Biotechnology and Aquaculture in Sustainable Development

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Abstract

Aquaculture is the fastest growing food sector in the world with its increasing role for economy and safe food strategy of countries. Due to the continuing depletion of the fish stocks, farming of aquatic organisms such as fish, crustaceans, molluscs and aquatic plants, is now a substantial global industry supplying a significant proportion of the aquatic products consumed. Shortage in food supply and high prices are the possible important risks in the future, and aquatic products are the valuable sources of protein and essential nutrient components for global food security and eliminating malnutrition. Aquaculture also plays an important role in rural economies through the creation of new employments. In these cases, aquaculture outputs will need to be enhanced several fold in order to meet the rising demands for fish and other aquatic products in coming years.

Biotechnology options seem to be good potential for increasing aquacultural productivity, food security and environmental quality worldwide. Biotechnology is offering valuable options such as protein expression, microsatellite, gene mapping and genomic, DNA vaccines, DNA chips, proteomics, transgenic technology and embryonic stem cell technology. This technology provides genetic manipulations, molecular cloning, embryo manipulation, genetically-engineered diagnostics, immunoprophylactic agents. All of these applications could help improve the selective breeding, hybridization, productivity, health, growth, nutrition, cryopreservation and conservation of genetic resources in aquacultural stocks for the benefit of mankind. However, there is need for the regulation of biotechnology activities in terms of the potential adverse impacts on the environment and human health. There is also increasing concern about the impact of biotechnology on sustainable development in various fields. The main environmental safety issue of these applications is the effects of genetically modified organisms (GMOs) on biodiversity and gene transfer in the environment. Therefore, this review discussed the integration of biotechnology and biosafety in aquaculture, and policies for the environmentally sound use and management of aquacultural biotechnology in sustainable development.

Keywords: Biotechnology, Aquaculture, Sustainable Development, Food security, Public health

1.INTRODUCTION

Aquaculture is the farming of aquatic organisms such as fish, crustaceans, molluscs and aquatic plants under controlled conditions. Aquaculture is the fastest growing food sector in the world with its increasing role in the economic development and safe food strategy of countries. Recently aquaculture sector is faced with several challenges such as low productivity, low diversification of species, high competition in the market and environmental impacts that have resulted from the intensification and global development of aquaculture industry. Seasonal fluctuations in environmental conditions and in the supply of resources with good quality and stable costs such as feeds are also prevalent. Biotechnology is one tool that holds much promise towards addressing these aquacultural problems. The relatively new tools of biotechnology offer significant opportunities to improve aquacultural productivity and environmental quality worldwide. Today biotechnology has developed creative new methods to detect the gene liable for specific characteristics, such as disease resistance, nutrient composition, and insert them into another fish or aquatic organism (Fletcher et al., 2011). Biotechnology offers tremendous potential for improving production and it provides opportunities to reduce the need for additives in feeds and the use of chemicals (e.g. hormones). Advanced biotechnology in feed are rapidly evolving and promise to improve the composition, digestibility and bio-availability of feed towards high growth rate (Brinker and Reiter, 2011). All of these contribute to increase the intensity and produce more products at less economic and environmental cost, thereby helping to build global food security and more sustainable and environmentally friendly farming.

Aquacultural biotechnology could generally be separated into techniques; biochemical and molecular markers, protein expression technology, microsatellite, RFLP and QTL analysis and applications (gene mapping, gene cloning, transgenesis, population genetics, chromosome (ploidy) manipulation, gynogenesis, androgenesis, sex reversal, proteomics, DNA chips technology and embryonic stem cell technology. Protein expression technology allows producing many bioactive molecules such as hormones, gonadotropins and enzymes. DNA fingerprinting and mapping technologies are principally used in stock idenfication, breeding selection and identification of genetic markers for significant traits such as growth enhancement and disease resistance in the genome (Hew and Fletcher, 2001). This technology is more effective and faster than traditional breeding techniques to develop new strains.

2.Sustainable development of aquaculture

According to the current trends in food sectors, wild fisheries, natural stocks and demand for aquaculture products, it is awaited that aquaculture will become a major driving force to increase food production worldwide. Products from aquaculture will need to be increased several fold in order to meet the rising demands for fish and other aquatic foods in coming years (Figure 1). It was recently estimated that aquaculture provides about 50% of all the fish consumed by human today (FAO, 2010). On the other hand, the aquaculture industry will have to double its food produce with less land and water in the next decades, mainly because of growing pressures from urbanisation, industrialisation and climate change. Moreover, water scarcity that results in competition for water amongst local people, farmers and industry, is raising the potential for conflict.

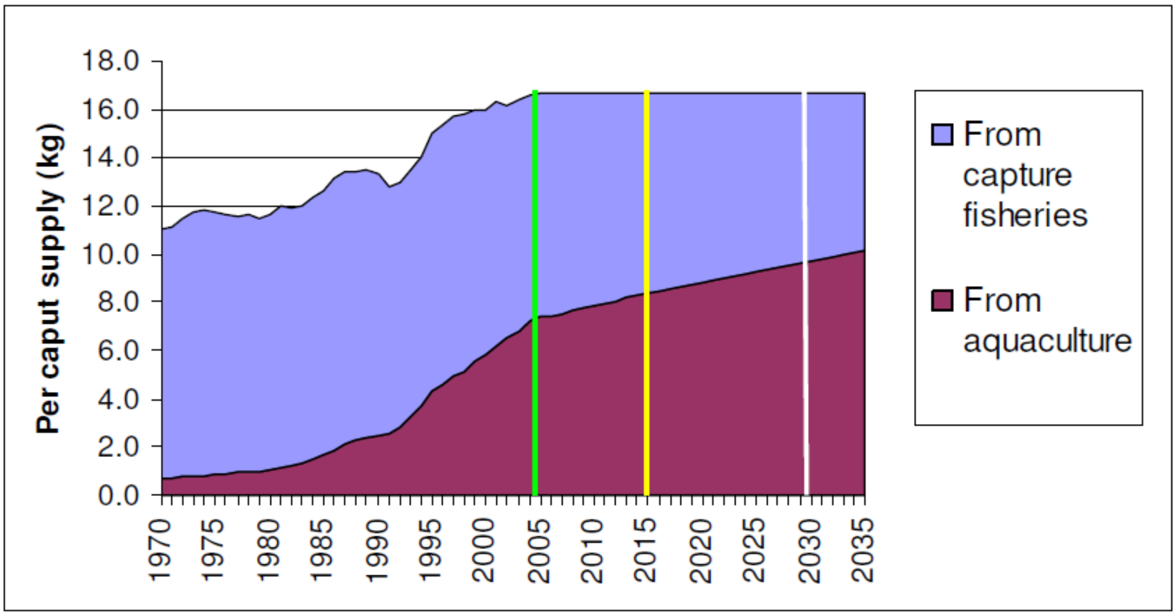

Figure 1. Projected supply of food fish originating from aquaculture and capture fisheries; based on assumed constant capture fisheries production, constant production of fish meal, constant demand for food fish and projected population increases. The line at 2015 represents the point where the food fish supply from aquaculture is projected to equal that from capture fisheries.(FAO, 2007):

The intensification of aquaculture has led to concerns attached to environmental impacts, food safety, animal health and welfare, and socio-economic issues (Subasinghe et al., 2009). All of these factors influence the sustainability in development of current aquaculture system. As a principle for the sustainable development of aquaculture, it can be said that as the improvement of economic productivity for aquaculture is necessary and this must be environmentally acceptable. Therefore, the ecosystem where the aquaculture operation takes place has to be identified to control unwanted interactions. The identifying process includes a wide range of topics relevant to ecological equilibrium and biodiversity conservation. Hence, environmental acceptability is the most difficult component of the sustainable development. In addition to this, as an indicator, economic viability and improving the economic performance of the aquaculture practices are also critical to achieve the improvements in aquaculture efficiency and to meet the world's increasing demand for aquatic food.

General trends in development of the aquaculture sector are the following (Subasinghe, 2007):

(a) continuing intensification of aquaculture production;

(b) continuing diversification of species use;

(c) continuing diversification of production systems and practices;

(d) increasing influence of markets, trade and consumers;

(e) enhancing regulation and improving governance of the sector and

(f) increasing attention on better management of the sector.

Aquaculture production increases but there is a question remains whether the industry grows in a sustainable manner and fast enough to meet the future projected demand while preserving the natural resources. To cope with this global uncertainity, biotechnology plays a key role in the sustainable development of aquaculture includes economic and social development as well as environmental protection throughout the world. Application of biotechnology to production of aquatic species has great potential to improve aquaculture and to meet demand for aquatic foods. Along with increasing production of aquatic food products, biological techniques should be applied to increase productivity and improve product quality. In parallel, there are several potential key contributions of biotechnology both to increase resistance against diseases and to increase growth rates of aquatic species. Biotechnology contributes to sustainable aquaculture by reducing the dependence on chemicals, particularly antibiotics, through the deployment of genes conferring resistance to diseases. Biotechnology also provides powerful tools for the enhancement and protection of wild and cultured aquatic species, particularly the improvement of fish stocks in commercial aquaculture production. Also, biotechnology allows the production of species in more quantities on the same area (intensification) at a lower cost, the support biodiversity and vital ecosystems, and the reduction of environmentally damaging aquacultural practices.

3.Aquacultural biotechnology

Biotechnology has potential to affect aquaculture and can provide at least a partial solution to the problem of feeding the world's growing population because without dramatic increases in production this cannot be achieved. Exploiting more resources such as more water, fish for meal and oil, and heavy use of chemicals for aquacultural use is environmentally unsustainable. Modern biotechnology has also opened up opportunities to increase production and enhance the quality of fresh and processed farmed species. In addition, farmed species are now being developed to resist disease, and this will reduce losses and allows increased production on same area, and therefore bring possible benefits to rural areas. Finally biotechnology can contribute significantly to aquaculture industry, for example by helping to make more diversification in farmed species that will more attractive to consumers. Modern biotechnology will be a useful for the genetic improvement of aquacultured species and the protection and management of wild aquatic populations.

4.Genetically modified species (Transgenics)

Recently, aquaculture sector is growing and developing in biotechonogy advance for genetic improvements in aquatic species. As a main application of modern biotechnology transgenics are new varieties of species have been bred by cross of two strains in order to transfer desirable traits from each into the new variety to improve the genetic traits of the species used in aquaculture. Transgenics involves the selective transfer of one or more genes for desired traits from one variety to another. These traits may include improvement of growth rates, larger size, more efficient feed convertion into muscle and control of sexuel maturation (El-zaeems, 2004). growth hormone genes from human or animal sources was successfully introduced into several fish species such as salmon, trout and tilapia, resulted several times faster growth than their natural counterparts. This is a faster and more accurate method of breeding new varieties. If desired traits cannot be achieved by traditional breeding, the transfer of genes between species also is possible. For exemple, better tolerance to environmental stresses and increasing of resistance to extreme environments are important applications to establish unique characteristics and produce a valuable biological product such as antifreeze protein gene (AFP) transfer in fish for adaptation to a freezing environment (Hew at al., 1992). In this regard, one more constraints should be the potential impacts of climate change on aquaculture. Biotechnology responsible for the practical response to climate change and can help to strengthen the adaptive capacity and resilience of the sector. Tolerant of low oxygen levels in the water is a desirable genetic trait that can also be developed in the aquatic organisms by using different transgenic techniques. Intensification and sustainable development of aquaculture will rely on disease prevention, and therefore, biotechnology is essential way for greater resistance to pathogens and improvement of farmed species health through selection for disease resistance (El-Zaeem and Aseem, 2004). Also, by using this technique disease transfer between cultured and wild populations can be reduced. New products and market opportunities can be developed related to aquatic species welfare. There are two main techniques to transfer genetic material in fish. These are micro-injection (injection of genetic material into newly fertilized fish eggs) and electroporation (transferring of DNA into embryos or directly into tissues through the use of an electrical current).

RISK: However recent concerns about genetically modified species and food products derived from them may curtail their widespread use. GMOs have not gained worldwide acceptance. At this point, there is not enough independent scientific research to introduce their potential risks to human health. Horizontal gene transfer from genetically modified plants to microorganisms was shown in a previous study that genes from a transgenic crop move quickly into weedy population (Snow at all., 1999). Questions concerning the transfer of allergenic proteins and potential ecological impact of virus-resistant transgenic plants have been also raised (Tepfer, 2002). Transgenic fish is offered new species for aquaculture development but any escapes into the environment can threat wild populations and biodiversity8.

5.Hybridization

Hybridization is a simple genetic technology that is the most practical way is the crosses in captivity of males of one species and females of the other. Inter-specific hybridisation have been practiced for aquaculture to increase growth rate, transfer or combine desirable traits of two species and increase resistance to culture conditions. Hybridization also produces monosex populations for the advantage of sexual dimorphism when the sex-determining mechanisms in the parental lines are different such as hybridisation of tilapias. It is also preferred for stocking programmes to reduce unwanted reproduction through production of sterile fish or mono-sex populations and increase environmental tolerances. It is widely practiced with many fish species throughout the world such as hybrid striped bass in the USA, hybrid clarid catfish in Thailand and salmonids in general. This helps diversification and to ensure a steady and consistent supply of fish to the market. The development of artificial breeding techniques and the improvements in reproductive technologies allows more domestication of aquatic species and mating many of them through artificial fertilization after hand striping eggs and milt from fish. In marine fish culture, sterile hybrid fish should be usefull because of the environmental concern (unwanted reproduction). Despite its widespread use, hybridization has still to cope with some problems depend on the genetic structure of the parents, particularly in the context of unexpected and undesirable results in hybrid progeny, such as failure to produce sterile fish, loss of color pattern, and reduced viability.

RISK: Hybridization does represent a genetic modification wherein genes are moved between different species. Thus, escaped hybrids may be aquaculture industry's biggest environmental challenges regarding to the genetic resources and biodiversity.

6.Hormonal applications

Biotechnological tools can be applied to induce breeding of fish and early development of aquatic species. Gonadotropin releasing hormone (GnRH) is the most used now in the induced breeding of fish and marked commercially throughout the world (Alok et al., 2000).

Hormonal stimulation allows year-round production of gametes and fry of economically valuable species. Domestication of species for aquaculture is necessary and the number of domesticated aquatic species is still rising rapidly. Hormone therapy is applied to improve and control of reproductive cycles during the domestication. Similarly, this tool may provide techniques for improving the reproductive success and survival of endangered species, thereby helping to preserve the biodiversity in wild. Higher growth of species in aquaculture sector is one of the main goals for farmers, and therefore various types of growth hormone is applyed in fish and other aquatic animals. Hormone treatment also includes inducing sterility and triploidy.

RISK: Hormones are issues of great public concern because they pose a serious threat to human and environment. The significance of these substances for the environment and human health is not yet fully understood but they accumulate in environment and play important role on sexsual dimorphism, fertility and toxicity in ecosystem.

7.Chromosome set manipulation

Chromosome manipulations have been applied extensively in the improvement of fish breeding for gonadal sterilization, sex control and clonation. It is important practical way in cultured fish species to induce polyploidy and uniparental chromosome inheritance. There are two types of uniparental inheritance: gynogenesis that is the process of development with maternal inheritance and androgenesis that is paternal. Poliploidy used to induce triploids to produce sterile progenies. Induction of tetraploidy provides sterile triploids through interploidy crosses between tetraploids and diploids. The technique also can be used to generate homozygous lines in fish such as tilapias, cyprinids and salmonids.

8.Cryopreservation

Cryopreservation is a process where biological material is long-term preserved by cooling to low temperatures usually at −196 °C in liquid nitrogen. As any physiological activities and biochemical reactions is tranquilized and effectively stopped at these low temperatures, therefore making it possible to keep them viable for long period. Cryoprotectant solutions are used in the process to prevent preserved cells from damage due to freezing during the cooling and thawing process. The development of cryopreservation technology provides short and long term storage of gametes, and thus the technology has been adapted to cryopreservation of fish spermatozoa. Application of the method to aquaculture increases the flexibility in breeding of species; specificly if the sexes mature at different times (in hybridization) or spawning season is very short. Cryopreservation overcomes problems of low amount of semen from males in photoperiod treatment. The resulting benefits could include year-round production of gametes and creation of new markets (cryopreservation of genetically improved or phenotypic sperm). Gene banking of cultivated and wild aquatic organisms is also essential and the technique may help to conserve genetic resources and biodiversity.

9.Aquatic species health and vaccines

Disease has become a primary constraint to sustainable aquaculture production and improvements in aquatic animal health are coming from modern biotechnology. Biotechnological tools such as gene probes and polymerase chain reaction (PCR) has showed great potential in this area. Genetically engineered (DNA) vaccines are also being developed to protect fish against pathogens and are expected to replace other methods of vaccine production. In general, DNA vaccines contain only genes of the pathogen, which produce the antigen whereas conventional vaccines are made from live, weakened or killed pathogen. The cost of this technique is low compared to producing weakened live organisms and these vaccines more stable at normal temperatures. Previous studies showed that the non specific defense system can be stimulated using microbials such as lipopoliysacharides, peptidoglycans or glucans (Soltanian at al., 2009). This technology has been adopted for aquaculture to improve the health and well being of cultivated aquatic organisms. The development of new vaccines help the organisms recognize and fight diseases causing losses to millions of dollars annually throughout the world. It also prevents the using chemicals in aqauaculture, means preventing chemical pollution in environment and potential hazardaous effects to human health.

RISK: However, genetically modified vaccines carry significant unpredictability and a number of inherent harmful potentials and hazards such as potential risks about the vaccine DNA to invade the host's genome and possibly trigger genes relating to tumour development.

Effects of these vaccines on the non-targeted species, possible genetic recombinations with naturally occurring relatives and hybrid virus progenies are other unpredictable options. There is, therefore, a great deal of caution surrounding the development of DNA vaccines at this time.

Feed production

Nutrition is essential in maintaing a healthy stock in a sustainable and profitable aquaculture and still in the developing stage. As feed costs rise and markets become more competitive, biotechnological aplications are currently being used in the feed sources and the improvement of the feed composition. In the farming of aquatic species fish meal is the most common protein source in diets. However, wild fish stocks are declining and the available fish resources will not be enough to meet the increasing demand for fish meal and fish oil. Therefore, there are environmental concerns regarding fish feed such as conservation of wild stocks and waste dischargers into the water due to excess phosphorus in diets causing eutrophication. These are main limiting factors regarding to feed in sustainable development of aquaculture, thus biotechnology are used to produce alternative plant based protein sources because plants contain anti-nutritional compounds and requires processing to improve its quality. In this regard, biotechnology allows the producing feed enzymes that help to improve the utilization of plant-protein based feed by aquatic species. As another environmental concern regarding the problem of phosphorus pollution, modern biotechnology is working on the development of low environmental-loading feed.

10.CONCLUSION

Aquacultural biotechnology is now evolving very rapidly and making a significant contribution to the development of sector. In general, the technology promises immense gains in food security, economic issues and environmental protection. Efforts are directed to:

the improvement of fish feed quality;

genetic engineering in order to improve the protein value of fishes;

the reproduction of species;

disease diagnoses;

hybridization technology

genetic engineering for the production of vaccines.

the treatment of pollutants generated by aquaculture.

All of these factors influence the sustainability of an aquaculture system and may play fundamental role in future aquacultural development policies. Improved productivity and the resulting increase in production would benefit the rural poor by providing more food, poverty reduction and through improved employment opportunities. Advances in biotechnology applied to aquaculture can be useful in understanding waste treatment and reducing pollution risks. To eliminate uncertainties and vulnerabilities in the risks, governmental support is the essential element in enhancing aquaculture development without any environmental impact. Thus, sustainable biotechnological applications in aquaculture have to be identified and developed according to the risk assessments of the product and method. There are some principles that aquacultural biotechnology must adhere to in order to be sustainable, namely;

environmentally acceptable in terms of methods, improved species and discharges.

safety for human health

large scale and heavy restrictions for non-native and geneticly modified species (farming in land-based tanks)

supporting the long-term economic and social well-being of local communities

ensuring a strong healthy and welfare for farmed species

economically feasable and sustainable

more investment for biotechnology industry.

achieving a sustainable feed resources

promoting good menagment

involving human resource development

regulations of the modifications

Biotechnology is almost becoming an industry but still there is no any knowledge what the impacts will be. Moreover, biotechnology has raised important ethical and morality issues which need to be carefully addressed before its application to aquaculture. Therefore, to ensure maximum social benefit at minimal risk is high on the policy agenda of the countries In addition development of biotechnology will need to be shared among diferent disciplines and stakeholders. In this regard, educating of decision-makers in food safety and biotechnology regulation will be also very important. In conclusion biotechnology is important key for aquaculture, but it might still be too early to judge the future impact of biotechnology on its sustainable development.

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