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REVIEW

Future of Rice-Fish Culture, Desert Aquaculture and Feed Development in Africa: The Case of Egypt as the Leading Country in Africa

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Abstract

World aquaculture production in 2002 reached 39.8 million metric tons (Mt). However, despite a general understanding that the advancement of aquaculture is very important for food security and poverty alleviation, aquaculture in Africa is insignificant compared to the rest of the world. African aquaculture contributed only 1.2% (463×10^3 Mt) of world aquaculture production. Moreover, our calculation based on FAO statistics revealed that the average per capita consumption of fish in Africa decreased from 9 kg in 1990 to 7.8 kg in 2001. This decrease in the per capita consumption of fish appears to be a threatening sign for food security in Africa. There are many political, economic and technical issues that are obstructing the development and promotion of aquaculture in Africa. Egypt, the desert but rice producing country, has a long history of aquaculture and is the leading producer, especially of freshwater aquaculture in Africa. Total aquaculture production in Egypt in 2002 was 376×10^3 Mt, which supplied 81% of that in Africa. In the present review, based on the case of Egypt, we propose measures and research areas to develop and promote rice-fish culture and desert aquaculture. Rice-fish culture is a model of aquaculture styles for wet and pluvial regions, and desert aquaculture is also a model for arid and semi-arid regions not only in Egypt but also for other African countries. Poor knowledge on fish feeds and feeding technology is one of the major constraints in the expansion of aquaculture. In order to improve and increase the productivity of aquaculture in Africa, we propose measures and research subjects for developing supplementary and complete feeds using regional ingredients.

Discipline: Aquaculture
Additional key words: carp, catfish, mullet, tilapia

Introduction

The fish production sector is very important not only as an animal protein source to ensure food security but also to improve employment and income for poverty elimination in developing countries. Total world production of capture fisheries and aquaculture amounted to about 133.0 million metric tons (Mt) in 2002, providing an apparent per capita supply of 16.3 kg. World aquaculture production in 2002 was 39.8 million Mt, and more than a half of the aquaculture production continues to come from the freshwater environment (57.7% by quantity and 48.4% by value)[8].

In 2002, total fish production in Africa was 7.5 million Mt, which was 5.6% of world production (Fig. 1). Four countries, Egypt, Morocco, South Africa, and Nigeria contributed 41% of the African total in 2002, while the other 50 African countries contributed the remaining 59%. On the other hand, aquaculture in Africa is fairly insignificant compared to the rest of the world. African aquaculture contributed merely 1.2% (463×10^3 Mt) of total world aquaculture production. Only four countries, Egypt, Nigeria, Madagascar, and Ghana, represented

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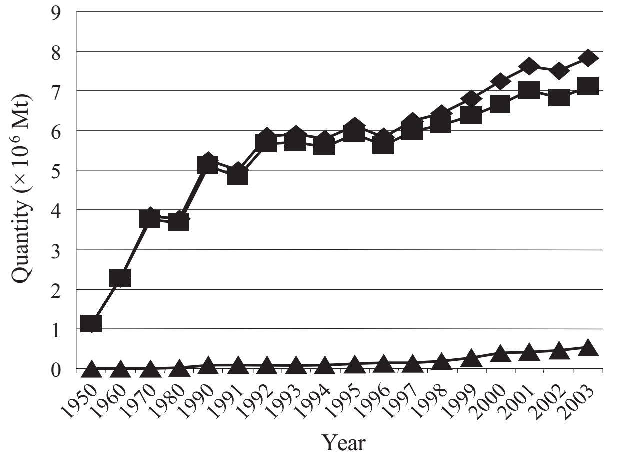

Fig. 1. Capture fisheries and aquaculture productivities in Africa

Source: FAO (2004)[8].

: Total production. : Capture fisheries.

: Aquaculture.

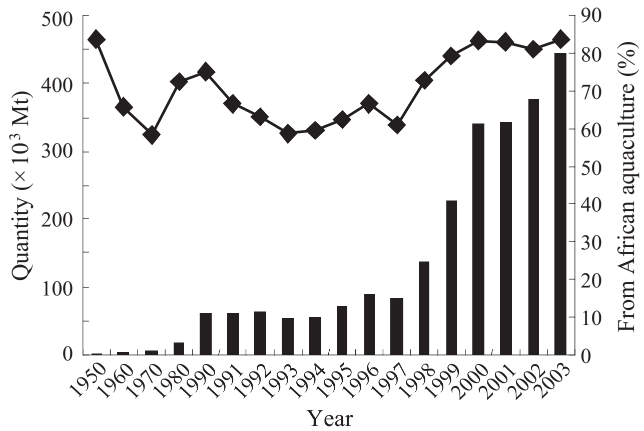

Fig. 2. Egyptian aquaculture production and its % contribution in Africa

: Aquaculture production in Egypt.

: % contribution in Africa.

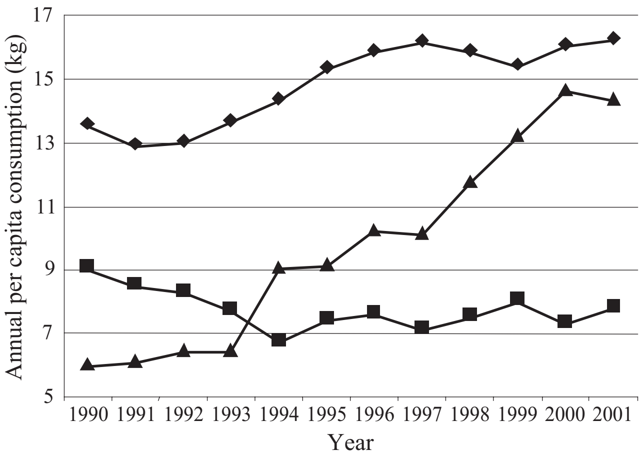

Fig. 3. Total per capita consumption of fish (kg) in world, Africa and Egypt

: World. : Africa. : Egypt.

90% of the continental total aquaculture production. Total aquaculture production in Egypt in 2002 was 376 × 10^3 Mt, which supplied 81% of that in Africa (Fig. 2). The total aquaculture production has increased from 82 × 10^3 Mt in 1990 to 463 × 10^3 Mt in 2002 (Δ381 × 10^3 Mt) in Africa and from 62 × 10^3 Mt in 1990 to 376 × 10^3 Mt in 2002 (Δ314 × 10^3 Mt) in Egypt, respectively. Egypt contributed 82.4% of the increase during the period between 1990 and 2002 in Africa. Egyptian per capita fish consumption more than doubled from below 7 kg in 1990 to over 14 kg in 2002 as shown in Fig. 3. However, if we calculate the average per capita consumption in Africa, the average per capita consumption shows the opposite trend: it tends to drop slightly from 9 kg in 1990 to 7.8 kg in 2001, despite the fact that total fisheries production in Africa increased during this period. This decrease in per capita consumption in the other 53 countries appears serious. This is a consequence of the increasing gap between supply and demand due to the rapidly growing population, stagnating supplies from fisheries, poor aquaculture implementation, and increased exports of high-value fisheries commodities. The decrease in the per capita consumption of fish seems to be a threatening sign for food security in Africa.

Egypt is the leading aquaculture country, especially freshwater aquaculture, in Africa. The national government aims to increase the annual per capita consumption of fish and to ensure the availability of low-priced fish to the consumer by increasing national production. The government gives aquaculture development high priority in the national development plan. However, there are still many issues to solve in the development of the aquaculture industry. According to Zwirn[26], inequity in access to capital and political influence may be the most salient obstacle to the long-term development of aquaculture in Egypt. Needless to say, not only technical researches but also socio-economic and political analyses are important to identify issues and solve the issues in aquaculture development. Nevertheless, it is also the case that for future sustainable development there are still issues such as poor production technology, an underdeveloped feed industry and the competition for land/water availability with agriculture, which are able to be solved through technology development. In the present review, we will first introduce the characteristics of African and Egyptian aquaculture. Next, we will introduce rice-fish culture and desert aquaculture which are being practiced or are under experiment in Egypt. We strongly believe that rice-fish culture is a model of aquaculture styles for wet and pluvial regions, and that desert aquaculture is also a model for arid/semi-arid regions not only in Egypt but also in the other African countries. We will propose measures and research subjects to develop and extend rice-fish culture and desert aquaculture. Finally, we will describe the necessity of feed development research and propose research areas to develop aquaculture industry in Africa as well as in Egypt.

History and characteristics of African and Egyptian aquaculture

Carvings on an ancient tomb (3,000 BC) show that Egyptians were farming tilapia[14]. In Madagascar, traditional water management for aquaculture began in the 18th century under the reign of King Andrianampoinimerina[9]. Although Southern Zaire first succeeded in pond production of tilapias in 1946[5], the modern concept of aquaculture was introduced from Europe into African countries as a measure of the colonial administrations[9]. In the 1950s, about 300,000 fish ponds were operating by mainly rearing tilapia in about 20 African countries[18,21]. However, pond aquaculture did not progress further, and many ponds were abandoned due to poor husbandry, poor returns, lack of seed fish, and competition for water resources with agricultural farmers. According to Meschkat[18], "Policymakers misjudged the motivation of the rural fish farmers and created the myth that the rural farmer will willingly take up fish farming for food security or as a source of protein for their family. This is most likely not the case, the primary motivation of the rural fish farmer generally being income generation". Since the late 60s, African aquaculture has started to develop again under the increased technical assistance which was financed by multilateral and bilateral donors[9]. More than US$500 million have been provided to Africa over the past 20 years to promote aquaculture development.

Now despite the existence of aquaculture for the past 55 years in Africa, the total aquaculture output is still very low compared with the production from the capture fisheries (Fig. 1). This results from a lack of regular planning and exercises for aquaculture development in most African countries. African aquaculture is still a secondary and part-time activity in small farms with small freshwater ponds, and it is still an industry in its early developmental stage. Freshwater aquaculture in ponds is the most widespread type of aquaculture in Africa today, and it produces the greatest amount of fish equivalent to 80% of the total aquaculture harvests. Thus freshwater aquaculture is the most promising avenue to increase aquaculture production in the short and medium term. Anetekhai[2] reported that freshwater aquaculture is the most understood form in Africa, but that the inadequate and expensive feed is one of the major factors affecting poor performance, as described later. The dominant countries of freshwater aquaculture are Egypt and Nigeria. Although aquaculture is thus mostly practiced in freshwater environments, there is an upward trend in the use of brackish and marine waters in coastal countries, particularly in Nigeria and Kenya[5]. The main aquaculture species in Africa are tilapia, catfish, common carp, other cyprinids, mussels, mullet, shrimps, and seaweed.

Extensive systems are the oldest and most widespread systems in Africa. Extensive aquaculture, a secondary part time activity, is carried out as family-based aquaculture by rural small-scale farmers using small freshwater ponds. The production of this system depends on natural food with or without fertilization of substrates using manure or organic wastes that increase natural food availability. The main characteristics of this system are low input in fish density and very poor output. On the other hand, there are plenty of underdeveloped small water bodies in African rural areas, especially in Sub-Saharan countries and in the Nile Valley/Delta in Egypt. However, it is difficult to practice modern-advanced aquaculture (intensive aquaculture) in these small rural water bodies. We should reconsider the potential importance of small water bodies as extensive aquaculture space[5], even if extensive system results in poor output.

The semi-intensive system is preferred by small and large-scale commercial farmers who are increasingly contributing to the development of aquaculture in a number of countries, especially in Egypt, which represented about 84% of total aquaculture production in Africa. In this system, fish density is usually higher than in extensive culture, and farmers use organic fertilization plus some supplementary feeds from locally available agricultural by-products. However, the output performance from this system is still relatively low compared to that of other continents, because of the lack of feed and feeding knowledge. The intensive system with high stocking density is dependent on big capital investment and complete formulated feeds which represent 40–60% of the production costs. This is the most advanced system in Africa but is still rarely practiced successfully. We should pay more attention to the intensive system to improve fish production in Africa in the near future.

In Egypt, aquaculture has been practiced for thousands of years, but practical aquaculture started in the 1950s with very low production. The annual average production between 1950 and 1970 was less than 15,000 Mt as shown in Fig. 2. Progress was very slow until 1978, when the national government established public aquaculture farms and hatcheries in Zawia, Barsiqu and Manzala. The government sector has played a major role in producing fish fry of carp and tilapia and providing them to the private sector. The establishment of fry production and fry supply systems by the government drastically motivated aquaculture in the private sector. Then, the private sector started to grow and the aquaculture production in Egypt has increased progressively (Fig. 2), and in 2003 the aquaculture production reached 445,180 Mt (by FISHSTAT Plus, FAO Fisheries, Software ver. 2.3, 2001). Egypt still continues to be the leading aquaculture country in Africa, contributing approximately 84% (by FISHSTAT Plus, FAO Fisheries, Software ver. 2.3, 2001) of the total aquaculture production of the continent in 2003 (Fig. 2).

In Egypt, aquaculture production is based on semi-intensive systems of freshwater and brackish water farms with average production/ha of about 11.9–19.0 Mt. The main aquaculture species are freshwater fish, tilapias—mainly *Oreochromis niloticus*, carps—mostly *Cyprinus carpio*, mullets—mainly *Mugil ramada* and *M. cephalus*, and African catfish—*Clarias gariepinus*. Most of the aquaculture products are consumed locally. Although intensive aquaculture in Egypt is still scarce, tilapia and mullet are mainly farmed in concrete or fiber-reinforced plastic tanks. Intensive aquaculture systems would become potentially more important to ensure food security in Egypt, when we consider its production efficiency and production capacity.

The availability of land and water for fish culture is a major constraint to the expansion of freshwater aquaculture in Egypt, and the government prohibits the use of major (national) irrigation canals for fish culture. As described later, Egypt has vast groundwater resources[1]. Oasis water in the west desert, Bahariya, Farafra, Dakhla, Kharga, and Siwa, comes from underground natural wells and springs, which are brackish water with a salinity range of 1.5 ppt to 8 ppt. Research institutions have to pay more attention to aquaculture in the desert and search for new integrated systems with agriculture crops. There is a need for more thorough information based on the long-term availability of land and water resources.

Rice-fish culture in Egypt

Rice-fish culture can provide additional food and income, can be practiced with small investment and can maximize the use of existing resources. Rice-fish culture is one way to increase the economic benefits from rice fields and develop freshwater fisheries. Rice-fish culture has been practiced in 28 countries on six continents: Africa, Asia, Australia, Europe, North America, and South America. Egypt is the largest rice producer in the Middle East and African countries. Egyptian rice yield is one of the highest in the world (9.1 Mt per ha in 2001). Expansion of fish production in rice fields is one of the national aquaculture plans in Egypt. Egypt started with a capture-type of rice-fish culture based totally on occasional fish stock from the irrigation water[11]. Field experiments of rice-fish culture using common carp in the early 1970s led to encouraging results[7]. In 1995, rice-fish culture was practiced in 172,769 ha and contributed about 32% of the total aquaculture production in the country[22]. Since then, 58,000 ha of farmland have been added producing 7,000 Mt of common carp in 1997[24]. Thus, rice-fish culture has contributed to the increase of total aquaculture production in Egypt. The improved rice-fish culture can effectively give a great contribution in a short time, and it is very important not only for Egypt but also for all African countries where the rice farming exists. Here, we propose measures and research areas to evolve traditional rice-fish culture (capture style or extensive style) into advanced but sustainable rice-fish culture (semi-intensive style) for maximizing fish production from rice-fish culture in harmony with the rice-field environment.

1. Improvement of traditional system

The output performance from traditional rice-fish culture (capture style) is extremely low, and some modifications are needed to maximize the output performance. The following research should be conducted:

- Estimation of carrying capacity and production capacity of each rice field.
- Determination of optimum stocking size and stocking density.
- Establishment of stocking/harvesting system according to rice crop cycle.
- Interaction between rice production and fish production (fertilizer, pesticides, soil quality etc.).
- Establishment of management technologies of rice culture and rice field under fish culture.

2. Expansion of the area of rice-fish culture with improved technology

The area of rice-fish culture should be expanded through technology improvement, technical training and increased funding. Technology improvement should be according to regional rice crop style in newly expanded areas. In principal, there are two ways to combine rice and fish: "growing rice and raising fish simultaneously only for the period of rice culture in the same field" and "rotating rice and fish".

The extensive style of "growing rice and raising fish simultaneously only for the period of rice culture in the same field" is traditional and most popular in Egypt. The advantage of this style is that sophisticated engineering, facilities and supplementary feeds are not needed, while the disadvantage is that the growth period of the fish is comparatively short and the harvested fish are small. In the style of "rotating rice and fish", rice and fish are alternatively raised in the same rice field. The fallowed fields after rice harvest can be used for fish culture, if the water can be available for fish culture even for the fallow season. This rotation method makes full use of the rice fields after rice harvest until the next rice crop. Fingerlings are released right after rice harvest. The straw decay may make the water suitable for fish growth, and supplementary feeding may further enhance it. As the growth period is relatively longer, a higher output of fish can be estimated compared with that of the traditional style. However, in Egypt, "rotating rice and fish" might be not accepted, because farmers use rice fields for other crop culture during the fallow period. In practice, farmers would decide if they accept "rotating rice and fish", according to the results of socio-economic analyses. The new techniques of agriculture-engineering should also be developed to make rice-fish culture adaptable to local conditions. Effective engineering facilities help avoid conflicts between rice and fish and improve the ability of the rice field to resist drought and flood. Rice production is therefore guaranteed along with substantial increases in both rice and fish harvests. Thus, the following research and measures should be included:

- Expansion of the area of rice-fish culture.
- Extension of sustainable technologies of rice-fish culture to new areas.
- Socio-economic analysis to investigate which culture style is best for each rural area (the family-based economy, the village-based economy, the location, rice crop style etc.).
- Establishment of fry production system and fry delivery system according to each rice crop style (because there may be a time lag between rice plant and fry/fingerling production).
- Development of agriculture-engineering suitable for each regional condition.

3. Development of supplementary feeds and feeding technology in rice-fish culture

The presence and abundance of food organisms are very important factors in rice-fish culture[10]. Food preferences vary among species as well as within species with developmental stage. For example, common carp have the widest range in preferences and can feed on a variety of plant and animal foods[11]. Tilapia species also have varying feeding habits. For example, *O. mossambicus* and *Tilapia zillii* can consume weeds even in a pond or rice field situation[12], *T. zillii* being regarded as more superior as a natural weedicide. Although Nile tilapia appears to prefer certain species of algae[19], this species is known to feed on chopped terrestrial plants such as napier grass and aquatic plants including water spinach *Ipomoea aquatica* as well as bran, cassava or termites. The rice field ecosystem is rich in phytoplankton, zooplankton, macrophyton, benthos, detritus, and bacteria.

However, to increase the output performance from the same area and at the same density it is necessary to apply supplementary feeds. Farmers use fertilizers to increase the naturally occurring food organisms in the rice field and supplements to feed the fish directly. Locally available supplementary feeds may consist of wheat bran, copra meal, wheat flour, oilseed cakes (for instance, rapeseed, peanuts and soybean), grasses, green fodder, maize bran, napier grass, chicken waste, and/or kitchen waste. Indeed, Wang and Zhang[23] showed that the use of supplementary feeds resulted in higher survival rates and improved production. Egypt has many kinds of agricultural by-products, such as rice bran, oil seeds, and poultry by-products which are promising as supplementary feeds in Egyptian rice-fish culture. However, the knowledge on how to use and how to process the agricultural by-products is lacking. Moreover, there is little knowledge on feeding level, feeding frequency and feeding time in rice-fish culture. Thus, the following research is needed to develop feeding systems in rice-fish culture:

- Elucidation of feeding habits and natural food availability in rice fields.
- Identification of locally available supplements.
- Development of the processing methods of fish feeds using the agricultural by-products.
- Determination of their nutritional value by field-feeding trials.
- Establishment of suitable feeding regimes (feeding level, feeding frequency and feeding time) in rice-fish culture.

4. Introduction of new species

In Egypt, common carp and tilapia (*Oreochromis niloticus*) are the main species used in traditional rice-fish culture. The introduction of new species should also be considered. According to Hora & Pillay[15] and Khoo & Tan[16], new species should meet the following requirements: availability of quality fry and fingerlings in desired quantity, feeding habits have to be herbivorous or omnivorous, capable of tolerating a harsh environment characterized by shallow water, high and variable temperatures, low oxygen levels and high turbidity, and have good performance under poor conditions. Our recommendation of new species is as follows.

- Catfish: *Clarias gariepinus* gives high yields but its

price is low due to poor acceptance by consumers. The hybrid between *C. gariepinus* and local catfish *C. fuscus* is better, because of improved taste and high tolerance of undesirable environment conditions.
- Gourami: *Trichogaster pectoralis* is numerically the most important species. This species and the three-spot gourami (*T. trichopterus*) are herbivore/planktivore and occupy the lower rung in the food chain.
- Climbing perch: *Anabas testudineus* is an insectivore.
- Freshwater prawn: African *Macrobrachium* is a relatively new aquaculture species.

Desert aquaculture

Limited water is the biggest constraint for aquaculture in arid/semi-arid regions. There are some problems in the availability and competition of land and water with agriculture. Recently, more attention is given to "Desert Aquaculture" that has been developed in Israel. For instance, in Negev desert (Southern Israel), which possesses tremendous amounts of saline underground and geothermal water, super-intensive fish farms have been constructed under financial assistance of the Israeli Ministry of Agriculture. Hybrid-tilapia are cultured, and the production presently reaches average annual yields of 20–27 kg/m^3 [20]. According to Kolkovski et al.[17], "desert aquaculture means the aquaculture production of fish and aquatic animals in arid areas". The main goal of aquaculture in the desert is to utilize productively and maximally the water resources of oases and groundwater for an integrated aquaculture-agriculture system. Desert aquaculture appears to give water resources an economical value rather than a competition in water consumption between aquaculture and agriculture. The aquaculture-agriculture system in the desert could enable us to produce highly priced off-season fish, vegetables and fruits all the year round.

Egypt has suitable natural conditions for desert aquaculture. Egypt has vast resources of groundwater[1]. Fresh groundwater resources in Egypt contribute 20% to the potential water resources in Egypt. One of the groundwater resources is the Nile Valley and Delta system with the storage capacities of 200 billion m^3 and 300 billion m^3, respectively. Oasis water in the west desert, Bahariya, Farafra, Dakhla, Kharga, and Siwa, comes from underground natural wells and springs. The Faculty of Agriculture, Cairo University (Cairo, Egypt) launched a test plant of a desert aquaculture unit in a desert of the Wadi Natron (between Cairo and Alexandria). Regarding the surface water in Egypt, the government is driving a national plan (the Toshka Development Plan) to convert some of 225,000 ha of desert into farmland by constructing 240 km of irrigation waterways from Lake Nasser to the desert area. One of the goals of this plan is to establish agriculture, livestock, poultry, and aquaculture industries to meet local and export demands. The Central Laboratory for Aquaculture Research, which is located in the Nile River Delta (Abbassa, Egypt: arid area), uses the surface water from the Ismalia canal originating from the Nile River. Egypt has a warm and hot ambient climate, which can be a natural heater, and pre-warm groundwater stored in reservoir ponds. Moreover, Egypt can provide cheap supporting infrastructure: lands, electricity and fuels.

Needless to say, before taking an approach to desert aquaculture, we should identify sites where aquaculture and agriculture can be integrated. We should evaluate local economic conditions including water quality and quantity, soil condition, topography, and climate. In arid regions in Africa, desert aquaculture, which has succeeded in Israel, will need modifications to become a promising production system according to each economic situation.

Fig. 4 illustrates a model of desert aquaculture in Egypt. Since we can directly pump oasis water which comes from groundwater unlike the case of Negev (Israel) (well depth: 550–1,000 m), high investments are not required to construct pump systems. Israel is using super-intensive, indoor, closed (circulation) systems in greenhouses, where 10% of the aquaculture water is daily exchanged for agriculture. This style increases the production costs and market prices of fish and agricultural products due to a high management cost including water. Considering that one of our missions is to produce and provide low-priced food to people, Egypt and other African countries are not able to accept the same style as does Israel. As illustrated in Fig. 4, our model adopts an outdoor open system, which leads to low construction cost, low supporting infrastructure cost and low maintenance cost compared to a super-intensive system. In Egypt, groundwater or surface water is now separately used for agriculture, aquaculture and other industries including human consumption. Desert agriculture in Egypt is presently consuming water without fish culture. Although we need a huge amount of water for aquaculture practice, fish themselves do not waste a large amount of water for their growth (fish consume less water than poultry). Irrespective of the existence of aquaculture practice, water requirement for desert agriculture will not change so much. When we consider the limited water availability and the productive and efficient use of water in arid regions, aquaculture and agriculture should be at least integrated to one unit. Here, we propose a model that well water is first used for fish culture, and the drain

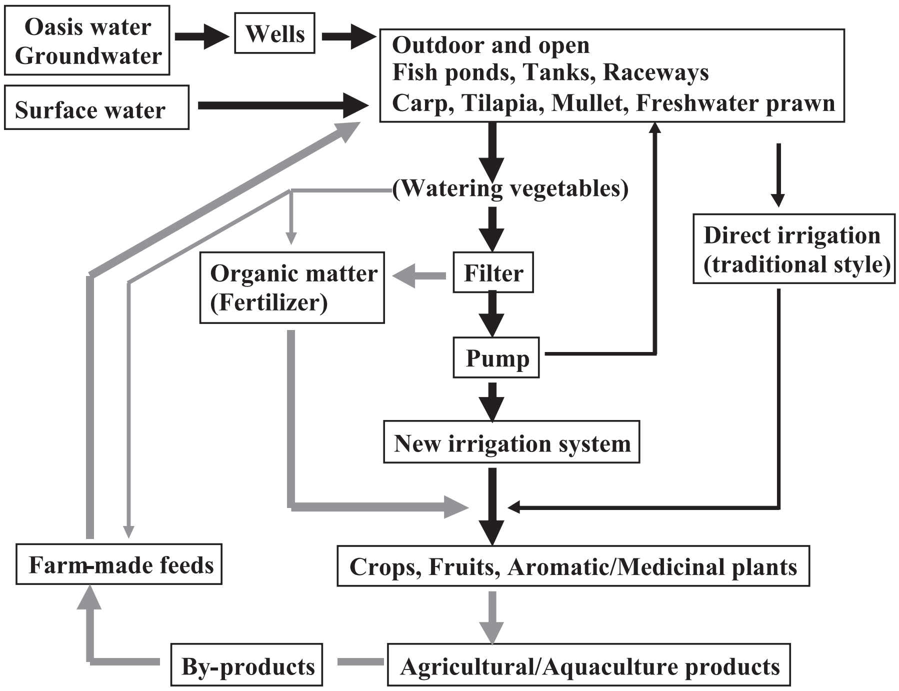

Fig. 4. A model of desert aquaculture in Egypt, and possibly in other arid regions in Africa

water is used to irrigate with or without filtration. Thus, we can produce and provide low-priced fish and agricultural products without an increase in water consumption, using an integrated aquaculture-agriculture unit. The candidate species are tilapia, mullet and common carp, and freshwater prawn (*Macrobrachium*) might become a candidate, if we can establish a hatchery.

Development of feeds and feeding technologies

1. The necessity of feeds development for freshwater aquaculture

Needless to say, external assistance continues to be essential for further development. Some projects supported by FAO and Japan in Africa focused on improving aquaculture techniques and aquaculture production by breeding a strain with high growth, while little attention has been paid to improving fish feeds and feeding technologies. For example, in 2002, Japan through the World Fish Center (Penang, Malaysia) has supported research on genetics and aquaculture in Africa[3]. Two projects were conducted. Project 1 was aimed at breeding tilapia with fast growth. Project 2 was focusing on improving aquaculture management techniques. Through these projects, the necessity of the development in feeds, especially local farm-made feeds, and feeding technology has been emphasized as the second step to increase production capacity and efficiency under unstable/hostile and poverty environments. Poor development of fish feed sectors is the second major constraint to aquaculture development in Egypt and Africa. Our opinion is that more attention should be given to the rural production system with low cost feeds which can be processed from regional ingredients.

In the aquaculture industry, feed development is critical because feeds represent 40%–60% of the production costs. Formulated and complete fish feeds based on fish nutrition have advanced dramatically in recent years, which promotes optimal fish growth and health. The development of new species-specific diets supports the aquaculture industry. At present, the high cost and low quality of fish feeds are major limiting factors in the development of aquaculture in Africa, and this situation is likely to remain unsolved even in the near future. Therefore, basic and practical research that can reduce the cost of fish feeds without lowering feed efficiency will be crucial to the successful development of aquaculture in Africa. So far, feed research has been concentrated on the replacement of animal proteins by plant proteins with a view to reducing the cost of supplementary feeds[6]. Hecht[13] has suggested that more efforts should be put into research on how much of the animal proteins can be replaced with plant proteins in the feeding of fish in Africa. Recognizing that pond farming will remain as the major aquaculture production system in Africa and developing feed strategies that maximize the

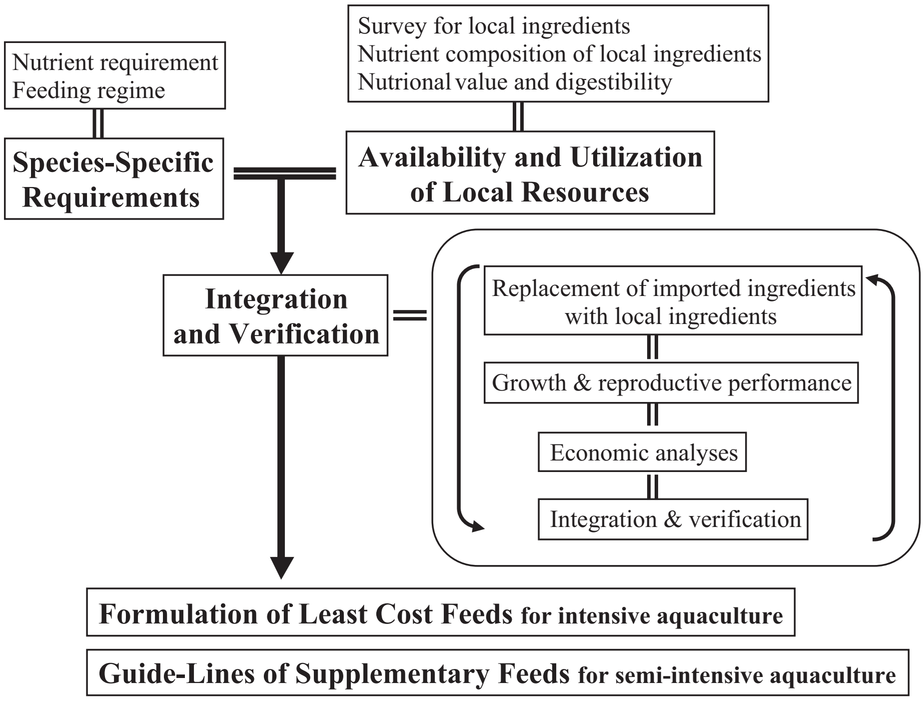

Fig. 5. Proposed research subjects and measures to develop feeds and feeding technologies

contribution of natural and supplementary feeds in fish ponds, would help to expand aquaculture production. Feeding regimes should be also modified and developed according to regional environments (climate, geography, economic condition etc.). For instance, Brown et al.[4] and Yi & Lin[25] recently reported that feed costs are reduced by delaying the timing of supplementary feeding without reducing fish yields.

2. Research proposed and recommendations for improving feeds and feeding techniques

Most aquaculture farms in Egypt use minimal feed supply in both extensive and semi-intensive culture due to the low stocking density. Originally, pelleted cattle or poultry feeds, which contain cotton seed meal, wheat or rice bran, were the only available feeds for fish farming in Egypt. The land-animal feeds gave bad feed conversion ratios, which were reflected in poor production efficiency. Cage culture systems in Damiet, the main place of the private aquaculture sector, use a mixture of ingredients containing corn, wheat and agricultural by-products as fish feeds. A few animal-feed mills have been also available as production lines of fish feeds. As far as we know, a private company in El Kanater El Khairia used a poultry feed manufacture unit for producing mash-type fish feeds, which gave worse feed conversion ratios. Recently the production of pelleted fish feeds has started. The General Authority for Fish Resources Development (Cairo, Egypt) has installed two feed mills for the production of formulated fish feeds. The Fish Research Centre (Suez University) has a feed mill. There are now two new feed companies which produce artificial fish feeds. Although the feeds are species-unspecific, they may be better than using poultry or cattle feeds. Due to the low availability and high price of fish meal, meat meal and soybean meal, most of the aquaculture feed researches in Egypt are giving more attention to investigate if the imported fish meal and soybean meal can be replaced with locally available ingredients. There still remain some problems on how to extend the improved knowledge on feed processing to the local private sector. Thus, the fish feed industry has yet to develop not only in Egypt but also in Africa. Therefore, there are short and long-term needs to conduct studies on fish feeds and feeding technology for rural freshwater species. From our point of view we suggest research subjects and measures as shown in Fig. 5, through the following steps.

(1) Species-specific nutritional requirements and optimum feeding regimes:
- Determination of energy and macro-/micro-nutrient requirements (qualitative and quantitative).
- Determination of optimum feeding regimes (feeding rate, feeding frequency and feeding time).

(2) Availability and utilization of regional feed resources:
- Search for locally available agricultural products and by-products.

• Determination of nutrient composition of regional ingredients and the data-base.
• Determination of the nutritional values and digestibility.

(3) Integration and verification of the results (1) and (2)—feeding tests on growth and reproduction:

• Replacement of imported ingredients with regional ingredients.
• Verification of the practicality and acceptability of the regional ingredients in growth and reproduction.
• Economic analyses on the practicality and acceptability.
• Integration of the results from economic analyses and field studies and its verification.

(4) Outputs:

• Formulation of least cost feeds for intensive aquaculture.
• Guide-line of supplementary feeds for semi-intensive aquaculture.

Conclusion

Rice-fish culture and desert aquaculture should be respectively promoted and extended for freshwater aquaculture in wet/pluvial regions and arid regions in other African countries as well as in Egypt. Studies on feeds and feeding technologies should be promoted, and feeds using rural ingredients should be developed to improve aquaculture productivity in Africa.

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