase. Phytochemicals may also compete with endogenous estrogens for binding sites to the estrogen receptor, thereby suppressing estrogen biosynthesis (Eng et al., 2001; Golan et al., 2008; Miyahara et al., 2003). Consequently, the phytochemicals act as “phytoandrogens” that exert functional effects similar to testosterone in animals, elevating male reproductive characteristics (Turan & Akyurt, 2005). The potential of phytochemicals in plant extracts to induce either masculinization or fertility impairment in fish has been harnessed to control prolific breeding in tilapia, with positive results (Ampofo-Yeboah, 2013; Gabriel et al., 2017; Ghosal et al., 2021; Jegede, 2010; Mukherjee, Ghosal, & Chakraborty, 2015a; Nian et al., 2017; Omitoyin, Ajani, & Sadiq, 2013; Stadtlander et al., 2008). The section that follows describes plant species, the respective phyto-constituents utilized to overcome unwanted tilapia reproduction and subsequently present results from previous studies.

2.1 | Plants with androgenic and fertility impairment effects on tilapia

Extracts from 20 plant species, belonging to 17 families are reported to control reproduction in tilapia culture systems. The geographical distribution, usable parts phytochemical composition, androgenic and fertility impairment attributes of these plants are described below:

2.1.1 | Aspilia plant, Aspilia mossambicensis

_A. mossambicensis_, also known as “wild sunflower,” belongs to the order Asterales and family Compositae (Musyimi, Ogur, & Muema, 2007). The plant is widespread in central and eastern tropical Africa (Norton, Huang, & Rodriguez, 1993). Aspilia is widely used as an uterotonic agent to induce uterine contraction and labor in pregnant women (Gruber & O’Brien, 2011; Musyimi, Ogur, & Muema, 2008). The leaves and roots extract of aspilia plants contain flavonoids, alkaloids, saponin, and steroids (Kapinga, Limbu, Madalla, Kimaro, & Tamatamah, 2019; Musyimi et al., 2007). The anti-fertility effect of _A. mossambicensis_ is linked to the presence of saponins, and flavonoids (Musyimi et al., 2007). The feeding of Nile tilapia (_Oreochromis niloticus_) on diets containing 2–8 g of _A. mossambicensis_ leaf extract kg$^{-1}$ of diet degenerated seminiferous tubules, thereby reducing the number of hatchlings in the experimental fish (Kapinga et al., 2019; Kapinga, Limbu, Madalla, Kimaro, & Tamatamah, 2018). The extracts from _A. mossambicensis_ are thus potent in the control of prolific breeding of Nile tilapia.

2.1.2 | Bitter kola, Garcinia kola

_G. kola_ is a flowering plant, indigenous to the tropical rain forests of West and Central Africa (Manourova et al., 2019), belonging to order Malpighiales and family Clusiaceae. The plant is commonly referred to as bitter kola, male kola, or wonder plant (Ekene & Erhirhie, 2014). Bitter kola contains flavonoids, mainly apigenin, which inhibits
the enzyme aromatase (Iwu & Igboko, 1982; Jeong, Shin, Kim, & Pezzuto, 1999). The enzyme aromatase catalyzes the conversion of androgens to estrogens, in the final step of the biosynthesis of the gonadal steroids, subsequently increasing testosterone (Elbrecht & Smith, 1992; Sanderson, 2006). The blockage of estrogen synthesis causes anti-fertility effects, which can be harnessed to control animal reproduction (Abu, Amuta, Buba, & Inusa, 2013; Akinloye, Igbara, Olaniyi, Alaka, & Oke, 1999). In aquaculture, the inclusion of 1, 3, and 6% of bitter kola seed powder in the diet of female Nile tilapia for 70 days diets mixed resulted in the impairment of gonadal development (Nyadjeu, Angoun, Ndasi, & Tabi-Tomedi, 2019). Besides, significant reduction (83.45%) in the number of eggs spawned by Nile tilapia, maintained on a diet constituting of 6% bitter kola seed powder for 44 days (Sulem-Yong et al., 2018) was linked to the presence of flavanoids.

2.1.3 | Cotton, *Gossypium herbaceum*

*G. herbaceum* is native to semi-arid regions of Sub-Saharan Africa and Arabia. Cotton is classified under order Malvales and family Malvaceae, and grows to approximately three meters tall (Al-Snafi, 2018). The plant contains a naturally occurring polyphenolic compound known as gossypol, which forms part of the self-defense system of the cotton plant against predators (Jodi & Gabriela, 2008). However, Gossypol, present in the stem, seeds, and roots also inhibit reproduction in fish, rats, and humans (El-Sharaky, Newairy, Elguindy, & Elwafa, 2010; Qian & Wang, 1984; Tope-Jegede, Fagbenro, & Olufayo, 2019). Inclusion of *G. herbaceum* root bark extracts in the diet of Nile tilapia at 20 g kg\(^{-1}\) of diet, for 70 days, eroded the connective tissue of the testes and disintegrated the seminiferous lobule, causing a reduction in the volume of milt (Akin-Obasola & Jegede, 2016). Similarly, the substitution of 25, 50, 75, and 100% of soybean meal protein with cottonseed meal for 90 days destroyed spermatocytes and distorted vitellogenic stages of Nile tilapia (Tope-Jegede et al., 2019). However, gossypol is a known anti-nutritional factor (Mbahinzireki, Dabrowski, Lee, El-Saidy, & Wisner, 2001) and could, therefore, result in undesirable effects on the growth performance of fish. Therefore, the dose of cottonseed meal recommended for control of unwanted spawning in tilapia should not inhibit growth performance of the fish.

2.1.4 | Fenugreek, *Trigonella foenum graecum*

*T. foenum-graecum* is a leguminous plant mainly grown in Europe, Africa, and Asia (Petropoulos, 2002). It belongs to the order: Fabales, family: Fabaceae, and grows up to a height of 30–60 cm (Ghosh, Chandra, & Chatterjee, 2015). The seeds of fenugreek contain rich steroidal saponins, especially Diosgenin (Marker et al., 1947; Murakami, Hishi, Matsuda, & Yoshikawa, 2000; Petropoulos, 2002). Diosgenin functions as a phytoandrogen (Raju, Patlolla, Swamy, & Rao, 2004), and hence masculinizes Nile tilapia (Stadtlander et al., 2008; Table 1).

2.1.5 | Guava, *Psidium guajava*

*P. guajava* is a member of the order Myrtales and family Myrtaceae (Shruthi, Timilsina, & Sunita, 2013). It is grown in tropical and sub-tropical countries, mainly to provide of fruit for human consumption (Gutierrez, Mitchell, & Solis, 2008). The extract from *P. guajava* leaves contains alkaloids, saponins, tannins, and flavanoids (Tariqan et al., 2016; Uboh, Okon, & Ekong, 2010). These extracts, especially saponins and flavanoids, have antifertility effects in rats (Nayaka, Londonkar, & Umesh, 2014) and fish (Obahor, Nzeh, & Oguntoyse, 2012). For example, anti-implantation and sterility was observed in rats treated with *P. guajava* extracts (Sri Retno, Endang, Elfi, & Setiyani, 2008). Dietary inclusion of *P. guajava* extracts *guajava* at 4.0 and 8.0 g kg\(^{-1}\) for 56 days, induced atrophy
| Botanical name | Treatment (parts/products used) | Dosage | Exposure period (days) | Treatment method | Tilapia species | Best dosage | Masculinization success (%) | Reference |
|---------------|---------------------------------|--------|------------------------|------------------|----------------|-------------|--------------------------|-----------|
| **Mucuna pruriens** | Seed methanol extract | 0.1, 0.15, & 0.2 g kg\(^{-1}\) of feed | 30 | Oral | *Oreochromis niloticus* | 0.2 g kg\(^{-1}\) of feed | 93.79 ± 0.95 | Mukherjee, Ghosal, Hancz, and Chakraborty (2018) |
| | Seed powder | 0.0, 0.0, 3.5, & 5.0 g kg\(^{-1}\) of feed | 30 | Oral | *O. niloticus* | 5.0 g kg\(^{-1}\) of feed | 73.33 ± 0.67 | Mukherjee, Ghosal, and Chakraborty (2015b) |
| | Seed aqueous extract | 0.02, 0.035, & 0.05 g L\(^{-1}\) | 30 | Immersion | *O. niloticus* | 0.05 g L\(^{-1}\) | 74.67 ± 0.33 | Mukherjee et al. (2015b) |
| **Asparagus racemosus** | Root methanol extract | 0.1, 0.15, & 0.2 g kg\(^{-1}\) of feed | 30 | Oral | *O. niloticus* | 0.2 g kg\(^{-1}\) of feed | 92.24 ± 0.13 | Mukherjee et al. (2018) |
| | Root aqueous extract | 0.01, 0.015, & 0.02 g L\(^{-1}\) | 30 | Immersion | *O. niloticus* | 0.015 g L\(^{-1}\) | 90.60 ± 1.56 | Mukherjee et al. (2015a) |
| **Carica papaya** | Seed powder | 15 g kg\(^{-1}\) of feed | 30 | Oral | *Oreochromis mossambicus* | 15 g kg\(^{-1}\) of feed | 65 | Amfo-yeboah (2013) |
| | Seed powder | 10, 15, 20, 25, & 30 g kg\(^{-1}\) of feed | 120 | Oral | *O. mossambicus* | 20 g kg\(^{-1}\) of feed | 77.8 | Omeje (2016); Omeje, Lambrechts, and Brink (2018) |
| | Seed powder | 6 g kg\(^{-1}\) of feed | 45 | Oral | *O. mossambicus* | 6 g kg\(^{-1}\) of feed | 68 | Ahmed et al. (2019) |
| **Moringa oleifera** | Seed powder | 15 g kg\(^{-1}\) of feed | 30 | Oral | *O. mossambicus* | 15 g kg\(^{-1}\) of feed | 65.5 | Amfo-yeboah (2013) |
| **Tribulus terrestris** | Seed powder aqueous, methanol, ethan, dichloromethane, hexane & successive methanol extracts | 0.5, 1.0, & 1.5 g kg\(^{-1}\) of feed | 30 | Oral | *O. niloticus* | 1.5 g of ethanol extract kg\(^{-1}\) of feed | 88.9 ± 1.1 | Ghosal, Mukherjee, Hancz, and Chakraborty (2015); Ghosal and Chakraborty (2020). |
| | Trib 60 extract (Tonvara premium natural supplements, UK) | 0.0, 1.0, 1.5, 2.0 & 2.5 g kg\(^{-1}\) of feed | 42 | Oral | *O. niloticus* | 2.5 g kg\(^{-1}\) of feed | 83.67 ± 4.04 | Omitoyin et al. (2013) |
| | Seed powder | 0.0, 5.0, 10.0, & 15.0 g kg\(^{-1}\) of feed | 30 | Oral | *O. niloticus* | 15.0 g kg\(^{-1}\) of feed | 76.6 ± 0.5 | Ghosal, Mukherjee, Hancz, and Chakraborty (2016) |
| Botanical name | Treatment (parts/products used) | Dosage | Exposure period (days) | Treatment method | Tilapia species | Best dosage | Masculinization success (%) | Reference |
|----------------|---------------------------------|--------|------------------------|------------------|----------------|-------------|---------------------------|-----------|
| Seed aqueous extract | 0.05, 0.1, & 0.15 g L⁻¹ | 30 | Immersion | O. niloticus | 0.15 g L⁻¹ | 81.4 ± 0.5 | Ghosal et al. (2016) |
| Seed aqueous extract | 0.00, 0.05, 0.10, & 0.15 g L⁻¹ | 30 | Immersion | O. niloticus | 0.15 g L⁻¹ | 81.4 ± 0.5 | Ghosal and Chakraborty (2014a) |
| Seed powder ethanol extract | 0.0, 2.0, 2.5, & 3.0 g kg⁻¹ of feed | 30 | Oral | O. niloticus | 2.0 g kg⁻¹ of feed | 91.53 ± 0.38 | Ghosal and Chakraborty (2020) |
| N/S | 1.0 & 2.0 g kg⁻¹ of feed | 28 | Oral | Oreochromis sp. (red tilapia) | 2.0 g kg⁻¹ feed | 84.4 | Zaki, Said, Tahoun, and Amer (2021) |
| Basella alba | Leaf powder of aqueous, methanol, ethanol, dichloromethane, hexane & successive methanol extracts | 0.5, 1.0, & 1.5 g kg⁻¹ of feed | 30 | Oral | O. niloticus | 1.0 g of ethanol extract kg⁻¹ of feed | 83.2 ± 0.7 | Ghosal et al. (2015); Ghosal and Chakraborty (2020) |
| | Leaf aqueous extract | 0.00, 0.05, 0.10, & 0.15 g L⁻¹ | 30 | Immersion | O. niloticus | 0.1 g L⁻¹ | 70.3 ± 1.9 | Ghosal and Chakraborty (2014b) |
| | Leaf powder | 0.0, 5.0, 10.0, & 15.0 g kg⁻¹ of feed | 30 | Oral | O. niloticus | 10.0 g kg⁻¹ of feed | 70.3 ± 1.2 | Ghosal et al. (2016) |
| | Leaf aqueous extract | 0.05, 0.10, & 0.15 g L⁻¹ | 30 | Immersion | O. niloticus | 0.1 g L⁻¹ | 71.9 ± 1.9 | Ghosal et al. (2016) |
| Trigonella foenum-graecum | Saponin methanol extract | 0.15 & 0.30 g kg⁻¹ of feed | 30 | Oral | O. niloticus | 0.30 g kg⁻¹ of feed | 56 ± 12.6 | Stadtlander et al. (2013) |
| | Saponin methanol extract | 40, 60, & 80% TS (0.15 and 1.00 g kg⁻¹ of feed) | 120 | Oral | O. niloticus | 80% TS (0.15 g kg⁻¹ of feed) | 73 | Stadtlander et al. (2008) |
| Quillaja saponaria | Saponin (QS; Sigma, St. Louis, MO) | 0.05, 0.15, 0.30, 0.50, & 0.70 g kg⁻¹ of feed | 60 | Oral | O. niloticus | 0.70 g kg⁻¹ of feed | 69 | Francis, Levavi-Sivan, Avitan, and Becker (2002) |
| | Saponin methanol extract | 40, 60, & 80% QS (0.15 & 1.00 g kg⁻¹ of feed) | 120 | Oral | O. niloticus | 80% QS (0.15 g kg⁻¹ of feed) | 73 | Stadtlander et al. (2008) |
| Botanical name | Treatment (parts/products used) | Dosage | Exposure period (days) | Treatment method | Tilapia species | Best dosage | Masculinization success (%) | Reference |
|---------------|---------------------------------|--------|------------------------|------------------|----------------|-------------|-----------------------------|-----------|
| *Pinus tabulaeformis* | Pollen powder | 0.00, 0.08, 0.16, 0.32, & 0.64 g kg\(^{-1}\) of feed | 60 | Oral | *O. niloticus* | 0.32 g kg\(^{-1}\) of feed | 89.1 ± 3.6 | Nian et al. (2017) |
| *Pinus kesiya* | Pollen powder | (0.5 g of pine pollen + 0.5 g MT) kg\(^{-1}\) of feed & 1.0 g of pine pollen kg\(^{-1}\) of feed | 28 | Oral | *O. niloticus* | 1.0 g of pine pollen kg\(^{-1}\) of feed | 88 | Nieves (2017) |
| *Aloe vera* | Crude powder extract | 0, 1.0, 2.0, & 4.0% of feed | 30 | Oral | *O. niloticus* | 4.0% of feed | 67.62 ± 4.37 | Gabriel et al. (2017) |
| *Hibiscus rosa-sinensis* | Flower extract | 0.16, 0.50, 1.00, 3.00, & 4.00 g kg\(^{-1}\) of feed | 28 | Oral | *O. niloticus* | 4.00 g kg\(^{-1}\) of feed | 73.13 ± 6.38 | Abella et al. (2015) |
| *Butea superba* | Root powder | 100, 200, & 300 g kg\(^{-1}\) of feed | 30 | Oral | *O. niloticus* | 200 g kg\(^{-1}\) of feed | 72.2 ± 25.5 | Mengumphan, Samitasiri, and Carandang (2006) |
| | Root powder ethanol extract | 0.00, 0.04, 0.08, 0.12, 0.16, & 0.20 g kg\(^{-1}\) of feed | 21 | Oral | *O. niloticus* | 0.20 g kg\(^{-1}\) of feed | 100 | Kiriyakit (2014) |
| *Eurycoma longifolia* | Root methanol extract | 0.00, 0.03, 0.06, & 0.09 g kg\(^{-1}\) of feed | 30 | Oral | *O. niloticus* | 0.06 g kg\(^{-1}\) of feed | 82.10 | Yusuf, Andayani, Risjani, & Faqih, 2019 |
| | Root powder ethanol extract | 0.00, 0.02, 0.04, & 0.06 g L\(^{-1}\) | 60 | Immersion | *O. niloticus* | 0.06 g L\(^{-1}\) | 67.44 | Rinaldi, Zairin-Jr, Soelistyowati, and Imron (2017) |
| *Garcinia kola* | Seed powder | 0, 10, 20, & 30 g kg\(^{-1}\) of feed | 28 | Oral | *O. niloticus* | 30 g kg\(^{-1}\) of feed | 65.75 ± 4.19 | Tigoli et al. (2018) |

Affiliations: MT, 17α-methyl testosterone; N/S, Not specified; QS, *Quillaja saponaria* saponin; TS, *Trigonella foenum-graecum* saponin.
and necrosis of the testicular tissues and ovaries of Nile tilapia (Obaroh et al., 2018). This distortion of Nile tilapia gonads reduces the number of hatchlings (Obaroh & Achionye-Nzeh, 2013), thus impairing breeding in this fish.

### 2.1.6 | Indian spinach, *Basella alba*

The Indian spinach is a leafy fast-growing vegetable, belonging to order Caryophyllales and family Basellaceae (Adhikari, Naveen, & Shruthi, 2012; Kumar, Prasad, Iyer, & Vaidya, 2013). *B. alba* is native to tropical Asia but was introduced in tropical Africa and South America (Deshmukh & Gaikwad, 2014; Roy, Gangopadhyay, & Mukherjee, 2010). The leaves of *B. alba* contain flavanoids, tannin, steroid, and saponin phyto-compounds (Ghosal et al., 2015). It is postulated that the presence of steroids increases testosterone levels in animals treated with *B. alba* extracts (Moundipa et al., 1999, 2005, 2006; Nantia et al., 2011). The incorporation of 1.0 g of *B. alba* methanol extract kg⁻¹ of diet masculinized *Poecilia reticulata* (Chakraborty, Molnar, & Hancz, 2012), which was linked to the ability to stimulate testosterone production. Similarly, treatment of Nile tilapia fry with *B. alba* extracts yielded up to 83.2% male individuals (Table 1).

### 2.1.7 | Jack plant, *Eurycoma longifolia*

Jack plant (*E. longifolia*), also known as Tongkat Ali, is a medium size slender tree (reaching a height of 18 m) belonging to order Sapindales and family Simaroubaceae (Bhat & Karim, 2010). *E. longifolia* is distributed in South East Asian countries, mainly: Malaysia, Indonesia, Vietnam, and Thailand (Arifah & Nurkhasanah, 2014; Bhat & Karim, 2010). The aphrodisiac properties of the root extracts of Jack plant increase sexual quality and libido in animals (Ang & Lee, 2002; Ang, Lee, & Kiyoshi, 2003, 2004). The *E. longifolia* extracts contain saponin, phytosterol, isoprenoid, alkaloid, and minerals (Fe, Co, Mg, Zn), which stimulate proliferation of spermatogenic, sertoli, and leydig cells in rats (Bogar, Tendean, & Turalaki, 2016; Rosida, 2003) and subsequently augment production of testosterone (Nainggolan & Simanjuntak, 2005). Notably, phytosterol (i.e., stigmasterol) in *E. longifolia* stimulated androgen hormone production in Nile tilapia, thus favoring masculinization (Rinaldi et al., 2017; Syarifuddin, Sri, Yenny, & Rahem, 2019; Yusuf et al., 2019; Table 1).

### 2.1.8 | Mango, *Mangifera indica*

Mangoes are native to tropical Asia (Nwinuka, Monanu, & Nwiloh, 2008), but introduced to most tropical countries. *M. indica* belongs to order Sapindales and family Anacardiaceae (Shah, Patel, Patel, & Parmar, 2010), and is utilized as a medicinal herb (Ojewole, 2005). The leaf extracts of *M. indica* have a high concentration of alkaloids, saponins, steroids, tannins, and alkaloids (Aiyelaagbe & Osamudiamen, 2009; Biu, Yusuf, & Rabo, 2009). Saponins occur in higher concentration compared to the other bioactive compounds, hence believed to be responsible for the antifertility effects of *M. indica* extracts (Obaroh et al., 2012). Inclusion of *M. indica* leaf powder in Nile tilapia diets at dosages of 0.5–8.0 g kg⁻¹ for 56 days reduced the number of spawned hatchlings, with complete inhibition of spawning observed at ≥2.0 g kg⁻¹ of diet (Obaroh & Achionye-Nzeh, 2013). The saponins in *M. indica* extract disintegrate sperm cells and rupture follicles of Nile tilapia, thus inhibiting reproduction (Obaroh et al., 2012).

### 2.1.9 | Moringa, *Moringa oleifera*

This species is a perennial tree, belonging to order Brassicales and family Moringaceae (Raja et al., 2016). It is indigenous to India, Pakistan, Bangladesh, and Afghanistan and is well adapted to tropical areas, growing to a height ranging
from 10 or 12 m (Ampofo-Yeboah, 2013). The leaves, roots, and bark of moringa plant contain flavonoids, steroids, and triterpenoids (oleanolic acid-3-glucoside and β-sitosterol; Bamishaiye, Olayemi, Awagui, & Bamshaiye, 2011; Kasole, Bimenya, Ojok, Ochieny, & Ogwal-Ogwal, 2010; Kawo et al., 2009; Kumar, Mishra, Ghosh, & Pand, 2010; Lambole & Kumar, 2011). Oleanolic acid-3-glucoside and β-sitosterol bioactive compounds in M. oleifera extracts are potential anti-fertility agents in animals (Ampofo-Yeboah, 2013; Das, 1980; Kumar et al., 2010). In fish, M. oleifera extracts caused skewness in sex ratios to mainly male gender (Table 1). Similarly, M. oleifera seed powder mixed in the diet of sexually immature and mature Mozambique tilapia (Oreochromis mossambicus) at 2.0 and 5.0 g kg$^{-1}$ fed for 60 days, expressed anti-fertility effect and prevented fish reproduction (Ampofo-Yeboah, 2013). Notably, prolonged treatment of Nile tilapia on diets with M. oleifera leaf extracts at 5% of total dietary protein, for 90 days, severely degenerated the oocyte cytoplasm (Nwankpa, 2017). The previous experimental studies suggest that M. oleifera extracts can be exploited to prevent unwanted breeding in tilapia culture facilities.

### 2.1.10 Neem tree, *Azadirachta indica*

*A. indica* is commonly known as “Neem tree” belongs to order Rutales, and is a member of mahogany family known as Meliaceae (Hashmat, Azad, & Ahmed, 2012). It is a broad-leaved plant that grows up to 30 m tall and with a girth of 2.5 m (Ndodo et al., 2013). The tree is native to the tropical and semi-tropical regions (Silayo & Kiwango, 2010). The extracts of various parts of neem tree have antimicrobial, anti-inflammatory, and spermicidal effects, as well as antifertility activity and abortifacient properties (Biswas, Chattopadhyay, Banerjee, & Bandyopadhyay, 2002; Jegede & Fagbenro, 2007; Priya, Saravanav, & Renuka, 2012). This is attributed to the high concentration of fertility-regulating-saponins and tannins in neem extracts (Atangwho et al., 2009; Bisu et al., 2009; Kapinda et al., 2018), in addition to sodium nimbinate, “a spermicide” (National Research Council, 1992). Consequently, the neem tree’s anti-fertility activity has been harnessed to control prolific breeding in tilapia in culture systems. The inclusion of 2.0 g kg$^{-1}$ of *A. indica* leaf powder rendered the testes and ovaries of *Tilapia zilli* devoid of spermatids and oocytes after 60 days of treatment (Jegede & Fagbenro, 2008b). Likewise, Nile tilapia, fed on diet containing 1.0–8 g kg$^{-1}$ of crude *A. indica* ethanol-based leaf extracts reduced the number of hatchings, with no spawning by the fifth week (Obaroh & Achionye-Nzeh, 2011; Obaroh & Achionye-Nzeh, 2013; Obaroh et al., 2012). However, *A. indica* only lowered the spawning of Nile tilapia by 76% at the highest inclusion of 8.0 g of the leaf powder kg$^{-1}$ diet for 90 days (Kapinga et al., 2018). This inconsistency in performance of *A. indica* extracts could be attributed to differences in extraction media and seasons (Ishah, 2019). These discrepancies hamper wide-scale utilization of neem extracts to control tilapia reproduction.

### 2.1.11 Pawpaw, *Carica papaya*

*C. papaya*, commonly known as “Pawpaw,” is an herbaceous succulent plant that belongs to Brassicales order and Caricaceae family (Yogiraj, Goyal, Chauhan, Goyal, & Vyas, 2014), growing mostly in tropical and subtropical countries (Krishna, Paridhai, & Patel, 2008). The plant grows to the height between 5 and 10 m, with leaves confined to the top of the trunk (Bamisaye, Ajani, & Minari, 2013). The fruit contains micronutrients such as vitamins A and C, carotene, and minerals (Krishna et al., 2008). Pawpaw seeds contain alkaloids, steroids, flavonoids, saponins, and tannins (Ezike, Akah, Okoli, Ezechhenne, & Ezeugwu, 2009; Krishna et al., 2008; Oloyede, 2005). The saponin, oleanolic acid 3-glucoside, is the main bioactive compound in pawpaw seeds with anti-fertility or sterility potential (Das, 1980; Lohiya et al., 2005; Mansura, Ameh, Ibrahim, Ayo, & Ambali, 2009; Udoh & Kehinde, 1999; Verma, Nambar, & Chinoy, 2006). The glucosides in pawpaw seed meal can also disintegrate gonadal cells in testes and ovaries of tilapia (Abbas & Abbas, 2011; Ekanem & Okoronkwo, 2003; Jegede & Fagbenro, 2008a; Waweru, Raburu, & Elizabeth, 2019). As a result, pawpaw seed meal has been utilized to prevent prolific spawning in tilapia culture.
systems. The inclusion of pawpaw seed powder in tilapia diets for 28–60 days, at dosages of 2.0 g–5.0 g kg\(^{-1}\) of the diet, rendered the testes and ovaries of Nile tilapia and Mozambique tilapia, devoid of spermatids and oocytes (Ampofo-Yeboah, 2013; Jegede & Fagbenro, 2008a; Solomon, Ugonna, Olufegba, & Okomoda, 2017). Dosage increment of pawpaw seed powder to at least 8.0 g kg\(^{-1}\) of feed for 60 days resulted in atretic follicles of ovaries and degenerates spermatozoa in testes of sterility in Nile tilapia (Abbas & Abbas, 2011; Ekanem & Okoronkwo, 2003; Waweru et al., 2019). The dosage of 120 g kg\(^{-1}\) led to permanent sterility in Nile tilapia (Abdelhak et al., 2013). Likewise, the inclusion of pawpaw seed powder in the diets of Nile tilapia and Mozambique tilapia fry (Table 1) shifted fish sex to all-male (Ahmed et al., 2019; Ampofo-Yeboah, 2013; Omeje et al., 2018). The masculinization of tilapia could be linked to the androgens in pawpaw seed meal that lower 17\(\beta\)-estradiol levels in the female fish, while favoring production of testosterone (Ampofo-Yeboah, 2013).

2.1.12 | Pine trees, Pinus spp.

Taxonomically, pine trees belong to the Pinales order and Pinaceae family (Christenhusz et al., 2011). The trees are mainly distributed in North America, China, South-East Asia, North Africa, and Europe (Keeley, 2012). The purplish male cones of pine trees are a source of “pollen,” containing high quantities of testosterone, epitestosterone, and androstenedione (Jones & Roddick, 1988; Velasco, Drexel, Lexter, & Tereso, 2018). For example, pollen from Pinus silvestris contains 80 ng g\(^{-1}\) of testosterone, 110 ng g\(^{-1}\) epitestosterone, and 590 ng g\(^{-1}\) androstenedione (Saden-Krehula, Tajic, & Kolbah, 1971; Zhong-han, Yin, Zong-xun, & Tsao, 1994). In Pinus bungeana and Pinus tabulaeformis, the testosterone concentrations range from 11 to 27 ng g\(^{-1}\) dry weight of pollen (Zhong-han et al., 1994). Pine pollen can be considered a store of testosterone (Adenigba, Tumbikon, & Serrano-Jr, 2017; Jones & Roddick, 1988; Saden-Krehula et al., 1971; Saden-Krehula, Tajic, & Kolbah, 1979; Velasco et al., 2018; Zhong-han et al., 1994). The utilization of pollen from Pinus tabulaeformis and Pinus kesiya to produce all-male individuals of Nile tilapia resulted in considerable increase in the rate of masculinization (Nian et al., 2017; Nieves, 2017; Table 1).

2.1.13 | Puncture vine, Tribulus terrestris

T. terrestris is an herbaceous perennial plant growing to a height of 10–60 cm. It belongs to order Zygophyllales and family Zygophyllaceae (Yanala, Sathyanarayana, & Kannan, 2016), occurring abundantly in Asia, Europe, and Africa (Yilmaz, Cek, & Mazlum, 2013). The seeds of T. terrestris contain alkaloids, steroid saponins, tannins, flavonoids, and flavonol glycosides, as bioactive compounds (Chhatre, Nesari, Somani, Kanchan, & Sathaye, 2014; Ghosal et al., 2015). The androgenic activity of T. terrestris is linked to the presence of protodioscin, a steroidal saponin (Dinchev et al., 2008; Ganzera, Bedir, & Khan, 2001), which induces production of testosterone phyto-dehydroepiandrosterone, dihydrotestosterone, and dehydroepiandrosteronesulfate in men (Adimoelja, Sartono, & Soedjono, 2005), rabbits and rats (Gauthaman, Adikan, & Prasad, 2002; Gauthaman & Ganesan, 2008). Therefore, puncture vine extracts are used to treat sexual infertility, improve libido and spermatogenesis in humans (Adaiakan, Gauthaman, Ng, & Prasad, 2000; Adikan, Gauthaman, & Prasad, 2001; Adimoelja, 2000; Adimoelja & Adikan, 1997; Bucci, 2000; Neychev & Mitev, 2005). In fish production, treatment of Clarias gariepinus, Cichlasoma nigrofasciatum, Poecilia reticulate, and Oncorhynchus mykiss with T. terrestris resulted in successful sex reversal, spermatogenesis, and better growth rates (Cek, Turan, & Atik, 2007a, 2007b; Kavitha & Subramanian, 2011; Turan & Cek, 2007; Yilmaz et al., 2013). The potential of T. terrestris extracts to trigger testosterone and 11-ketotestosterone (11-KT) production, which transforms fish sex to males (Gharaei, Ebrahimi, Mirdar, & Kolangi, 2020; Ghosal et al., 2021), can be harnessed to control prolific spawning in tilapia production. Studies achieved up to 91.5% masculinization success of Nile tilapia, through oral administration of 2.0 g of T. terrestris seed powder of kg\(^{-1}\) feed for 30 days (Table 1).
2.1.14 | Red hibiscus, *Hibiscus rosa-sinensis*

*H. rosa-sinensis* is an ornamental herb, commonly known as red hibiscus, belonging to order Malvales and family Malvaceae (Pekamwar, Kalyankar, & Jadhav, 2013). The herb is native to China; but was widely introduced in tropics and sub-tropics (Hou, Tong, Terahara, Lou, & Fuji, 2005; Khristi & Patel, 2016). The phytochemical analysis of flowers, leaves, and roots revealed the presence of saponins, steroids, tannins, and flavonoids (Pekamwar et al., 2013). The flavonoids in *H. rosa-sinensis* extracts are reported to induce anti-implantation and anti-spermatogenic effects in animals (Jiang, 1998; Murthy, Reddy, & Patil, 1997; Tan, 1983; Zhou, 1998). The treatment of Nile tilapia with *H. rosa-sinensis* leaf powder at 3.0 and 4.0 g kg$^{-1}$ of feed ruptured testes and ovary tissues after 60 days of treatment, thereby inducing sterility (Jegede, 2010). The inclusion of *H. rosa-sinensis* flower extracts also induced masculinization of Nile tilapia fry, producing up to 73.13% male individuals (Abella et al., 2015; Table 1). Therefore, more studies are required to clarify the specific effect of *H. rosa-sinensis* extracts on reproductive organs of fish, before recommendation for commercial adoption as population control agents in tilapia culture systems.

2.1.15 | Red kwao krua, *Butea superba*

*B. superba* belongs to order Fabales, and family Leguminosae (Cherdshewasart, Bhuntaku, Panriansaen, Dahlan, & Malaivijitnond, 2008). This indigenous Thai herb is used to increase men’s sexual performance (Kiriyakit, 2014). The roots of *B. superba* contain flavonoids, tannins, alkaloids, glycosides, and phenols (Vijayan, Seethalakshmi, Jayanthi, & Ragunathan, 2016). These phytochemicals, especially flavonol and flavonoid glycoside, isolated from Red kwao krua function as phytoandrogens, with similar effects as testosterone (Cherdshewasart & Nimsakul, 2003; Manosroi & Manosroi, 2005). The presence of flavonoid glycoside stimulates testosterone production, which augments sex shift to male individuals. Attempts to use *B. superb* extracts for controlling prolific spawning in tilapia through all-male production yielded up to 100% male tilapia individuals (Mengumphan et al., 2006; Kiriyakit, 2014; Table 1).

2.1.16 | Shatavari, *Asparagus racemosus*

*A. racemosus* is a woody climber that belongs to the Asparagales order and Asparagaceae family (Alok et al., 2013; Hasan, Ahmad, Zohraneena, Khalid, & Akhtar, 2016). It is native to India, but is distributed in the tropical and subtropical regions, growing to a height of one to two meters, mainly in low altitudes (Hasan et al., 2016; Tripathi, Pandey, Bhushan, Sahu, & Dubey, 2017). The root extracts of *A. racemosus* contain saponins, steroids, tannins, and flavonoids (Mukherjee et al., 2015a; Mukherjee et al., 2018). These bio-compounds, mainly the steroidal saponins, have therapeutic, aphrodisiac, and androgenic effects in animals (Alok et al., 2013; Mishra, Sheikh, Agnihotri, & Chourey, 2010; Thakur, Chauhan, Bhargava, & Dixit, 2009). The steroids in the root extracts of *A. racemosus* enhance production of 11-keto testosterone (11-KT) in testis of Nile tilapia, favoring sex change to all-male (Ghosal et al., 2021). As such, *A. racemosus* root extract inversed Nile tilapia sex resulting in significant masculinization (Table 1). This suggests that *A. racemosus* contains potential organic products that could be utilized for reproduction control in tilapia production systems.

2.1.17 | Soapbark tree, *Quillaja saponaria*

The soap bark tree belongs to the order Fabales and family Quillajaceae (Guerra & Sepulveda, 2020). This tree is native to China, Peru, and Chile (Angeles Jr., Gallego, Navarro, & Chien, 2017; Francis et al., 2002). The bark of *Q. saponaria* contains triterpenoidal saponins, mainly triterpene glycoside, which can inhibit fish reproduction and
increase growth performance (Bankefors, Nord, & Kenne, 2008; Francis, Makkar, & Becker, 2005; Stadtlander et al., 2008). The feeding of sexually mature female Nile tilapia on *Q. saponaria* extract at 300 mg kg$^{-1}$ of diet inhibited spawning (Francis et al., 2005; Francis, Makkar, & Becker, 2001), in addition to inducing masculinization of the female Nile tilapia fry (Table 1). A dose of 700 mg of *Q. saponaria* saponin kg$^{-1}$ of diet shifted the sex of Nile tilapia to mostly males (Francis et al., 2002). Similarly, *Q. saponaria* saponin extracts incorporated in Nile tilapia diets resulted in a significant increase in the number of male individuals (Stadtlander et al., 2008). As such, triterpenoid saponins in *Q. saponaria* need to be harnessed for production all-male populations in tilapia culture.

### 2.1.18 True aloe, *Aloe vera*

*A. vera* is a stemless or very short-stemmed perennial succulent plant that belongs to order Liliales, and family Asphodelaceae (Sanchez-Machado, Lopez-Cervantes, Sendon, & Sanches-Silva, 2017). It is widely distributed in tropical and semitropical regions. *A. vera* contains saponins, flavonoids, tannins, anthraquinones, and alkaloids (Langmead, Makins, & Rampton, 2004; Patel, Patel, & Dhanabal, 2012). Among the bioactive constituents, saponin and flavonoids were implicated in the control of reproduction in animals (Francis et al., 2002; Omitoyin et al., 2013; Patel et al., 2012). The inclusion of *A. vera* extracts, as low as 2.0 ml kg$^{-1}$ in Nile tilapia diets, caused disintegration of spermatids and follicles thus inhibiting gonadal development and functioning (Jegede, 2011; Kushwaha, 2013). The saponins in *A. vera* extracts (Kumar, Chandana, Preethi, & Chauhan, 2012) elevate testosterone production in animals such as rats (Gauthaman & Ganesan, 2008) and fish (Table 1), which favors development of male sex organs.

### 2.1.19 Velvet bean, *Mucuna pruriens*

*M. pruriens* is a widespread tropical and sub-tropical legume belonging to the order Fabales, family Leguminosae, and subfamily Fabaceae. The plant grows to a height of 3–18 m in bushes, hedges, and forests (Lampariello, Cortelazzo, Guerranti, Sticozzi, & Valacchi, 2012; Sathiyanarayanan & Arulmozhi, 2007). The seeds of *M. pruriens* contain tannin, saponin, alkaloid, glycoside, flavonoid, and steroid phytochemicals (Mukherjee et al., 2015b; Mukherjee et al., 2018). In particular, the steroids in *M. pruriens* extracts increased the serum testosterone in animals (Ahmad, Rahma, Akhtar, & Ali, 2012), stimulating androgenic effects, as was observed in rats (Muthu & Krishnamoorthy, 2011) and fish (Mukherjee et al., 2018). Accordingly, the phytoandrogens in *M. pruriens* seed extracts produced up to 93% all-male Nile tilapia (Table 1). However, the action of the plant extracts on gonadal function and spawning of tilapia has not been elucidated. Nonetheless, experimental treatment of rats with *M. pruriens* extract triggered increment in spermatozoa, together with the sexual and androgenic activities (Suresh & Prakash, 2012; Suresh, Prithiviraj, & Prakash, 2009).

### 3 ROUTE OF ADMINISTRATION OF PLANT EXTRACTS

During fish culture operations, plant extracts are administered either through incorporation in fish feeds (oral method), immersion, or injection (Bulfon, Volpatti, & Galeotti, 2015). The oral and immersion techniques are considered noninvasive, hence commonly used methods during reproduction control in tilapia (Table 1). Overall, oral administration is the predominant method because of the low cost of application, potential of treatment of large numbers of fish at the same time, causes no stress or reduced stress (Bulfon et al., 2015; Sakai, 1999; Yoshida, Kruger, & Inglis, 1995) and yields at least 95% sex masculinization (El-Greisy & El-Gamal, 2012; Phelps & Popma, 2000). Nonetheless, the effectiveness of oral method is reduced by differences in the amount of the sex steroids available to the fish, linked to non-uniform distribution of the extracts in the diets during mixing.
The immersion technique is crucial in fish species whose gonadal labile period occurs before first feeding, such as in yolk sac larvae or during embryogenesis (Devlin & Nagahama, 2002). In tilapia, the labile period of sex differentiation occurs during the first 30 days post-hatch, the period within which fry can ingest exogenous diets (Mateen & Ahmed, 2007). Immersion of tilapia in plant extracts during post-hatching stages has yielded up to 90% masculinization (Table 1). However, fish immersion method requires mixing the extracts with culture water at each exposure time, which results in wastages of the masculinization agent, and high rate of release into the environment.

Intra-peritoneal injection of fish is efficient and rapid, necessitated by quick absorption of the extracts (Reverter et al., 2014). However, the process of injecting fish is expensive, laborious, stressful to fish, and impractical for small fish, that is, less than 15 g fish\(^{-1}\) (Anderson, 1992; Beardmore et al., 2001; Blazer, 1992; Reverter et al., 2014; Sakai, 1999). Besides, the method requires technical skills to avoid inflicting damage onto the fish (Hoga, Almeida, & Reyes, 2018). As such, the injection method is rarely utilized to administer sex inversion reversal agents in tilapia culture systems.

4 | MECHANISM OF ACTION OF PLANT EXTRACTS AS CONTROL AGENTS OF REPRODUCTION IN TILAPIA

The precise mechanisms by which plant bioactive compounds manipulate reproduction in tilapia are not yet elucidated. Nevertheless, two pathways, that is, endocrine system modulation and induction of gonadal histological changes are postulated as plausible functional mechanisms responsible for changes on the reproductive physiology of fish.

4.1 | Endocrine system modulation

Phyto-compounds modulate the endocrine system of fish, hence referred to as endocrine disrupting compounds (EDCs). The phyto-compounds can disrupt the biosynthesis, distribution, and functions of steroid hormones subsequently interfering with the reproductive physiology of fish (Omeje, 2016). The EDCs interrupt gonadal differentiation in fish by interfering with the biosynthesis of sex steroids through: (a) inhibiting aromatase enzyme; and (b) antagonizing estrogen nuclear receptors (Cek et al., 2007a, 2007b; Chakraborty et al., 2013; Cheshenko, Pakdel, Segner, Kah, & Eggen, 2008; Francis et al., 2002; Rempel & Schlenk, 2008).

The phyto-compounds are hypothesized to inhibit aromatase enzyme Cytochrome P450 aromatase enzyme, which catalyzes the conversion of androgens to estrogens, thus favoring development of female characteristics (Eng et al., 2001). The enzyme is inhibited through either competitive inhibition of natural substrates for the enzyme, decreasing the expression of cyclic adenosine monophosphate (cAMP) responsive element binding (CREB) protein or inhibiting the generation of cAMP. Consequently, the pathway regulating aromatase expression is altered, which in turn augments production of androgens, modifying sex ratio in favor of male individuals (Cheshenko et al., 2008). Phyto-compounds such as flavonoids and steroidal saponins, are reported to inhibit aromatase enzyme activity (Gauthaman & Ganesan, 2008) increasing the production of testosterone, a process towards induction fish masculinization (Gauthaman & Ganesan, 2008).

The phyto-compounds may also antagonize endogenous estrogens by interacting with estrogen nuclear receptors. The antagonicity of phyto-compounds is facilitated by similarity in structures to estrogens and high affinity for estrogen receptors. Besides, the phytochemicals have stable structures and low molecular weights, which permit passage although the cell membranes (Ososki & Kenelly, 2003). Within the cytoplasm, the phyto-compounds compete with endogenous estrogens for binding sites of estrogen receptors, hence acting as estrogen antagonists (anti-estrogens). The anti-estrogens block or alter estrogen receptors, preventing estrogenic activity and consequently reversing the estrogenic effects (Matozzo, Gagne, Marin, Ricciardi, & Blaise, 2008; Ososki & Kenelly, 2003). Anti-
estrogenic compounds such as flavonoids have structures that mimic estrogens, enhancing the affinity for estrogen receptors (Bennetau-Pelissero et al., 2001; Chen & Chang, 2007; Green & Kelly, 2009; Miyahara et al., 2003; Tarigan et al., 2016). Therefore, the anti-estrogenic compounds can easily bind onto the estrogen receptors, subsequently disrupting the effect of estrogens.

4.2 Induction of gonadal histological changes

The phyto-compounds may impair fertility by inducing histological changes in the gonads of fish: (a) delay gonadal maturation and (b) obstruct reproductive functions. The histological changes in fish testes and ovaries include disintegration of gonad cells, rupture of seminiferous lobule and follicles as well as gonadal necrosis. As a consequence of gonadal damage, testes and ovaries become devoid of spermatids and oocytes, respectively (Abdelhak et al., 2013; Ampofo-Yeboah, 2013; Jegede, 2010; Jegede & Fagbenro, 2008a, 2008b). For example, the saponins in C. papaya seed powder rendered the testes and ovaries of O. niloticus and O. mossambicus devoid of spermatids and oocytes (Ampofo-Yeboah, 2013; Jegede & Fagbenro, 2008a, 2008b; Solomon et al., 2017).

5 LIMITATIONS TO THE UTILIZATION OF PLANT EXTRACTS AND FUTURE PERSPECTIVES

The use of plant extracts to control prolific spawning in tilapia culture systems is an emerging innovation. As such, a number of drawbacks continue to constrain commercial application of phytoextracts. Generally, technical and economic limitations continue to hinder the progress in application of plant extracts from experimental to field levels (Chakraborty et al., 2013; Ghosal & Chakraborty, 2020; Kapinga et al., 2019; Mukherjee et al., 2018).

5.1 Technical limitations

The existing knowledge lack reliable information on the: (a) ideal extraction methods of phytochemicals, (b) effective bioactive compounds in plants, (c) effect of seasons, environmental parameters and stage of plant growth on the yield and biological activity of extracts, (d) optimal dose requirements, (e) precise mechanism of action, and (f) long-term effects of plant extracts on quality of fish’s flesh and physiological processes such as growth and immunity (Chakraborty et al., 2013; Gabriel et al., 2017; Ghosal et al., 2021; Mukherjee et al., 2015b; Stadlander et al., 2008).

The present review observed discrepancies in extraction methods of plant extracts, especially extraction solvents used, yet the yield and functional properties of phytochemicals are dependent on the extraction techniques (Dhanani, Shah, Gajbhiye, & Kumar, 2017; Tiwari, Kumar, Kaur, Kaur, & Kaur, 2011). A variety of bioactive compounds from different plant extracts have varying solubility properties in different solvents such as aqueous, ethanol and methanol (Truong et al., 2019). It is therefore necessary to select an ideal extraction solvent especially, of appropriate polarity, to maximize the yield of the target bioactive compounds without disrupting their functional activities (Dhanani et al., 2017). Further, little is known on the effect of the plant’s growth stage (Akula & Ravishankar, 2011), seasons and environmental parameters (Isah, 2019) and geographical origin (Dinchev et al., 2008), on the concentration and composition of phytochemicals believed to control reproduction in tilapia. With regard to the effectiveness of plant extracts, variable optimal doses are reported by different studies, even for extracts from the same plant (Table 1). Similarly, the effects of specific bioactive compounds from the same plant are not defined. The reviewed studies, therefore, attribute the observed effects of plant extracts to various phytochemicals present in the plant. In addition, the precise mechanism modulating tilapia sex inversion or fertility impairment is not understood, further hampering the harmonization of the optimal dosages and treatment regimen.
Given the technical information gaps in utilizing plant extracts in tilapia culture, low reproducibility of results is reported, a concern that needs to be addressed before commercialization of the technology. Research on developing efficient methods for isolating and quantifying bioactive compounds in plant extracts, including determining ideal extraction solvents for target phytochemicals that induce sex manipulation in tilapia is vital. Further, the hypothesized mechanisms of action necessitate comprehensive analysis either by searching for sex gene expression profiles at the transcriptomic level or changes in the sex steroid levels (Capel & Tanaka, 2013; Ross & Capel, 2005), to validate the specific role/s of plant extracts on the tilapia sex differentiation pathway. This would facilitate the designing of a standard utilization protocol including: extraction procedure for bioactive ingredients of interest, extraction solvents that result in highly purified concentrations, administration approaches, and subsequently optimal doses levels of plant extracts (Dhanani et al., 2017; Mukherjee, Ghosal, Moniruzzaman, De, & Chakraborty, 2019).

The commercial application of plant extracts in masculinization of tilapia is also limited by inadequate information regarding the long-term effects of the extracts on the quality of fish’s flesh and other physiological processes. Plant extracts may either positively or negatively modulate the physiological functioning of fish, depending on plant type and the administered dose. Besides reproduction control, plant extracts such as saponins also enhance the immune system and subsequently growth performance of fish. However, a specific dosage of the extracts that is effective in controlling unwanted breeding may trigger negative growth response in the same fish. Some plant extracts also contain antinutritional factors such as gossypol in cotton, which interfere with feed utilization, hence adversely affecting health and growth of fish. (Ayotunde & Ofem, 2008; Chakraborty et al., 2013; Gabriel et al., 2015; Kapinge et al., 2018; Prasad & Mukthiraj, 2011). Thus, in-depth explorations focusing on determining optimal doses of plant extracts for sex manipulation that do not cause undesirable effects to the fish’s flesh and physiological processes are needed.

5.2 Economic limitations

Although viewed as relatively cheap and readily available alternative to synthetic hormones, no study has sufficiently described the economic viability of utilizing plant extracts in aquaculture. As such, information on the cost effectiveness of plant-based products for commercial application in tilapia culture is lacking. Therefore, research to determine the benefit–cost ratio of utilizing plant extracts is needed to guide recommendations for an economically feasible alternative to synthetic hormones.

6 CONCLUSION

This review underpins the potential of plant extracts as alternatives to synthetic steroids in controlling unwanted reproduction in tilapia culture. However, addressing the technical limitations and generating information on economic incentives are key to fostering adoption of plant extracts as effective, environmentally sustainable, and socially acceptable approach to masculinization of tilapia.

ACKNOWLEDGMENTS

This work was supported by the Intra-Africa Academic Mobility Scheme under European Union (Grant number: EACEA/05/2017) through Collaborative Training and Research in Fisheries and Aquaculture in East, Southern and Central Africa (COTRA) project.

CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.
REFERENCES

Abbas, H. H., & Abbas, T. W. (2011). Assessment on the use of pawpaw; Carica papaya seeds to control Oreochromis niloticus breeding. *Pakistan Journal of Biological Sciences*, 14(24), 1117–1123.

Abdelhak, M. E., Madkour, F. F., Ibrahim, M. A., Sharaf, M. S., Sharaf, M. M., & Mohammed, D. A. (2013). Effects of pawpaw, Carica papaya seeds meal on the productive performance and histological characters of gonads in Nile tilapia, Oreochromis niloticus. *Indian Applied Research*, 3(12), 34–37.

Abella, A. T., Espiritu, H. J., Viernes, M., Samelo, V. J., Velasco, R. R., Umagat, R. M., & Gonzales, L. R. (2015). Phytoandrogenic sources for sex inversion of Nile tilapia (Oreochromis niloticus). The Annual International Conference and Exposition of World Aquaculture Society, Asian-Pacific chapter, Jeju, Korea.

Abu, A. H., Amuta, P. O., Buba, E., & Inusa, T. R. (2013). Evaluation of antispermaogenic effect of Garcinia kola seed extract in Albino rats. *Asian Pacific Journal of Reproduction*, 2(1), 15–18.

Abucay, J. S., & Mair, G. C. (1997). Hormonal sex reversal of tilapias: Implications of hormone treatment application in closed water systems. *Aquaculture Research*, 28, 841–845.

Adak, P. G., Gauthaman, K., Ng, R. N. V., & Prasad, S. C. (2000). Proerectile pharmacological effects of *Tribulus terrestris* on the rabbit corpus cavernosum. *Annals Academy of Medicine Singapore*, 29(1), 22–26.

Adak, P. G., Gauthaman, K., & Prasad, R. N. V. (2001). History of herbal medicines with an insight on the pharmacological properties of *Tribulus terrestris*. *The Aging Male*, 4(3), 163–169.

Adenigba, I., Tumbokon, B. L. M., & Serrano-Jr, A. E. (2017). Androgenic and anabolic effects of *Pinus tabulaeformis* Carr. pollen in *Clarias gariepinus*. *The Israeli Journal of Aquaculture—Bamidgeh*, 69, 1–9.

Adhikari, R., Naveen, K. H. N., & Shrunthi, S. D. (2012). A review on medicinal importance of *Gossypium herbaceum* L. *International Journal of Pharmaceutical Sciences & Drug Research*, 4(2), 110–114.

Adimoejia, A. (2000). Photochemical and the breakthrough of traditional herbs in the management of sexual dysfunctions. *International Journal of Andrology*, 23(2), 82–84.

Adimoejia, A., & Adak, P. G. (1997). Protodioscin from herbal plant *Tribulus terrestris* L. improves male sexual functions possibly via DHEA. *International Journal of Impotence Research*, 9(1), 64.

Adimoejia, A., Sartono, S., & Soedjono, J. (2005). Phyto-DHEA treatment, an alternative option for aging men. *International Journal of Andrology*, 28(1), 25.

Ahmad, N., Rahma, Z. U., Akhtar, N., & Ali, S. (2012). Testosterone like activity of ethanolic and aqueous extracts of *Mucuna pruriens* seeds and its effects on serum biochemical metabolites in immature male rats. *Pakistan Veterinary Journal*, 32, 1–5.

Ahmed, I. M., Fathy, F. K., Fayek, H. F., & Mohamed, M. R. (2019). 17α-methyltestosterone and some medicine plants as reproductive controller agents of *Oreochromis niloticus*. *Journal of Biological Sciences*, 19, 407–417.

Aiyelaagbe, O. O., & Osamudiamen, P. M. (2009). Phytochemical screening for active compounds in *Mangifera indica* leaves from Ibadan, Oyo state. *Plant Sciences Research*, 2(1), 11–13.

Akinloye, A. K., Igharna, O. O., Olaniyi, M. O., Alaka, O. O., & Oke, B. O. (1999). Preliminary investigations on the effects of *Garcinia kola* (Bitter cola) on the rabbit’s testis and epididymis. *Tropical Veterinarian*, 18, 49–54.

Akin-Obasola, B. J., & Jegede, T. (2016). Reproduction control of male *Oreochromis niloticus* (Nile tilapia) using *Gossypium herbaceum* (cotton) root bark meals as fertility inhibitor. *European Scientific Journal*, 12, 218–230.

Akula, R., & Ravishankar, G. A. (2011). Influence of abiotic stress control on secondary metabolites in plants. *Plant Signaling & Behavior*, 6(11), 1720–1731.

Alok, S., Jain, S. K., Verma, A., Kumar, M., Mahor, A., & Sabharwal, M. (2013). Plant profile, phytochemistry and pharmacology of *Asparagus racemosus* (Shatavari): A review. *Asian Pacific Journal of Tropical Disease*, 3(3), 242–251.

Ali-Snafi, A. E. (2018). Chemical constituents and pharmacological activities of *Gossypium herbaceum* and *Gossypium hirsutum*—A review. *IOSR Journal of Pharmacy*, 8(5), 64–80.

Ampofo-Yeboah, A. (2013). Effect of phytochemical feed additives on gonadal development in Mozambique Tilapia, Oreochromis mossambicus. (PhD thesis). Stellenbosch University, South Africa.

Anderson, D. P. (1992). Immunostimulants, adjuvants, and vaccine carriers in fish: Applications to aquaculture. *Annual Review of Fish Diseases*, 2, 281–307.

Ang, H. H., & Lee, K. L. (2002). Effect of *Eurycoma longifolia* Jack on libido in middle-aged male rats. *Journal of Basic & Clinical Physiology & Pharmacology*, 13(3), 249–254.

Ang, H. H., Lee, K. L., & Kiyoshi, M. (2003). *Eurycoma longifolia* Jack enhances sexual motivation in middle-aged male mice. *Journal of Basic & Clinical Physiology & Pharmacology*, 14(3), 301–308.
Ang, H. H., Lee, K. L., & Kiyoshi, M. (2004). Sexual arousal in sexually sluggish old male rats after oral administration of Eurycoma longifolia Jack-Tongkat Ali. *Journal of Basic & Clinical Physiology & Pharmacology*, 15, 303–309.

Angeles, I. P., Jr., Gallego, M. L., Navarro, M. A. M., & Chien, Y.-H. (2017). Dietary effects of Quillaja saponaria and Yucca schidigera extract on rearing performance of Nile tilapia Oreochromis niloticus L. and its antioxidant capacity and metabolic response following hypoxic stress. *International Journal of Agricultural Technology*, 13(7.3), 2249–2266.

Angienda, P. O., Aketch, B. O., & Waindi, E. N. (2010). Development of all-male fingerlings by heat treatment and the genetic mechanism of heat induced sex determination in Nile tilapia (Oreochromis niloticus L.). *World Academy of Science. Engineering and Technology*, 37, 1104–1109.

Arifah, N. A., & Nurkhasanah. (2014). The effect of ethyl acetate fraction of Eurycoma longifolia, Jack root extracts on the phagocytic activity of macrophages in vitro. *Pharmaciana*, 4, 9–14.

Atangwo, I. J., Ebong, P. E., Eyong, E. U., Williams, I. O., Eteng, M. U., & Ebung, G. E. (2009). Comparative chemical composition of leaves of some antidiabetics medicinal plants: Azadirachta indica, Veronia amygdalina and Gongronema latifolium. *African Journal of Biotechnology*, 8(18), 4685–4689.

Ayotunde, E. O., & Ofem, B. O. (2008). Acute and chronic toxicity of pawpaw (*Carica papaya*) seed powder to adult Nile tilapia (*Oreochromis niloticus Linne 1757*). *African Journal of Biotechnology*, 7(13), 2265–2274.

Baluran, S. M. D. L., Quiazon, K. M. A., Garcia, G. G., Fernando, S. I. D., & Velasco, R. R. (2018). Immunostimulatory effect of Benguet pine (*Pinus kesiya*) pollen on Nile tilapia (*Oreochromis niloticus L.*). *International Journal of Biology, Pharmacy & Allied Sciences*, 7(9), 1652–1663.

Bamisaye, F. A., Ajani, E. O., & Minari, J. B. (2013). Prospects of ethnobotanical uses of pawpaw (*Carica Papaya*). *Journal of Medicinal Plants Studies*, 1(4), 171–177.

Bankefors, J., Nord, L. I., & Kenne, L. (2008). Structural classification of acyl-substituted Quillaja saponins by electrospray ionisation on ion trap multiple-stage mass spectrometry in combination with multivariate analysis. *Rapid Communications in Mass Spectrometry*, 22, 3851–3860.

Barioiller, J. F., & D’Cotta, H. (2018). Sex control in tilapias. In H.-P. Wang, F. Piferrer, S.-L. Chen, & Z.-G. Shen (Eds.), *Sex control in aquaculture* (pp. 189–234). Hoboken, NJ: John Wiley & Sons, Ltd.

Bennetau-Pelissero, C., Breton, B., Bennetau, B., Corraze, G., LeMenn, E., Davail-Cuisset, B., ... Kaushik, S. J. (2001). Effect of Genistein-enriched diets on the endocrine process of gametogenesis and on reproduction efficiency of the rainbow trout, *Oncorhynchus mykiss*. *General & Comparative Endocrinology*, 121, 173–187.

Bhat, R., & Karim, A. A. (2010). Tongkat Ali (*Eurycoma longifolia* Jack): A review on its ethnobotanical and pharmacological importance. *Fitoterapia*, 81, 669–679.

Biswas, A. K., Morita, T., Yoshizaki, G., Maita, M., & Takeuchi, T. (2005). Control of reproduction in Nile tilapia Oreochromis niloticus, (L.) by photoperiod manipulation. *Aquaculture*, 243(1), 229–239.

Bissau, K., Chattopadhyay, I., Banerjee, B. K., & Bandyopadhyay, U. (2002). Biological activities and medicinal properties of neem (*Azadirachta indica*). *Current Science*, 82, 1336–1345.

Biu, A. A., Yusuf, D. S., & Rabo, S. J. (2009). Phytochemical screening of *Azadirachta indica* (Meliaceae) in Maiduguri, Nigeria. *Bioscience Research Communications*, 21, 281–283.

Blazer, V. S. (1992). Nutrition and disease resistance in fish. *Annual Review of Fish Diseases*, 2, 309–323.

Bogar, B. C. A., Tendean, L., & Turalaki, G. L. A. (2016). Effect of *Eurycoma longifolia* extract on earth extract Jack on the quality of *Rattus norvegicus* rat spermatzoa. *Journal of Biomedical*, 4, 205–209.

Bucci, L. R. (2000). Selected herbas and human exercise performance. *The American Journal of Clinical Nutrition*, 72(2 Suppl), 6245–6365.

Bulfon, C., Volpatti, D., & Galeotti, M. (2015). Current research on the use of plant derived products in farmed fish. *Aquaculture Research*, 46, 513–551.

Capel, B., & Tanaka, M. (2013). Forward to the special issue on sex determination. *Developmental Dynamics*, 242(4), 303–306.

Cek, S., Turan, F., & Atlik, E. (2007a). Masculinization of convict cichlid (*Cichlasoma nigrofasciatum*) by immersion in Tribulus terrestris extract. *Aquaculture International*, 15(2), 109–119.

Cek, S., Turan, F., & Atlik, E. (2007b). The effects of Gokshura, *Tribulus terrestris* on sex reversal of Guppy, *Poecilia reticulate*. *Pakistan Journal of Biological Sciences*, 10(5), 718–725.

Chakraborty, S. B., & Hancz, C. (2011). Application of phytochemicals as immunostimulant, antipathogenic and antistress agents in finfish culture. *Reviews in Aquaculture*, 3, 103–119.

Chakraborty, S. B., Horn, P., & Hancz, C. (2013). Application of phytochemicals as growth promoters and endocrine modulators in fish culture. *Reviews in Aquaculture*, 5, 1–19.
Chakraborty, S. B., Molnar, T., & Hanz, C. (2012). Effects of methyltestosterone, tamoxifen, genistein and Basella alba extract on masculinization of guppy (Poecilia reticulata). *Journal of Applied Pharmaceutical Science*, 2, 48–52.

Chen, J. J., & Chang, H. C. (2007). By modulating androgen receptor coactivators, daidzein may act as a phytoandrogen. *The Prostate*, 67, 457–462.

Cherdhiewasart, W., Bhuntaku, P., Panriansen, R., Dahlan, W., & Malaiwijtnond, S. (2008). Androgen disruption and toxicity tests of Butea superba Roxb., a traditional herb used for treatment of erectile dysfunction, in male rats. *Maturitas*, 60, 131–137.

Cherdhiewasart, W., & Nimsakul, N. (2003). Clinical trial of Butea superba, an alternative herbal treatment for erectile dysfunction. *Asian Journal Andrology*, 5, 243–246.

Cheshenko, K., Pakdel, F., Segner, H., Kah, O., & Eggen, R. I. L. (2008). Interference of endocrine disrupting chemicals with aromatase CYP19 expression or activity, and consequences for reproduction of teleost fish. *General & Comparative Endocrinology*, 155, 31–62.

Chhatre, S., Nesari, T., Somani, G., Kanchan, D., & Sathaye, S. (2014). Phytopharmacological overview of Tribulus terrestris. *Pharmacognosy Reviews*, 8(15), 45–51.

Christenhusz, M. J. M., Reveal, J. L., Farjon, A., Gardner, M. F., Mill, R. R., & Chase, M. W. (2011). A new classification and linear sequence of extant gymnosperms. *Phytotaxa*, 19, 55–70.

Citarasu, T. (2010). Herbal biomedicines: A new opportunity for aquaculture industry. *Aquaculture International*, 18, 403–414.

Dabrowski, K., Rodriquez, G., Abiado, M. A. G., Sanchez, W. C., & de Jesus, C. G. M. (2005). Use of phytochemicals as an environmentally friendly method to sex reverse Nile tilapia. In J. Burritt, C. Flemming, & H. Egna (Eds.), Twenty second annual technical report. *Aquaculture CRSP* (pp. 287–303). Corvallis, Oregon: Oregon State University.

Das, R. P. (1980). Effect of papaya seeds on the genital organs and fertility of male rats. *Indian Journal of Experimental Biology*, 18, 408–409.

Dauda, A. B., Yakubu, S. S., & Oke, A. O. (2014). Curbing the menace of prolific breeding in “aquatic chicken” (tilapia): A way out to improve fish production in Nigeria. *New York Science Journal*, 7(4), 112–118.

de Ziegler, D., & Fanchin, R. (2000). Progesterone and progestins: Applications in gynecology. *Steroids*, 65, 671–679.

Deshmukh, S. A., & Gaikwad, D. K. (2014). A review of the taxonomy, ethnobotany, phytochemistry and pharmacology of Basella alba (Basellaceae). *Journal of Applied Pharmaceutical Science*, 4, 153–165.

Desprez, D., Geraz, E., Hoareau, M. C., Melard, C., Bosc, P., & Baroiller, J. F. (2003). Production of a high percentage of male offspring with a natural androgen, 11β-hydroxyandrostenedione (11βOHA4), in Florida red tilapia. *Aquaculture*, 216, 55–65.

Devlin, R. H., & Nagahama, Y. (2002). Sex determination and sex differentiation in fish: An overview of genetic, physiological, and environmental influences. *Aquaculture*, 208, 191–364.

Dhanani, T., Shah, S., Gajbhiye, N. A., & Kumar, S. (2017). Effect of extraction methods on yield, phytochemical constituents and antioxidant activity of Withania somnifera. *Arabian Journal of Chemistry*, 10, S1193–S1199.

Dinchev, D., Janda, B., Evstatieva, L., Oleszek, W., Aslani, M. R., & Kostova, I. (2008). Distribution of steroidal saponins in Tripterygium wilfordii Hook. in phytochemical studies. *Phytotherapy Research*, 22, 756–762.

Ekanem, S. B., & Okoronkwo, T. E. (2003). Pawpaw seed as a fertility control agent on male tilapia. *NAGA. World FISH Center Quarterly*, 26(2), 8–10.

Ekene, E. N., & Erhirhe, E. O. (2014). *Garcinia kola*: A review of its ethnomedicinal, chemical and pharmacological properties. *International Journal of Current Research & Review*, 04(11), 1–7.

Elbrecht, A., & Smith, R. (1992). Aromatase enzyme activity and sex determination in chickens. *Science*, 255(5043), 467–470.

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. *Egyptian Journal of Aquatic Research*, 38, 59–66.

El-Rayes, A. M. F. (2006). *Tilapia Culture* (1st ed.). Oxford shire, England: CABI Publishing, CAB International.

El-Sharawy, A. S., Newairy, A. A., Elguindy, N. M., & Elwafa, A. A. (2010). Spermatotoxicity, biochemical changes and histological alteration induced by gossypol in testicular and hepatic tissues of male rats. *Food & Chemical Toxicology*, 48(12), 3354–3361.

Eng, E. T., Williams, D., Mandy, U., Kirmu, U., Tekmal, R. R., & Chen, S. (2001). Suppression of aromatase (estrogen synthesis) by red wine phytochemicals. *Breast Cancer Research & Treatment*, 67, 133–146.

Ezike, A. C., Akah, P. A., Okoli, C. O., Ezechuene, N. A., & Ezeugwu, S. (2009). *Carica papaya* (paw-paw) unripe fruit may be beneficial in ulcer. *Journal of Medicinal Food*, 12(6), 1268–1273.

FAO. (2017). *Social and economic performance of tilapia farming in Africa*. FAO Fisheries and Aquaculture Circular No. 1130. Food and Agriculture Organization of the United Nations Rome, Italy.

FAO. (2020). *The state of world fisheries and aquaculture. Sustainability in action*. Food and Agriculture Organization of the United Nations. Rome, Italy.
Fortes, D. R. (2005). Review of techniques and practice in controlling tilapia population and identification of methods that may have practical applications in Nauru including a National Tilapia Plan. Aquaculture section, secretariat of the pacific community (SPC), Marine Resources Division, Noumea, New Caledonia.

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.

Francis, G., Makkar, H. P. S., & Becker, K. (2001). Effects of Quillaja saponins on growth, metabolism, egg production and muscle cholesterol in individually reared Nile tilapia (Oreochromis niloticus). Comparative Biochemistry & Physiology Part C, 129, 105–114.

Francis, G., Makkar, H. P. S., & Becker, K. (2005). Quillaja saponins—A natural growth promoter for fish. Animal Feed Science & Technology, 121, 147–157.

Gabriel, N. N., Qiang, J., Kpundeh, D. M., & Xu, P. (2015). Use of herbal extracts for controlling reproduction in tilapia culture: Trends and prospects—A review. The Israel Journal of Aquaculture—Bamidgeh, 67(1178), 1–12.

Gabriel, N. N., Qiang, J., Ma, X. Y., He, J., Xu, P., & Omoregie, E. (2017). Sex-reversal effect of dietary Aloe vera (Liliaceae) on genetically improved farmed Nile tilapia fry. North American Journal of Aquaculture, 79(1), 100–105.

Gale, W. L., Fitzpatrick, M. S., Lucero, M., Contreras-Sanchez, W. M., & Schreck, C. B. (1999). Masculinization of Nile tilapia (Oreochromis niloticus) by immersion in androgens. Aquaculture, 178, 349–357.

Ganzer, M., Bedir, E., & Khan, I. A. (2001). Determination of steroidal saponins in Tribulus terrestris by reversed-phase high-performance liquid chromatography and evaporative light scattering detection. Journal of Pharmaceutical Sciences, 90(11), 1752–1758.

Gauthaman, K., Adaikan, P. G., & Prasad, R. N. V. (2002). Aphrodisiac properties of Tribulus terrestris extract (Protodioscin) in normal and castrated rats. Life Science, 71(12), 1385–1396.

Gauthaman, K., & Ganesan, A. P. (2008). The hormonal effects of Tribulus terrestris and its role in the management of male erectile dysfunction—An evaluation using primates, rabbit and rat. Phytomedicine, 15, 44–54.

Gharai, A., Ebrahimi, J. H., Mirdar, H. J., & Kolangi, M. H. (2020). Effects of Tribulus terrestris extract on masculinization, growth indices, sex determination and steroid hormones level in Zebra fish (Danio rerio). International Aquatic Research, 12(1), 22–29.

Ghosal, I., & Chakraborty, S. B. (2014a). Effects of the aqueous leaf extract of Basella alba on sex reversal Nile tilapia, Oreochromis niloticus L. IOSR Journal of Pharmacy & Biological Sciences, 9, 162–164.

Ghosal, I., & Chakraborty, S. B. (2014b). Effects of the aqueous seed extract of Tribulus terrestris on sex reversal of Nile tilapia, Oreochromis niloticus. Indian Journal of Applied Research, 4, 459–461.

Ghosal, I., & Chakraborty, S. B. (2020). Production of monosex all-male Nile tilapia using ethanol extract of Tribulus terrestris seeds. Proceedings of the Zoological Society, 73(2), 188–191.

Ghosal, I., Mukherjee, D., & Chakraborty, S. B. (2021). The effects of four plant extracts on growth, sex reversal, immunological and haematobiochemical parameters in Nile tilapia, Oreochromis niloticus (Linnaeus, 1758). Aquaculture Research, 52, 559–576.

Ghosal, I., Mukherjee, D., Hancz, C., & Chakraborty, S. B. (2015). Efficacy of Basella alba and Tribulus terrestris extracts for production of monosex Nile tilapia, Oreochromis niloticus. Journal of Applied Pharmaceutical Science, 5(08), 152–158.

Ghosal, I., Mukherjee, D., Hancz, C., & Chakraborty, S. B. (2016). Production of monosex Nile tilapia, Oreochromis niloticus by dietary and immersion treatment with Basella alba leaves and Tribulus terrestris seeds. International Journal of Fisheries & Aquatic Studies, 4(1), 358–363.

Ghosh, B., Chandra, I., & Chatterjee, S. (2015). Fenugreek (Trigonella foenum-graecum L.) and its necessity (review paper). Fire Journal of Engineering & Technology, 1(1), 60–67.

Godwin, J., Luckenbach, J. A., & Borski, R. J. (2003). Ecology meets endocrinology: Environmental sex determination in fishes. Evolution & Development, 5(1), 40–49.

Golan, M., Avitan, A., Qutob, M., Dweik, H., Abu-Lafi, S., Focken, U., ... Levavi-Sivan, B. (2008). Quillaja saponins inhibit tilapia aromatase activity in vitro. Cybium, 32(Suppl), 80–82.

Golan, M., & Levavi-Sivan, B. (2014). Artificial masculinization in tilapia involves androgen receptor activation. General & Comparative Endocrinology, 207, 50–55.

Gomelsky, B., Cherfas, N. B., Peretz, Y., Ben-Don, N., & Hulata, G. (1994). Hormonal sex inversion in the common carp (Cyprinus carpio L.). Aquaculture, 126, 265–270.

Green, B. W., Veverica, K. L., & Fitzpatrick, M. S. (1997). Fry and fingerling production. In H. Egna & C. Boyd (Eds.), Dynamics of pond aquaculture (pp. 215–243). Boca Raton, FL: CRC Press.

Green, C. C., & Kelly, A. M. (2009). Effects of the estrogen mimic genistein as a dietary component on sex differentiation and ethoxyresorufin-O-deethylase (EROD) activity in channel catfish Ictalurus punctatus. Fish Physiology and Biochemistry, 35, 377–384.

Gruber, C. W., & O’Brien, M. (2011). Uterotonic plants and their bioactive constituents. Planta Medica, 77, 207–220.
Guerrero, F., & Sepulveda, D. (2020). Saponin production from Quillaja genus species. An insight into its applications and biology. *Science Agricola*, 78(5), 1–9.

Guerrero, R. D. (1982). Control of tilapia reproduction. In R. S. V. Pullin, & R. H. L. McConnell (Eds.), *The biology and culture of tilapias* (pp. 309–316). ICLARM conference proceedings No 7, Manila, Philippines.

Gutierrez, R. M. P., Mitchell, S., & Solis, R. V. (2008). *Psidium guajava*: A review of its traditional uses, phytochemistry and pharmacology. *Journal of Ethnopharmacology*, 117(1), 1–27.

Haitham, G. A. (2018). Hormones and fish monosex farming: A spotlight on immunity. *Fish and Shellfish Immunology*, 72, 23–30.

Hartleb, M., & Nowak, A. (1990). Severe jaundice with destructive cholangitis after administration of methyltestosterone. *American Journal of Gastroenterology*, 85, 766–767.

Hasan, N., Ahmad, N., Zohrameena, S., Khalid, M., & Akhtar, J. (2016). *Asparagus racemosus*: For medicinal uses and pharmacological actions. *International Journal of Advanced Research*, 4(3), 259–267.

Hashmat, I., Azad, H., & Ahmed, A. (2012). Neem (*Azadirachta indica* A. Juss)—A nature’s drugstore: An overview. *International Research Journal of Biological Sciences*, 1(6), 76–79.

Hoga, A. C., Almeida, L. F., & Reyes, R. G. F. (2018). A review on the use of hormones in fish farming: Analytical methods to determine their residues. *CyTA—Journal of Food*, 16(1), 679–691.

Hompkin, S., Ong, S. K., & Limpiyakorn, T. (2011). Biotransformation of 17α-methyltestosterone in sediment under different electron acceptor conditions. *Chemosphere*, 82, 1401–1407.

Hoseini, M. S., Mirhaed, T. A., & Yousef, M. (2019). Application of herbal anaesthetics in aquaculture. *Reviews in Aquaculture*, 11, 550–564.

Hou, D. X., Tong, X., Terahara, N., Lou, D., & Fujii, M. (2005). Delphinidin 3-sambubioside, a hibiscus anthocyanin, induces apoptosis in human leukemia cells through reactive oxygen species-mediated mitochondrial pathway. *Archives of Biochemistry & Biophysics*, 440, 101–109.

Hulak, M., Paroulek, M., Simek, P., Kocour, M., Gela, D., Rodina, M., & Linhart, O. (2008). Water polluted by *Psidium guajava*—an example of assessment. *Journal of Ethnopharmacology*, 117, 76–79.

Hulak, M., Paroulek, M., Simek, P., Kocour, M., Gela, D., Rodina, M., & Linhart, O. (2008). Water polluted by *Psidium guajava*—an example of assessment. *Journal of Ethnopharmacology*, 117, 76–79.

Iwu, M., & Igboko, O. (1982). Flavonoids of *Aloe vera*—a nature’s drugstore: An overview. *CyTA—Journal of Food*, 16(1), 679–691.

Isah, T. (2019). Stress and defense responses in plant secondary metabolites production. *Biological Research*, 52(1), 39.

Iwu, M., & Igboho, O. (1982). Flavonoids of *Garcinia kola* seeds. *Journal of Natural Products*, 45, 650–651.

Jegede, T. (2010). Control of reproduction in *Oreochromis niloticus* (Linnaeus 1758) using *Hibiscus rosa-sinensis* (Linn.) leaf meal as a reproduction inhibitor. *Journal of Agricultural Science*, 2, 149–154.

Jegede, T. (2011). Effects of *Aloe vera* (Liliaceae) on the gonad development in Nile tilapia (*Oreochromis niloticus*) (Linnaeus 1758). In K. Fitzsimmons, & L. Liping (Eds.), *Proceedings of the 9th International symposiums on tilapia aquaculture* (pp. 222–227). Aquafish CRSP, Shanghai, China.

Jegede, T., & Fagbenro, O. (2008a). Histology of gonads in *Oreochromis niloticus* (Trewavas) fed pawpaw (*Carica papaya*) seed meal diets. In H. El-Ghobasshy, K. Fitzsimmons, & S. Diab (Eds.), *Proceedings of the 8th International Symposium on Tilapia in Aquaculture* (pp. 1135–1141). Egypt.

Jegede, T., & Fagbenro, O. (2008b). Histology of gonads in *Tilapia zillii* (Gervais) fed neem (*Azadirachta indica*) leaf meal diets. In H. El-Ghobasshy, K. Fitzsimmons, & S. Diab (Eds.), *Proceedings of the 8th International Symposium on Tilapia in Aquaculture* (pp. 1129–1134). Cairo, Egypt.

Jegede, T., & Fagbenro, O. A. (2007). Tilapia husbandry vs. midwifery: Use of anti-fertility plants. In G. E. Onibi, S. O. Agele, V. A. J. Adekunle, & M. O. Olufayo (Eds.), *Proceedings of the 3rd Annual Conference of School of Agriculture and Agricultural Technology* (pp. 118–122). Federal University of Technology Akure, Nigeria.

Jeong, H. J., Shin, Y. G., Kim, I. H., & Pezzuto, J. M. (1999). Inhibition of aromatase activity by flavonoids. *Archives of Pharmacal Research*, 22, 309–312.

Jiang, Y. (1998). Effect of petroleum ether extract of *Hibiscus rosa-sinensis* flowers on early pregnancy and some reproductive hormones in rats. *Yunnan Daxue Xuebao, Ziran Kexueban*, 20, 162–165.

Jodi, S. A., & Gabriela, B. R. (2008). Modifying gossypol in cotton (*Gossypium hirsutum* L.): A cost effective method for small seed samples. *The Journal of Cotton Science*, 12, 202–209.

Jones, J. L., & Roddick, J. G. (1988). Steroidal estrogens and androgens in relation to reproductive development in higher plants. *Journal of Plant Physiology*, 133, 510–518.

Kapinga, B. I., Limbu, M. S., Madalla, A. N., Kimaro, H. W., & Tamatamaha, A. R. (2018). *Aspilia mossambicensis* and *Azadirachta indica* medicinal leaf powders modulate physiological parameters of Nile tilapia (*Oreochromis niloticus*). *International Journal of Veterinary Science & Medicine*, 6, 31–38.

Kapinga, B. I., Limbu, M. S., Madalla, A. N., Kimaro, H. W., & Tamatamaha, A. R. (2019). Dietary *Aspilia mossambicensis* and *Azadirachta indica* supplementation alter gonadal characteristics and histology of juvenile Nile tilapia (*Oreochromis niloticus*). *Aquatculture Research*, 50, 573–580.

Kasole, J. N., Bimenya, G. S., Ojok, L., Ochieng, J., & Ogwal-Ogeng, J. W. (2010). Phytochemicals and uses of *Moringa oleifera* leaves in Ugandan rural communities. *Journal of Medicinal Plants Research*, 4(9), 753–757.
Kavitha, P., & Subramanian, P. (2011). Effect of Tribulus terrestris on monosex production in Poecilia latipinna. Current Science, 10, 100–104.

Kawo, A. H., Abdullahi, B. A., Gaiya, Z. A., Halilu, A., Babai, M., & Dakare, M. A. (2009). Preliminary phytochemical screening, proximate and elemental composition of Moringa oleifera Lam seed powder. Bayero Journal of Pure & Applied Sciences, 2(1), 96–100.

Keeley, J. E. (2012). Ecology and evolution of pine life histories. Annals of Forest Science, 69, 445–453.

Khristi, V., & Patel, V. H. (2016). Therapeutic potential of Hibiscus rosa sinensis: A review. International Journal of Nutrition and Dietetics, 4(2), 105–123.

Kiriyakit, A. (2014). Efficacy of red Kwao Krua (Butea superb Roxb.) crude extract for all male production of Nile tilapia (Oreochromis niloticus). Journal of Agricultural Technology, 10(2), 391–398.

Krishna, K. L., Paridhavi, M., & Patel, J. A. (2008). Review on nutritional, medicinal and pharmacological properties of papaya (Carica papaya Linn.). Natural Product Research, 7(4), 364–373.

Kumar, K. H. N., Chandana, E., Preehthi, S. D., & Chauhan, B. J. (2012). In vitro antimicrobial activity and phytochemical screening of Aloe vera Linn. International Journal of Current Pharmaceutical Research, 4, 45–47.

Kumar, P. S., Mishra, D., Ghosh, G., & Pand, C. S. (2010). Medicinal uses and pharmacological properties of Moringa oleifera. International Journal of Phytotherapy. 2, 210–216.

Kumar, S., Prasad, A. K., Iyer, S. V., & Vaidya, S. K. (2013). Systematic pharmacognostical, phytochemical and pharmacological review on an ethno medicinal plant, Basella alba L. Journal of Pharmacognosy & Phytotherapy, 5(4), 53–58.

Kushwaha, M. P. (2013). Effects of Aloe vera (Liliaceae) on gonad development in Nile tilapia, Oreochromis niloticus (L) during intensive aquaculture. International Journal of Fisheries & Aquatic Studies, 1(2), 56–60.

Lambole, V., & Kumar, U. (2011). Phytochemicals and acute toxicity of Moringa oleifera barks in rats. International Journal of Biomedical Research, 2(10), 548–553.

Lampariello, R. L., Cortelazzo, A., Guerranti, R., Sticozzi, C., & Valacchi, G. (2012). The magic velvet bean of Aloe vera Linn. Journal of Traditional & Complementary Medicine, 2(4), 331–339.

Langmead, L., Makins, R. J., & Rampton, D. S. (2004). Anti-inflammatory effects of Aloe vera gel in human colorectal mucosa in vitro. Alimentary Pharmacology & Therapeutics, 19, 521–527.

Leet, K. J., Gall, E. H., & Sepulveda, S. M. (2011). A review of studies on androgen and estrogen exposure in fish early life stages: Effects on gene and hormonal control of sexual differentiation. Journal of Applied Toxicology, 31, 379–398.

Logambal, S. M., Venkatalakshmi, S., & Michael, R. D. (2000). Immunostimulatory effect of leaf extract of Ocimum sanctum Linn. In Oreochromis mossambicus (peters). Hydrobiologia, 430, 113–120.

Lohiya, N. K., Mishra, P. K., Pathak, N., Manivannan, B., Bhande, S. S., Panneerdess, S., & Sriram, S. (2005). Efficacy trial on the purified compounds of the seeds of Carica Papaya for male contraception in albino rats. Reproductive Toxicology, 20, 135–148.

Mair, G. (2001). Genetics in tilapia aquaculture. Tilapia production in the Americas. In S. Subasinghe, & S. Tarlochan (Eds.), Tilapia: Production, marketing and technological developments (pp. 136–148). Proceedings of the Tilapia 2001 International Technical and Trade Conference on Tilapia, Kuala Lumpur, Malaysia.

Mair, G. C., & Little, D. C. (1991). Population control in farmed tilapias. NAGA International Center for Living Aquatic Resources Management (ICLARM), 4, 8–9.

Makkar, H. P. S., Francis, G., & Becker, K. (2007). Bioactivity of phytochemicals in some lesser-known plants and their effects and potential applications in livestock and aquaculture production systems. Animal, 1(9), 1371–1391.

Manosroi, A., & Manosroi, J. (2005). Determination of bioactive compounds in roots of different ages Poeraria mirifica, ash sway savatabhandhu and Butea superba, roxb. From various locations in Thailand. Acta Horticulturae, 680, 93–96.

Manourouva, A., Leuner, O., Tchoundjeu, Z., Van Damme, P. V., Verner, V., Pribyl, O., & Lojka, B. (2019). Medicinal potential, utilization and domestication status of bitter kola (Garcinia kola Heckel) in west and Central Africa. Forests, 10, 124.

Mansura, A. A., Ameh, D. A., Ibrahim, S., Ayo, J., & Ambali, S. F. (2009). Effect of fermented and unfermented seed extracts of Carica papaya on pre-implantation embryo development in female Wistar rats (Rattus norvegicus). Scientific Research & Essay, 4(10), 1080–1084.

Marker, R. E., Wagner, R. B., Ulshafier, P. R., Wittbecker, E. L., Goldsmith, D. P. J., & Ruof, C. H. (1947). New sources for androgenic compounds in aquatic invertebrates: A review. Environment International, 34, 531–545.

Mbahinireki, G. B., Dabrowski, K., Lee, K. J., El-Saidy, D., & Wisner, E. R. (2001). Growth, feed utilization and body composition of tilapia (Oreochromis sp.) fed with cottonseed meal–based diets in a recirculating system. Aquaculture Nutrition, 7, 189–200.

Megbowon, I., & Mojekwu, T. (2014). Tilapia sex reversal using methyl testosterone (MT) and its effect on fish, man and environment. Biotechnology, 13, 213–216.
Mukherjee, D., Ghosal, I., & Chakraborty, S. B. (2015a). Application of 17α-methyltestosterone (MT). Asian Fisheries Science, 19, 271–279.

Mishra, V. K., Sheikh, S., Agnihotri, V., & Choure, N. (2010). Effects of Asparagus racemosus, (shatavari) on mounting behaviour of male rats. International Journal of Pharmacy & Life Sciences, 1(1), 30–34.

Miyahara, M., Ishibashi, H., Inudo, M., Nishijima, H., Iuchi, T., Guillette, L. J., & Arizona, K. (2003). Estrogenic activity of a diet of estrogen receptors-alpha and -beta in an experimental animal. Journal of Health Science, 49, 48–491.

Mialila, N., Mahika, C., Kalombo, L., Swai, H., & Hilonga, A. (2015). Human food safety and environmental hazards associated with the use of methyltestosterone and other steroids in production of all-male tilapia. Environmental Science & Pollution Research, 22(7), 4922–4931.

Moundipa, P. F., Beboy, N. S. E., Zelefack, F., Ngouela, S., Tsamo, E., Schill, W. B., & Monsees, T. K. (2005). Effects of extracts from Hibiscus macroanthus and Basella alba in mature rat testis function. Journal of Ethnopharmacology, 65, 133–139.

Moundipa, P. F., Ngouela, S., Kamtchouing, P., Tsamo, E., Tchouanguep, F. M., & Carreau, S. (2006). Effects of extracts from Hibiscus macroanthus and Basella alba on testosterone production in vitro in adult rat testes slices. Asian Journal of Andrology, 8, 111–114.

Mukherjee, D., Ghosal, I., & Chakraborty, S. B. (2015a). Application of Asparagus racemosus roots for production of monosex Nile tilapia (Oreochromis niloticus). International Journal of Advanced Research, 3(9), 828–833.

Mukherjee, D., Ghosal, I., & Chakraborty, S. B. (2015b). Production of monosex Nile tilapia, (Oreochromis niloticus) using seed of Mucuna pruriens. International Organization of Scientific Research. Journal of Pharmacy & Biological Sciences, 10, 55–59.

Mukherjee, D., Ghosal, I., Hancz, C., & Chakraborty, S. B. (2018). Dietary administration of plant extracts for production of monosex tilapia: Searching a suitable alternative to synthetic steroids in tilapia culture. Turkish Journal of Fisheries & Aquatic Sciences, 18, 267–275.

Mukherjee, D., Ghosal, I., Moniruzzaman, M., De, M., & Chakraborty, S. B. (2019). Dietary administration of ethanol and methanol extracts of Withania somnifera root stimulates innate immunity, physiological parameters and growth in Nile tilapia (Oreochromis niloticus). Croatian Journal of Fisheries, 77, 106–117.

Murakami, T., Hishi, A., Matsuda, H., & Yoshikawa, M. (2000). Medicinal foodstuffs XVII. Fenugreek seed. (3): Structures of new furostanol-type steroid saponins, Trigoneosides Xa, Xb, XIIa, XIIb and XIIIa from the seeds of Egyptian Trigonella foenum-graecum L. Chemical & Pharmaceutical Bulletin, 48, 994–1000.

Murthy, D. R. K., Reddy, C. M., & Patil, S. B. (1997). Effect of benzene extract of Hibiscus rosa-sinensis on the oestrous cycle and ovarian activity in albino mice. Biological & Pharmaceutical Bulletin, 20, 756–758.

Musyimi, D. M., Ogur, J. A., & Muema, P. M. (2007). Effects of leaf and root extracts of Aspilia plant (Aspilia mossambicensis) (Oliv) wild on some selected micro-organisms. International Journal of Biological Chemistry, 1, 213–220.

Musyimi, D. M., Ogur, J. A., & Muema, P. M. (2008). Phytochemical compounds and antimicrobial activity of extracts of Aspilia plant (Aspilia mossambicensis) (Oliv) wild. International Journal of Botany, 4, 56–61.

Muthu, K., & Krishnamoorthy, P. (2011). Evaluation of androgenic activity of Mucuna pruriens in male rats. African Journal of Biotechnology, 10(66), 15017–15019.

Nairngolan, O., & Simanjuntak, J. W. (2005). Effect of methanol extract of pasak bumi (Eurycoma longifolia Jack) root on sexual behavior of white rat. Cermin Dunia Kedokteran, 146, 55–57.

Nantia, E. A., Travert, C., Manfo, F. P. T., Carreau, S., Monsees, T. K., & Moundipa, P. F. (2011). Effects of the methanol extract of Basella alba L (Basellaceae) on steroid production in Leydig cells. International Journal of Molecular Sciences, 12(1), 376–384.

National Research Council (NRC). (1992). Neem: A tree for solving global problems. Washington, DC: National Academy Press.

Nayaka, H., Londonkar, R. L., & Umesh, M. K. (2014). Evaluation of potential antifertility activity of total flavonoids, isolated from Portulaca oleracea L on female albino rats. International Journal of PharmTech Research, 6, 783–793.

Ndodo, N. D., Anuka, J. A., Esomonu, U. G., Onu, J. E., Okolo, R. U., & Onwuchekwa, C. (2013). The effects of neem (Azadirachta indica) leaves extracts, on some haematological indices of Wistar rats. IOSR Journal of Pharmacy, 3, 24–28.

Neychev, V. K., & Mitev, V. I. (2005). The aphrodisiac herb Tribulus terrestris does not influence the androgen production in young men. Journal of Ethnopharmacology, 101(1), 319–323.

Nian, C. T., Tumbokon, B. L. M., & Serrano-Jr, E. A. (2017). Pinus tabulaeformis pollen as replacement for 17α-methyltestosterone in the diet of Oreochromis niloticus larvae for sex reversal and growth. The Israeli Journal of Aquaculture – Bamidghe, 69, 1–9.

Nieves, P. M. (2017). On-farm trials of phytoandrogen for sex inversion of tilapia. Symposium proceedings. Kuroshio Science, 11(1), 8–13.
Zaki, F. M., Said, M. M., Tahoun, A.-Z., & Amer, M. (2021). Evaluation of different sex reversal treatments in red tilapia hybrid. *Egyptian Journal of Aquatic Biology & Fisheries*, 25(1), 279–292.

Zhong-han, Y., Yin, T., Zong-xun, C., & Tsao, T. H. (1994). The changes of steroidal sex hormone testosterone contents in reproductive organs of *Lilium davidii* Duch. *Acta Botanica Sinica*, 36, 215–220.

Zhou, M. (1998). Study of anti-fertility agent in petroleum extract of *Hibiscus rosasinensis* L. flower. *Yunnan Daxue Xuebao. Ziran Kexueban*, 20, 170–174.

**How to cite this article:** Abaho, I., Masembe, C., Akoll, P., & Jones, C. L. W. (2021). The use of plant extracts to control tilapia reproduction: Current status and future perspectives. *Journal of the World Aquaculture Society*, 1–27. [https://doi.org/10.1111/jwas.12863](https://doi.org/10.1111/jwas.12863)