Aquaculture in Egypt: Insights on the Current Trends and Future Perspectives for Sustainable Development

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Aquaculture in Egypt: Insights on the Current Trends and Future Perspectives for Sustainable Development

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ABSTRACT
Aquaculture has been practiced in Egypt for millennia, but modern approaches have only recently been adopted to maximize its output. Today, aquaculture production in Egypt is the largest in Africa with about one million tonnes per annum. In this review, different freshwater and marine fish species that are cultured in Egypt are reviewed; the most important species are the tilapias, followed by mullets and carps. Current practices for aquaculture in Egypt are highlighted, which include extensive, semi-intensive and intensive aquaculture systems, integrated aquaculture systems, aquaponics and rice-field aquaculture, desert aquaculture and mariculture. This review focuses on the constraints that threaten fast growing and sustainable development of aquaculture industry, such as production costs, availability of feed and seed, lack of current technologies for feed production and domestic regulations. Also, the future perspectives with regard to overcoming of these obstacles are presented.

KEYWORDS
Aquaculture; Egypt; freshwater; mariculture; sustainability

1. Introduction

Aquaculture had been practiced in Egypt for millennia, since the ancient Egyptian dynasties. A drawing on the wall of a pharaoh's tomb dating back to 2500 BC shows a man harvesting a tilapia fish from an earthen pond, documenting the first aquacultural activity in history (Bardach et al., 1972).

Fish are an important economic source of protein compared to other sources of animal protein. In developing countries, fish contribute about 30% of the total consumption of animal protein per capita (Wang et al., 2015). Aquaculture contributes more than half of the total fish production in the world (Subasinghe et al., 2009). In Egypt, the aquaculture industry provides about 77% of the total national fish production and secures more than 580,000 jobs for workers in this sector (GAFRD, 2014; Mur, 2014; El-Sayed et al., 2015; FAO, 2016a, FAO, 2016b).

The value of fish production from aquaculture exceeds USD 2 billion per year as shown in Table 1 (FAO, 2016a; FishStatJ, 2016). Development in the aquaculture industry in Egypt has been rapid in the last two decades. In the late nineties, aquaculture production contributed about 30% of the total fish production with the remaining 70% came from fisheries (Kleih et al., 2013; El-Sayed et al., 2015; Samy-Kamal, 2015). Since the beginning of the third millennium, there has been a tremendous increase in fish production with remarkable annual growth as shown in Figure 1 (FishStatJ, 2016). This rapid increase is attributed to the shift from extensive and semi-intensive aquaculture towards the intensive aquaculture systems (FAO, 2010). In addition, this has been supported by the introduction of new technologies for aquafeed production (eg. extruded feed), the application of farm best management practices (USDA, 2016) and the prioritization of aquaculture development sector by the government (Dickson et al., 2016).

Fish yields from aquaculture exceeded one million tonnes per annum ranking Egyptian aquaculture 8th among the top fish producing countries in the world by 2014 (FAO, 2016a). Accordingly, this is reflected in the total national income coming from the aquaculture industry as shown in Figure 2 (FishStatJ, 2016).

In addition, capture fish production accounts for 344,791 tonnes annually, which represents about one quarter of the total national fish production (FAO, 2016a). The largest proportion of captured fish comes from the northern lakes, which include El-Manzala, El-Borollos, Maryot and Edko lakes, with a total surface area of 1430 km^2, while the Mediterranean Sea and the

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Table 1. Production value of cultured fish and shellfish species in Egypt at 2014 (Data calculated by FishStatJ, 2016).

Fish species	Production value (USD 1000 /year)
Nile tilapia	1,039,056
Carps	449,150
Mullets	303,484
Gilthead seabream	90,558
European seabass	50,731
Penaeus shrimp	48,103
Catfish	22,933
Meagre	19,539
Total	2,023,554

Red Sea follow in second and third place, respectively (Samy-Kamal, 2015).

Aquaculture production together with production from capture fisheries (more than 1.3 million tonnes) provides an annual per capita supply of 16.5 kg fish (Hebisha and Fathi, 2014; Samy-Kamal, 2015; FAO, 2016a). At the same time, Egypt imports about 600,322 tonnes of fish and fish products every year. Most of the fish imports are mackerel (162,088 tonnes) and tuna (149,397 tonnes). Mackerel and tuna together constitute about 51.9% of the total fish imports (FishStatJ, 2016). The importation of fish and fish products is necessary to fill the gap between production and consumption. Only 25,855 tonnes of fish were exported in 2013 and most of these were from capture fisheries (FishStatJ, 2016).

Tlapia production leads the way and Egypt is the second largest producer globally after China (Norman-López and Bjorndal, 2009). Egypt produces the greatest number of fish in Africa with 4 out of every 5 fish farms in Africa located in Egypt (Shaheen, 2013). Fish production in Egypt contributes about 70.5% of the total fish production on the African continent (Sadek, 2011; FAO, 2013; Kleih et al., 2013; Samy-Kamal, 2015). The

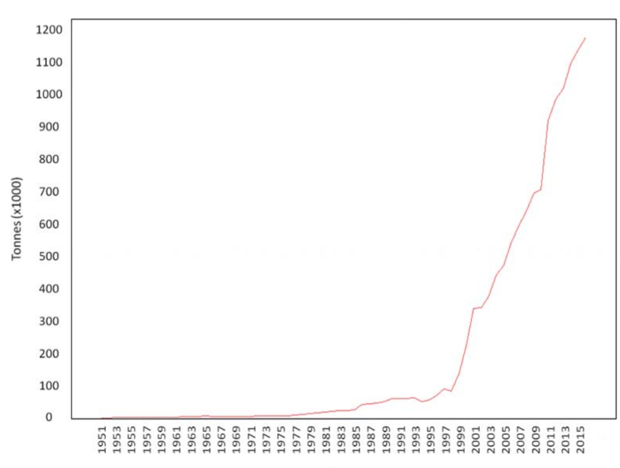

Figure 1. A chart showing the total fish production from aquaculture in Egypt (Tonnes x1000) in the period 1950-2014 (FishStatJ, 2016).

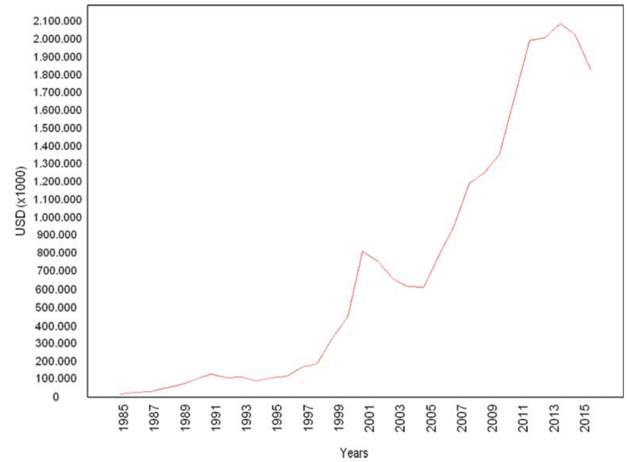

Figure 2. A chart showing the total value of aquaculture-produced fish in Egypt (USD x1000) in the period 1984-2014 (FishStatJ, 2016).

majority of fish production in Egypt comes from the private sector (GAFRD, 2012).

The Egyptian government realized the need to establish a specific authority to control aquaculture activities, so the General Authority for Fish Resources Development (GAFRD) was founded at 1982 as a subdivision under the ministry of agriculture. GAFRD is responsible for giving licenses and issuing regulations to organize the aquaculture industry.

Geographically, the majority of the fish farms are located in the Delta region in the northern part of the country and close to the Nile river banks as shown on the map (Figure 3) (FAO, 2010). The top governorates in aquaculture production are Kafr El-Sheikh, Port Said, Fayoum, Behira and Sharkia (GAFRD, 2014).

The majority of fish production is distributed fresh, since fish processing plants are still in their infancy (Rothuis et al., 2013). Primary processing, such as filleting, degutting, salting and smoking of fish are practiced in small plants for a small proportion of the total production (Macfadyen et al., 2012; Nasr-Allah et al., 2016).

In this review, the different types of cultured fish species, current practices and recent developments in aquaculture in Egypt, with reference to the major constraints facing the development and sustainability of aquaculture industry, are discussed. Future perspectives for overcoming obstacles and for further development of this sector are highlighted.

2. Common cultured fish species in Egypt

Different species of finfish and shellfish have been cultured in Egypt as shown in Table 2. Tilapia occupies the first position in the industry, with regards to production size (about 67% of the total cultured fish) and market

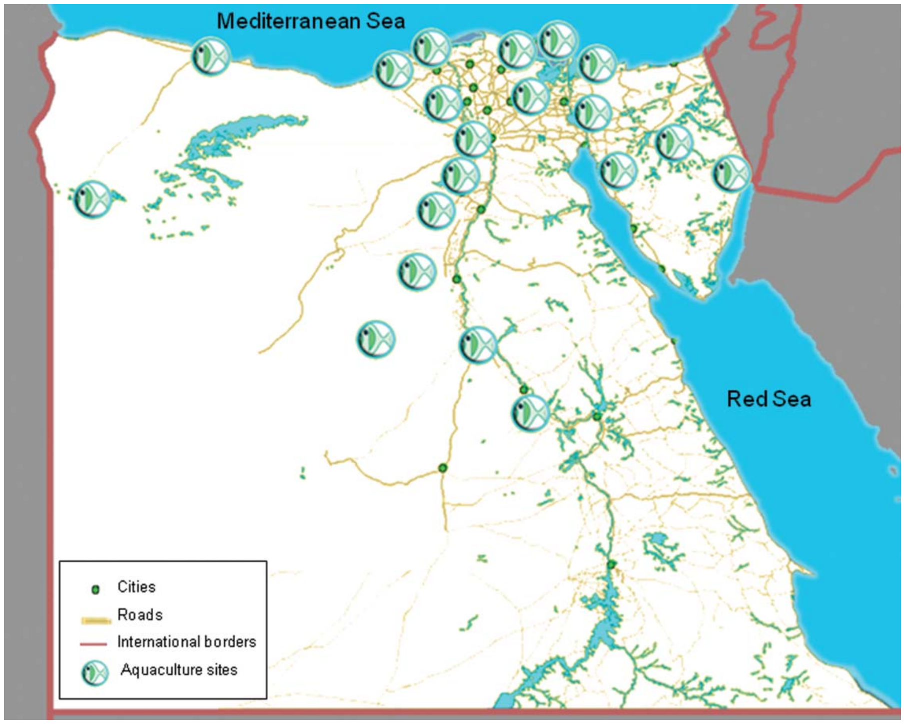

Figure 3. Egypt Map illustrating the distribution of aquaculture activity all over the country, modified from the original source with permissions from FAO (FAO, 2010).

share (El-Gayar, 2003; Nassr-Alla, 2008; GAFRD, 2014; FishStatJ, 2016; Soliman and Yacout, 2016a). Nile tilapia (*Oreochromis niloticus*), blue tilapia (*O. aureus*) and hybrid red tilapia are the most commonly cultured tilapia species in Egypt (Sadek, 2011; Hagar Dighiesh, 2014). A big advantage of tilapia rearing is that they can tolerate low quality water with low amounts of dissolved oxygen compared to other fish species (Shaheen, 2013). Interestingly, before the 1990s, tilapia was harvested as an accidental by-product from carp fish ponds (FAO, 2010) and today cultured tilapia production in Egypt ranks second in the world after China (Norman-López and Bjorndal, 2009). Production of male mono-sex fry is essential for economic reasons as they attain bigger weights with a better feed conversion rate. The application of super male (YY) technology in tilapia is one of the methods to produce all-male progeny (Beardmore et al., 2001; Shaheen, 2013). In spite of the huge tilapia production in Egypt, they are not exported due to restrictions on the exportation to USA and EU due to food safety concerns, the lack of regular monitoring and assessment of drug residues and contaminants in fish tissues. Currently, all of the tilapia production in Egypt is marketed locally (Feidi, 2004; Norman-López and Bjorndal, 2009; Rothius et al., 2013; Hebisha and Fathi, 2014; Soliman and Yacout, 2016a). Only 10 fish-producing entities in Egypt are permitted to export their production to the EU, all of them are marine fish producers (Rothius et al., 2013).

Table 2. Aquaculture production quantity in Egypt at 2014 (Data calculated by FishStatJ, 2016).

Fish species	Production quantity (Tonnes/year)
Nile tilapia	759,601
Carps	198,829
Mullets	119,645
Gilthead Seabream	16,967
European Seabass	15,167
Catfish	14,109
Penaeus shrimp	7,235
Meagre	5,884
Total	1,137,437

With about 17% of the total fish production, carp aquaculture comes in second in Egypt after tilapia (GAFRD, 2014; FishStatJ, 2016). The cultured carp species are common carp (*Cyprinus carpio*), silver carp (*Hypophthalmichthys molitrix*), and grass carp (*Ctenopharyngodon idella*) (Hagar Dighiesh, 2014). Common carp were initially introduced to Egypt from Indonesia in 1934 (El Bolock and Labib, 1967). Common carp are usually polycultured with tilapia, mullet or other carp species such as silver carp. This is to ensure maximum utilization of the natural feed in the fish pond as they have different feeding habits (Abdelghany and Ahmad, 2002; Saleh, 2008). Silver carp was imported from Japan to Egypt at 1962 (Moreau and Costa−Pierce, 1997) and it was cultured in floating cages or polycultured with tilapia and common carp as they are surface feeders (Abdelghany and Ahmad, 2002; Cardia and Lovatelli, 2007). Grass carp were imported to Egypt from Hong Kong and the USA in 1968 and 1975, respectively (Moreau and Costa−Pierce, 1997). They were introduced into irrigation canals, as an environmentally-friendly solution to combat aquatic weeds (Dubbers, et al., 1981; Khattab, et al., 1981; van Zon, 1984).

The third ranked aquaculture product from Egypt is mullet, with about 10.5% of the total cultured fish production (GAFRD, 2014). Thin-lipped mullet (*Liza ramada*), flathead grey mullet (*Mugil cephalus*), thicklip grey mullet (*Chelon labrosus*), golden grey mullet (*Liza aurata*), black keeled mullet (*Liza carinata*), leaping mullet (*Liza saliens*) and bluespot mullet (*Valamugil seheli*) are cultured in Egypt (Hagar Dighiesh, 2014; Sadek, 2016). Egypt is the worldwide leader for cultured flathead grey mullet (Sadek, 2016). They are the preferred choice for farmers among all mullet species as they can reach up to 120 cm in length (Saleh, 2008). Thin-lipped mullet contribute the largest portion of mullet production from fish farms as their seed are more available than the flat-head grey mullet (Sadek and Mires, 2000). Mullet aquaculture depends on wild caught fry that are stocked in lakes as a monoculture crop, or in polyculture with carp and tilapia (Sadek and Mires, 2000; Saleh, 2008). Thin-lipped grey mullet and grey head mullet were firstly introduced from the Mediterranean Sea for breeding in Lake Qarun, Fayoum starting in 1928 (Wimpenny and Faouzi, 1935; Faouzi, 1936). To further develop mullet aquaculture, Mousa (2010) applied hormonal induction of spawning for *L. ramada* in fresh water ponds. Blue spot mullet achieve lower growth rates than the other two mullet species as they can reach only 60 cm in length, but they have a special taste (Saleh, 2008).

Marine fish species, such as European sea bass (*Dicentrarchus labrax*) and gilthead sea bream (*Sparus aurata*) are also cultured in Egypt. The combined production from both species contributes to about 2.8% of the total fish farm production (GAFRD, 2014).

Meagre (*Argyrosomus regius*) production started in 2008 with about 2000 tonnes then reached 5,884 tonnes in 2014 (Rothius et al., 2013; FishStatJ, 2016). Aquaculture of meagre is desired due to their fast growth rates and tolerance to higher salinity levels (Rothius et al., 2013).

Aquaculture of North African catfish (*Clarias gariepinus*) makes up only 1% of the total fish production in Egypt (GAFRD, 2014). African catfish are known for their tolerance to poor water conditions and they can adapt to low quality food, while achieving high growth rates (El-Naggar, 2007). They are usually polycultured with Nile tilapia to increase fish output from the same farm, and to control undesired reproduction of tilapia (El-Naggar, 2007; Ibrahim and El Naggar, 2010).

To a lesser extent, koi carp and molly are also cultured for the ornamental fish trade; river eel production reached 4 tonnes in 2014 (Sadek, 2011; FishStatJ, 2016).

Shellfish, such as penaied shrimp and giant freshwater prawn are also cultured in semi-intensive systems (Sadek, 2011; Rothius et al., 2013; GAFRD, 2014; Hagar Dighiesh, 2014). The production of cultured shrimp in Egypt reached 7,235 tonnes per year, while an additional 54,937 tonnes of shrimps and prawns were imported during 2013 to fulfill domestic consumer demand (GAFRD, 2014; FishStatJ, 2016).

3. Types of aquaculture systems in Egypt

There are different systems for aquaculture in Egypt. The most predominant form is the semi-intensive earthen ponds for fresh water aquaculture (El-Gayar, 2003; Kleih et al., 2013). Extensive and intensive forms of aquaculture are also present and expanding. Semi-intensive and extensive aquaculture are widely applied in the earthen ponds, while for the intensive aquaculture usually concrete tanks are adopted (El-Gayar, 2003; Kleih et al., 2013).

Moreover, floating cages are one of the important forms of aquaculture, with fish production reaching 249,385 tonnes per year (GAFRD, 2012). Since the beginning of the 1990s, aquaculture cages in the Nile river branches were established for culturing of Nile tilapia and silver carp (Cardia and Lovatelli, 2007). Floating cages are common in the branches of the Nile river especially in Damietta and Rashid at the northern of Egypt with more than 37,000 operating cages all over the country (Cardia and Lovatelli, 2007; El-Sayed, 2007; GAFRD, 2012).

One of the major problems facing floating cages aquaculture is legislation. Cages were regulated and restricted in some areas by the authorities due to environmental concerns (Bostock et al., 2010; Goulding and Kamel, 2013; Rothius et al., 2013). It has been shown that the impact of cages on environment is relatively minimal and only extends 5 meters around each cage (Brigolin et al., 2016).

3.1. Extensive system

This form is the least economical, but has been practiced for centuries and remains present in some regions, commonly known as net enclosures or “Howash” (El-Gayar, 2003). The level of production in extensive system is typically low and ranges from 0.25-0.75 tonnes/ha per year (Shaheen, 2013; Soliman and Yacout, 2016a) and requires about 25 m^3 of water to produce only one kg of fish (Soliman and Yakout, 2016b). Howash is usually practiced in low-level areas especially around the northern lakes. Fish become trapped during high water levels in summer, where they remain until they reach marketable size and are harvested when the water level drops in winter (El-Gayar, 2003). Howash is now prohibited as it has a destructive effect on the environment but it is still practiced illegally in some areas (Zwirn 2002; El-Sayed, 2007). Extensive system does not require artificial aeration or any feeding and depends only on the already available natural food sources in the pond (Shaheen, 2013). Usually, it is practiced by farmers on a small scale as a family business (Suloma and Ogata, 2006). Extensive systems for shrimp culture have been practiced through stocking of shrimp larvae in Lake Qarun since 1977 till now (Sadek et al., 2002).

3.2. Semi-intensive system

The semi-intensive system is the most common form of aquaculture in Egypt, per GAFRD. Food fish from this system account for 86% of the total production, with large portions of northern lakes enclosed for semi-intensive aquaculture purposes (El-Sayed, 2007). Semi-intensive aquaculture yields range from 5 to 20 tonnes/ha of fish annually (Shaheen, 2013). Different water and energy inputs and stocking densities from farm to farm account for this variation. The water usage to produce one tonne of fish in this system is approximately 5,000-6000 m^3 (Henriksson et al., 2017). Both aquafeed and fertilizers are supplied in this system, with the feed protein requirements ranging from 10 to 30% (Soliman and Yakout, 2016b). This protein percentage is readily available in the market, as 95% of aquafeeds contain 25% crude protein (El-Sayed et al., 2015). The production from semi-intensive systems in 2012 was less than the half of 2011 production (GAFRD, 2012). This may be attributed to aquaculture intensification, which replaces both extensive and semi-intensive systems.

3.3. Intensive system

Recently, intensive systems are replacing many extensive and semi-intensive farms due to economic factors and to counteract the lack of land and water resource problems (FAO, 2010). It maximizes the use of water and land with an annual production range of 100-150 tonnes/ha (Shaheen, 2013). On benefit is only 200 m^3 are needed to produce one tonne of fish at a density of 30-35 kg/m^3 (Yakout et al., 2016).

Currently, this practice is developing well in many areas of Egypt especially in the desert (El-Sayed, 2007). Annual fish production from this system in 2012 was 3-times more than 2011 production due to the current progress towards intensification (GAFRD, 2012). This system requires artificial aeration and water pumps in addition to higher protein diets (> 30%) to cover the nutritional demands for the high number of fish (Soliman and Yakout, 2016b). The problem is only 5% of the commercial aquafeed in Egypt contains $\geq$ 30% crude protein (El-Sayed et al., 2015).

4. Integrated aquaculture

An integrated system in aquaculture is defined as the use of outputs from fish farms in other farm systems (Edwards et al., 1988; Edwards, 1998), which depend on maximizing the benefits from used water, using water effluent from fish farms to grow crops and for animal farming (Rakocy et al., 2004). Another form of integrated systems is aquaculture and fisheries integration, by stocking of cultured fish in open water to enhance the output of fisheries (Bostock et al., 2010). Integrated multitrophic culture utilizes stocking of different fish species with different feeding habits in the same pond to maximize the feed usage, for example culturing of tilapia and carp together (Abdelghany and Ahmad, 2002; Bostock et al., 2010). One practice performed by some farmers in Kafr El-Sheikh governorate involves seeding their fish ponds with wheat or alfalfa and letting them grow without harvesting to be utilized as food for the fish (El-Sayed, 2007).

In the following sections, two examples of integrated aquaculture in Egypt, aquaponics and aquaculture in rice fields, are discussed.

4.1. Aquaponics

This type of aquaculture refers to the combination of fish farming and planting of secondary crops that consume large amounts of water. This system saves water while plants grow rapidly as they get the benefit from dissolved nutrients in water effluents coming from fish farms (Rakocy, 2012). Plants purify water from dissolved phosphorus and nitrogenous substances that resulted from fish wastes and utilize them for their growth (Goada et al., 2015), which eventually increases the net income from both fish and crop production. In Egypt, the national institute of oceanography and fisheries (NIOF) established a small aquaponics model farm in 2006 to produce tilapia, vegetables and ornamental plants. This aquaponics system was studied by Essa et al., (2008) and they found that besides economic profits, a better health status was accomplished for both fish and crops with fewer incidences of disease problems. van der Heijden et al. (2012) investigated four integrated aquaponics farms in Behira, Sharkia and North Sinai governorates. Two farms used underground water for tilapia production and the other two farms utilized water from irrigation canals. The water effluent from these tilapia farms were reused for irrigation for the vegetable and fruit farms. An additional advantage of this practice is that there is no need to add fertilizers to the crops, which decreases the total farm operation costs. Recently, a group of companies are constructing aquaponics under the umbrella of the EcoFutura project (Rothius et al., 2013). Expansion in aquaponics in Egypt is essential due to water scarcity especially in arid areas (Essa et al., 2008; Goada et al., 2015; Soethoudt et al., 2016).

4.2. *Rice-fields aquaculture*

Stocking of fish and shell fish in rice fields had been practiced for a long time in Asian countries like China, Vietnam, Bangladesh, the Philippines and Indonesia (Prein, 2002). This practice resulted in maximizing profits from both fish and rice production. Also, fish reared in rice fields feed on rice pests and small insects helping control rice diseases (Cagauan, 1995; Prein, 2002). Combining aquaculture and rice farming is a promising direction towards maximizing the efficiency of land and water usage and to increase the production of both fish and rice aimed at food security, especially in rural areas (Suloma and Ogata, 2006). Rice yields in Egypt are around 6 million tonnes per annum, the highest in Africa and the Middle East (Sadek, 2013; FAO, 2016c). The high water requirements for rice agriculture combined with the problem of fresh water scarcity provoke the necessity to integrate aquaculture with the currently present rice farms. Although this type of aquaculture has been practiced in Egypt since 1984 (FAO, 2010), a big jump in fish production from rice fields occurred in 2008 (GAFRD, 2012). In most cases, the fish and rice are grown at the same time, known as the simultaneous method (Shaheen, 2013). In order to encourage farmers for this practice, GAFRD distributed free common carp seeds to rice farmers (Sadek, 2013). In Egypt, rice field aquaculture contributes to about 34,537 tonnes of fish per year, with around half of the production tilapia, and the other half comprised of catfish and common carp (Sadek, 2013; GAFRD, 2014). The highest income in rice fish aquaculture can be achieved by stocking mono-sex male tilapia and ducks in rice paddies (Salama, 2009). In 1998, Sadek and Moreau stocked freshwater prawn as a monoculture and also as a polyculture with tilapia in rice fields. Both aquaculture practices yielded a higher income than the rice fields alone (Sadek and Moreau, 1998; Marques et al., 2016) but currently there is no integrated rice-prawn aquaculture in Egypt (Marques et al., 2016).

4.3. *Desert aquaculture*

In Egypt, the majority of the land area is desert but with a large reservoir of underground water which contributes to 20% of the fresh water sources all over the country. This makes it a perfect model for applying desert aquaculture (Allam et al., 2003; Suloma and Ogata, 2006; Sadek, 2011; Rothius et al., 2013). 120 farms have been established in the Egyptian desert which contributes 13,000 tonnes per year (Sadek, 2011; Sadek, 2013). Cultured species are mainly tilapia, especially the hybrid red tilapia, as they tolerate relatively higher salinity (Stickney,1986; Watanabe et al., 1989; Sadek, 2011), followed by the African cat fish (*Clarias gariepinus*), carp, mullet, gilt head sea bream, European sea bass and ornamental fish such as koi carp and molly (Bakeer, 2006; Sadek, 2011). Aquaculture in the desert could be sustainable if a recirculating aquaculture system (RAS) was applied, to maximize the benefits from used water and to improve nutrient recycling (Martins et al., 2010). Most of the desert farms in Egypt use flow through system (FTS) which irrigate agricultural farms with effluent water from fish farms, while only a few farms apply the RAS system (Sadek, 2011). One example of a RAS systems is El-Keram integrated farm in the desert of Behira governorate (El-Guindy, 2006; Sadek, 2011). El-Keram farm utilizes the underground water for polyculture of tilapia with catfish to yield 200 tonnes fish/year, and then effluent water from the fish farm is reused to irrigate the clover fields with 7,800 tonnes/year production. The clover is used to feed 1,300 sheep head/year, which their manure is used as an organic fertilizer for the clover farm again and also as a source of biogas production for warming of tilapia hatcheries as shown in Figure 4 (El-Guindy, 2006; Sadek, 2011). This integrated system produces minimal waste and conserves fresh water usage up to 67% better than non-integrated farming (Sadek, 2011).

5. Mariculture in Egypt

Egypt is surrounded from the north and east by long coastal lines along the Mediterranean Sea (950 km) and the Red Sea (1500 km) (Sadek, 2000; Bird, 2010). Yet, mariculture in Egypt is still in its infancy and not as developed as its fresh water aquaculture (Rothius et al., 2013; Shaheen, 2013).

With concerns regarding a scarcity of fresh water resources, marine aquaculture is considered a promising direction towards increasing fish production in Egypt.

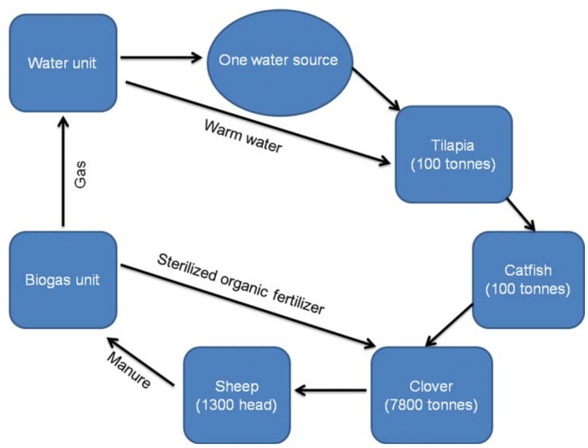

Figure 4. A diagram showing the sequential steps of integrated aquaculture in El-Keram farm using only one source of water, re-designed from the original source (El-Guindy, 2006).

Another added value of expansion in mariculture is that it would open new markets for exportation, which will reflect positively on the economy.

Mariculture activity in Egypt is mainly found in the north, Damietta (Mosallas), Port Said (Sahl El-Tina), Alexandria (King Maryut), and around the Suez Canal (Sadek, 2000). Flat head grey mullet (*Mugil cephalus*), European sea bass (*Dicentrarchus labrax*) and gilthead sea bream (*Sparus aurata*) are the main components of Egyptian mariculture (Rodger and Davies, 2000; Sadek, 2000; Essa et al., 2005; Rothius et al., 2013; GAFRD, 2014). Shrimp aquaculture is also present but on a limited scale through extensive farming in Lake Qarun, semi-intensive ponds in commercial farms and recently around the Suez Canal (Sadek et al., 2002; Megahed et al., 2013; Rothius et al., 2013; GAFRD, 2014). Mariculture of gilthead sea bream was introduced to Egypt for the first time in 1976 (Eisawy and Wassef, 1984), while the first shrimp farm was established in Alexandria at 1985 (Sadek et al., 2002).

During the last three years, there was a national and governmental focus towards the expansion of mariculture and huge projects were established beside the Suez Canal in 2016, in addition to Lake Gilion project in Kafr El-Sheikh and the East Port Said project for the production of sea bream, sea bass, mullet and shrimp (USDA, 2016).

Marine fish production in Egypt contributes to about 70% of the total production of marine fish from North Africa as most of the North African countries depend on fishery catches rather than aquaculture (Rodger and Davies, 2000, Mustapha et al., 2014). Securing fry supply for marine fish is a cornerstone in the mariculture process (Sadek and Mires, 2000). Many challenges face the development of mariculture in Egypt are discussed in the next section.

6. Constraints and obstacles facing the aquaculture industry in Egypt

To ensure sustainability of fresh water and marine aquaculture, it is important to determine the constraints and limitations facing the development of this industry and plan to alleviate or remove these issues where possible.

6.1. Fish feed

One of the most important obstacles hindering sustainable aquaculture development in Egypt is the feed, maintaining quality and reasonable price point. Fish food contributes to about 75 to 85% of the running costs of fish production (Kleih et al., 2013; Dickson et al., 2016). The fish feed prices have increased tremendously in the last few years in Egypt and comprises a large proportion of the farm costs (Macfadyen et al., 2012). This increase has been attributed to the importation of ingredients and increased foreign currency exchange rates (El-Sayed et al., 2015). The price of fish feed are continuously increasing without much increase in the price of the final product, impacting economic feasibility. Moreover, the farmers usually must buy feed on credit which puts an additional burden on them (El-Sayed et al., 2015; Eltholth et al., 2015).

In 1999, there were only 5 feed mills producing about 20,000 tonnes/year (Hebisha and Fathi, 2014). Currently, there are about 73 feed mills which produce about 1 million tonnes of aquafeed annually, and about 90% of this production comes from the private sector leaving only 10% of the production to the governmental feed mills (El-Sayed et al., 2015; USDA, 2016).

The largest aquafeed producer in Egypt is Skretting nutreco with a production of 150,000 tonnes of tilapia feed annually, in addition to their production of aquafeed for catfish, sea bream and sea bass. Aller Aqua Egypt comes in 2nd place with production of feed for freshwater and marine fish (USDA, 2016), and a 3rd production line was established recently.

Intensification requires high quality food with species-specific designation in addition to a higher percentage protein content. There is a problem in some fish farms that they use poultry and cattle feed for fish which results in poor growth of the fish (Suloma and Ogata, 2006). The advanced technologies of fish feed production have been adopted for producing specific feed for each species (Suloma and Ogata, 2006).

Most of the aquafeed is produced in the pelleted form (80-85%) and only 15-20% is extruded feed (Rothius et al., 2013; El-Sayed et al., 2015; USDA, 2016). The expansion in production of extruded feed rather than the pelleted one is important in order to increase the feed conversion rate and to avoid feed losses (Rothius et al., 2013).

6.2. Fish seed

Another obstacle facing the aquaculture industry is the seed availability and price. There are two main sources for seed: they may be obtained from hatcheries or wild catch.

The problem of seed price and accessibility usually affects mariculture more than fresh water aquaculture (Sadek, 2000). GAFRD controls the fry trade to avoid black market practices (El-Gayar, 2003). On the other hand, legislation from the 1990s allows farmers to build their own hatcheries for mono-sex tilapia fry and carp fry as the government-owned hatcheries were not able to supply the increasing demands for fry from fish farms.

The first tilapia hatchery from the private sector was established in 1992, expanding to more than 600 hatcheries currently (El-Gayar, 2003; Nassr-Alla, 2008; Rothius et al., 2013; Nasr-Allah et al., 2014a). This expansion in hatcheries allowed rapid growth for the aquaculture industry. The total fry production from freshwater fish hatcheries is 411 million units/annually (GAFRD, 2014; Soliman and Yacout, 2016a). For marine fish, there are about 73 wild-caught fry collection stations in seven governorates in Egypt (Rothius et al., 2013; GAFRD, 2014).

Important factors for sustainability of hatcheries include their ability to produce mono-sex fry which is preferred for its high feed to weight conversion rate, their capacity to produce fingerlings at the favorable size at the beginning of the season and their capability to produce fish species that can tolerate higher levels of water salinity, such as red hybrid tilapia (Stickney, 1986; El-Gayar, 2003).

A genetically selected strain of *O. niloticus* (Abbassa line) which was developed in Abbassa regional research station in Egypt, is characterized by a higher growth rate compared to the widely used Kafr El-Sheikh strain (Ibrahim et al., 2013). The Abbassa selection line (G9) is currently being distributed to many tilapia farms for production promotion (Rothius et al., 2013; Nassr-Allah et al., 2014b).

The tilapia hatcheries function seasonally in summer as the weather is more favorable for spawning and fry production. Some hatcheries use warming systems to extend their season of production but with higher operation costs (Nasr-Allah et al., 2014b). Different methods for warming of hatcheries are used, including biogas (El-Guindy, 2006; Sadek, 2011). The most economically feasible system for warming hatcheries is the hapas covered with a green house system (Nasr-Allah et al., 2014b).

6.3. Land and water availability

Another problem is the scarcity of land and water resources designated for aquacultural activities (Eltholth et al., 2015). Legislation allows construction of fish farms on the sterile lands that are not suitable for other activities like agriculture or tourism villages. Moreover, current laws prohibit usage of the Nile River for fish farms and only allow the use of drainage water from agricultural farms which reflects on water quality. The license to establish an aquaculture facility must be issued from the ministry of agriculture (El-Gayar, 2003; Rothius et al., 2013; Hebisha and Fathi, 2014).

Water problems arise from irrigation drainage that is influenced by agricultural seasons, variations in water levels all year, and that it may be polluted with agricultural pesticides (Eltholth et al., 2015). Water quality is degrading especially when there is no proper designation for water inlets and outlets (Rothius et al., 2013). Aeration of ponds improves water quality and increases biofloc formation (Soliman and Yakout 2016b).

Khalil and Hussein (1997) conducted a field experiment for growing *O. niloticus* on treated sewage water. They observed higher growth rates when compared with the fish reared on other water sources but concerns included higher microbial load in the gills and heavy metal accumulation in the liver.

Regarding the issue of land availability, freshwater fish farms face competition from agriculture, using land not sustainable for crop farming (El-Gayar, 2003; Suloma and Ogata, 2006; Hebisha and Fathi, 2014). Mariculture also faces competition from the expansion of touristic villages and urbanization on the coasts of the Mediterranean and the Red Sea (El-Gayar, 2003). As explained previously in this review, desert aquaculture could serve as a promising alternative without land competition because of the vast deserts in Egypt.

6.4. Infectious diseases

Parasites, bacteria, fungi and viruses are incriminated for high economic losses and mortalities in fish farms. Besides mortalities, fish pathogens have a negative impact on feed conversion rates and total body weights of recovered fish post infection.

Summer mortalities commonly occur especially in tilapias from June to October every year with economic losses up to USD 100 million (Fathi et al., 2017). This has been linked to infectious diseases but no definite causative agent has yet been found.

Parasites are the most commonly found pathogen with a prevalence rate up to 80% of the total infections in fish on farms (Shaheen, 2013). Common parasites in fish include monogenetic and digenetic trematodes, *Ichthyophthirius multifilis*, *Trichodina* spp., *Chilodonella hexasticha* and encysted metacercariae (Aly, 2013; Shaheen, 2013). Encysted metacercaria of *Heterophyes heterophyes* and other heterophyids can infect humans after consuming infested fish muscles (Yousef and Uga, 2014).

Bacterial infections in fish are also present with a higher incidence of mortalities when compared to the parasitic infestations. Infections with *Aeromonas hydrophila, Flavobacterium columnaris Pseudomonas fluorescens, Yersinia ruckeri, Edwarsiella tarda*, *Edwardsiella ictaluri*, *Vibrio* spp. and *Streptococcus* spp. were reported in Egyptian farms (Moustafa, et al., 2010; Aly, 2013; Shaheen, 2013, Abdelsalam et al., 2017).

To a lesser extent, there is an incidence of mycotic infections which are mostly induced by *Saprolegnia* spp., *Ichthyophonus hoferi* and *Branchiomyces* spp. (Shaheen, 2013). According to Saad et al. (2014), *A. hydrophila* and *Saprolegnia* spp. infections and their co-infection are the most important diseases in Egyptian fish farms.

There is not enough information about the real map of viral infections and distribution in fish in Egypt. The incidence of spring viremia of carp virus (SVCV) and infectious pancreatic necrosis (IPN) were reported (Aly, 2013). Recently, Tilapia Lake Virus (TiLV) was isolated from tilapia in Egypt and it was proposed to play a role in the summer mortalities in fish farms (Fathi et al., 2017). The absence of established surveillance program for monitoring of viral infections in fish may be the cause of the lack of information to this point.

To conclude the epidemiologic situation in Egyptian aquaculture, parasitic infestations constitute the highest prevalence rate while bacterial infections infduce the highest mortalities.

6.5. Lack of technical training for aquaculture personnel

Usually fish farmers don't receive specialized or updated technical training for their best practices to maximize yield and profits from the farm. Dickson et al. (2016) performed a technical training sessions for 3 years aiming to achieve the best management practice (BMP) in fish farms. The training focused on aspects of stocking density management and effective utilization of fish feed and fertilizers. The farms which applied BMP achieved higher profits when compared to the control farms.

Concerning shrimp aquaculture, the constraints facing this sector are much similar to marine fish aquaculture and they are summarized as follows: the availability of shrimp larvae, the competition on land from tourism, petroleum mining, the availability of high quality and specific feed, and the lack of trained personnel (Sadek et al., 2002; Megahed et al., 2013).

7. Conclusion and future perspectives

Aquaculture in Egypt is a promising field with a great capability for expansion and development. In order to maximize the total production from fish farms and to ensure the sustainability of aquaculture industry in Egypt, the following points were concluded from the current situation:

- Expansion in intensive farming and integrated aquaculture, especially in the desert, as it will be the best investment of these arid lands and underground water with avoidance of resource competition with agriculture and urban development. In addition to the added value of water conservation, this provides maximum utilization of resources using a RAS system to overcome the problem of water limitation.
- Application of recent technologies in fish feed production, especially extruded feed with an emphasis on good quality feed components and high protein percentage necessary for intensification and species-specific feed.
- Introducing recent technologies in hatcheries management, in order to have good quality fish and shrimp seeds at reasonable costs.
- Establishment of a regular system for monitoring and assessing fish tissues are free from diseases, drug residues and toxic contaminants, for the sake of public health and to open up new markets for exportation of fish and fish products.
- Biosecurity measures should be adopted in fish farms with strategies to prevent and control the disease incidence through vaccination, medications and genetic selection of disease-resistant breeds.
- Intensive technical training for workers in the field of aquaculture aimed at achieving the best management practice (BMP), especially in the fish feed mills and hatcheries.
- Modification of current legislation which may hinder the development of aquaculture such as banning of fresh water usage from the Nile River for aquaculture.
- Expansion of the mariculture industry along the coast lines of the Mediterranean and Red Sea, the Suez Canal, in addition to Lake Qarun and the Fayoum desert as well.

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