Review Article

Benefits and Risks of Genetically Modified Organisms in Aquaculture

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ABSTRACT

Aquaculture is the farming of aquatic organisms such as fish, crustaceans, molluscs and aquatic plants. It involves cultivating freshwater and saltwater populations under controlled conditions. But, aquaculture competes with other land and water users for space, and, the number of available sites which are suitable for aquaculture is finite throughout the world. Moreover, the technical problems associated with aquaculture in the coastal areas are to be solved yet. However, there is considerable scope to improve the efficiency, intensity and productivity of aquaculture systems worldwide. And, this task can be accomplished by the application of biotechnology and introduction of GMOs in the aquaculture. Genetically Modified Organism (GMO) refers to the organism whose genetic material is altered using genetic engineering techniques. The production of appropriate genetically modified organisms (GMOs) offers considerable opportunities for more efficient and more effective aquaculture across a wide range of species. This potential of GMOs has already been realized and commercially accepted in agricultural crop production, and, the area for sowing transgenic crop has exceeded 60 million hectares. However, in aquaculture, although many GMOs have been produced, but there is lack of any potential for the commercialisation of these GMOs. This is mainly due to some problems associated with the cultivation of GMOs in aquaculture. But at present, research is going on for overcoming all these problems. The international aquaculture industry is exploring measures to increase their efficiency due to the growing demand for fish worldwide that cannot be met from wild-caught fish alone. Research into developing genetically modified fish has been conducted in many maritime countries. Here, in this paper, the nature of GMOs, the range of aquatic species in which GMOs have been produced, the benefits to aquaculture, the problems attached to use of GMOs and the regulatory and other social frameworks surrounding them are presented.

Keywords: Aquaculture, fish, farming, genetically modified organisms.

INTRODUCTION

What is Aquaculture?

Aquaculture is the farming of aquatic organisms such as fish, crustaceans, molluscs and aquatic plants. It involves cultivating freshwater and saltwater populations under controlled conditions. Particular kinds of aquaculture include fish farming, shrimp farming, oyster farming, algal culture and the cultivation of ornamental fish.

According to the Food and Agricultural Organisation (FAO 2001), Sixty to seventy of the world's marine fisheries are threatened by over-fishing. So in this situation Aquaculture has been proposed to be the only way for a sustainable increase in seafood production on a global scale. As the focus is rapidly increasing on aquaculture farming, so the industry is trying to improve the efficiency and thus has started to explore modern biotechnological techniques which can be applied in aquaculture. These genetic technologies result in genetic modifications to enhance growth efficiency, resistance to freezing and diseases, resistance to polyploidy to control reproduction.

GMOs in Aquaculture

GMOs are organisms with modified genetic material. Gene technology has already found extensive applications in improving agricultural plant production. The first worldwide release of commercial GM crops was in 1996, and since then such cropping has grown rapidly. The area for sowing transgenic crop species exceeds 60 million hectares worldwide and covers more than 70 different species. However, gene technology has now also been utilised in research of genetically modified animals, mainly fish, in aquaculture.

Australian scientists were among the first in the world to produce GM aquatic animals. And, in modern times, most of the researches on transgenic fishes are being conducted in the United States of America and Canada, Cuba, China and New Zealand. But although many GMOs have been produced in aquaculture, there is almost no potential for the commercialisation of these GMOs. This uncertainty associated with the marketability of GMOs serves as a significant barrier to investment in research and development. But at present, the international aquaculture industry is exploring measures to increase their efficiency to commercialise GMOs.

Benefits of GMOs in Aquaculture

Application of gene technology in aquaculture has many potential benefits, like producing fish with increased growth rates, increased temperature tolerance, and improved disease resistance. Fish have been modified to grow six times faster than normal, survive in colder climates, and possess natural disease.

Potential Threats

But along with these benefits, there are some associated risks to consider prior to their use in commercial production. Ecological risks would arise if GM fish escaped from aquaculture facilities and into the wild, because they could potentially interact with the local wild population and produce reduced fitness, decline in other species in the community, transfer of disease and parasites, and a decrease in prey species. A number of potential human health risks may also occur. One of the major concerns is whether or not they are safe for human consumption.

In this review, the benefits and risks associated with introducing GMOs in aquaculture have been described to get a better perspective about GMOs.

AQUACULTURE

Aquaculture is the farming, i.e. breeding, rearing and harvesting of aquatic organisms under controlled conditions. Particular kinds of aquaculture include fish farming, shrimp farming, oyster farming, algal culture and the cultivation of ornamental fish.

Aquaculture is necessary for a variety of reasons, some of which are as follows:

- Producing fish, mussels and crustaceans for human consumption
- Cultivating fish to compensate or strengthen the natural population
- Producing bait fish, aquarium fish, mussels for the pearl industry
- Producing algae for chemical, medicine and food industries
- Preserving rare organisms
- Production of biotechnologically potential organisms

Problems associated with aquaculture

Like any other form of industrial production, aquaculture has also some problems associated with it.

The impacts are of two types mainly – environmental and social.

Environmental impacts:

The major impacts for the aquaculture industry include: use of more fish than what is produced, transfer of disease and parasite, introduction and spread of exotic species, chemical pollution, habitat destruction for setting the farm or due to farm activities, and, killing of predators that prey on the farmed species. These impacts are dictated by three main factors –

1. Species in production – For culturing species with higher trophic level position, the requirement of feed input will be more, thereby releasing large quantity of wastes.
2. Location of production – The impact on environment due to farm outputs (waste, amplified disease or parasites, escapes of cultured stock, or killing of predators) will be high in ecologically sensitive locations, such as mangroves, coastal estuaries and migration of fish routes.
3. System of production – Open net pens are completely open and thus, anything that happens in the farm can be transferred to outside of the farm whereas closed containment system contains all inputs and outputs within itself.

Most of the environmental problems associated with aquaculture are due to the occurrence of oxygen-deficient bottoms like eutrophication, poisonous algal blooms etc. These problems are commonly associated with the cultivation of fish. Modern fish farms are very intensive and usually run on a large scale. So they require the addition of resources from a large area, on both land and sea. These resources comprise fodder pellets, broods, spawn, chemicals and energy. Fodder pellets are usually made of fish that have been captured in other maritime areas and agricultural products, while chemicals are used to try and keep the fish well and healthy. Many of these resources are not utilized fully by the fish and pass straight through the farm and into the sea. Waste from fish farms is composed of excreta, waste food and chemicals.

Environmental effects can be reduced by a collection of measures, such as changing the composition of the fodder, collection and reuse of waste products, by combining cultivation methods (integration) and by using food that is found naturally in the water.

Social impacts:

Social impacts are also considered to be a major impact of aquaculture production and there are numerous conflicts around the world. The major conflicts include: traditional livelihood and community displacement and abusive labour practices. Social impacts are mainly driven by export driven commodity production like shrimp, where companies seek to maximize profits by exploiting poor countries which have poor regulations.

GENETICALLY MODIFIED ORGANISMS (GMO)

Genetically modified organism (GMO) refers to the organism in which there has been scientific alteration of genetic material. Organisms that have been genetically modified include micro-organisms (bacteria and yeast), insects, plants, fish and mammals.

Nature of GMOs

GMOs are transgenic organisms into which desired DNA (foreign DNA) is inserted and incorporated with the help of *in vitro* techniques of genetic engineering. But GMOs themselves do not act as the source of donor DNA. Thus, just like a carp in which a sequence from its own DNA has been incorporated within its genome is transgenic, in the same way a fish receiving and incorporating a sequence from a daffodil is equally transgenic. In this way, transgenic are classified into 2 groups: auto-transgenic (donor and recipient of same species) and allo-transgenic (donor and recipient of different species).

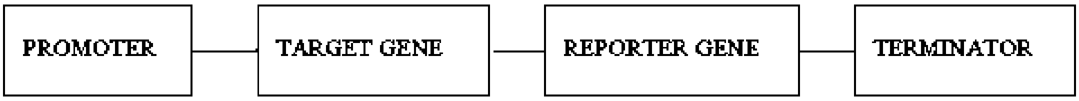

Figure 1: Diagram of DNA sequence of a typical construct for making transgenic organisms

Why are GMOs Produced?

The main reasons for genetic manipulation of species used in aquaculture are[1]:

a) enhancing growth and/or efficiency of food conversion

b) enhancing muscle characteristics for commercial purposes

c) controlling reproductive activity and/or sexual phenotype

d) increasing resistance of species to disease causing microorganisms

e) increasing tolerance to/of environmental variables such as temperature

f) modifying behaviour, e.g. aggression

g) controlling fertility and/or viability

GMOS IN AQUATIC SPECIES

The first transgenic animal to be produced was a mouse[2]. Rainbow trout[3] and goldfish[4] are the first recorded transgenic production in aquatic species. Some of the significant species in aquaculture are Atlantic and coho salmon, tilapia species, catfish, medaka and zebrafish.

Process of genetic modification

Production of GMOs is a multistage process which can be summarized as follows:

1. gene of interest is identified
2. gene is isolated
3. the gene is amplified to produce many copies
4. the gene is then associated with an appropriate promoter and poly A sequence and inserted into plasmids
5. the plasmid is multiplied in bacteria and the cloned construct for injection is recovered
6. the construct is transferred into the recipient tissue, usually fertilized eggs
7. gene is integrated into recipient genome
8. Gene is expressed in recipient genome; inheritance of gene through further generations.

POTENTIAL BENEFITS OF GMO IN AQUACULTURE

Improvement of growth rate

Fish is an important source of animal protein for humans. So it is of great significance to cultivate fast growing fish to satisfy the growing needs of the people. Transgenic technology can be used for transferring growth hormone genes into the fish in order to obtain fast-growing, high-yield "super-fish." Increase in growth rates can be achieved by genetic engineering is typically 200%-600% depending on the species, the structure of the gene construct and the nature of insertion[5].

GH is normally produced only in the pituitary gland of animals, and it circulates at relatively low levels in the blood. Insertion of an extra GH gene broadens the range of tissues producing the hormone. Various promoters are used in transgenic fish to drive growth hormone genes. A promoter is a sequence at the beginning of a gene that determines how often the gene is "switched on" to produce proteins – in this case growth hormone. Early experiments utilised human growth hormone attached to the metallothionein promoter from mice[6]. Other promoters from viruses have also been used in transgenic fish. Recently some promoters from fish have been isolated and it is thought that the marketplace will better accept these than viral or rodent promoters[3]. Antifreeze protein (AFP) promoter genes are naturally occurring in some fish and have proven effective in driving expression of the GH gene in transgenic fish. GH inhibits AFP promoter genes from species such as flounder, but genes from the ocean pout are not affected[7]. Two different AFP-GH constructs have been created: AFP-GH chimeric gene construct and AFP-GHf with the AFP promoter linked to the chinook salmon GH cDNA and a mini GH gene respectively[8]. These two "all fish" constructs are used to generate GH transgenic fish.[1] Other fish promoters used include: trout and salmon metallothionein, carp B actin, salmon histone, and protamine from fish species. When the AFP promoter gene from ocean pout is used it causes the GH transgene to be expressed most strongly in the liver of transgenic fish[3] stimulating GH production in the liver and its signalling cascade that leads to increased growth rates.

Freeze resistance

The low water temperature in winter can cause considerable stimulation to many fish, for example, most fish cannot tolerate temperatures as low as −1.4 to −19°C in the Arctic Ocean sea water. Fishes adaptive to warm water may all be dead in the face of rarely-confronted low temperatures, which is a serious problem in the aquaculture industry. Increasing the temperature tolerance of fish would expand the options for aquaculture. A common gene transplant is that of antifreeze protein genes where the intent is to develop fish that have an increased adaptability (particularly salmonids) to very cold waters.[9,10] To avoid freezing, several fish species are able to produce antifreeze proteins (AFPs) or antifreeze glycoproteins (AFGPs) that can interact with ice crystals and effectively lower the freezing temperature[11,12]. These proteins can also protect membranes from cold damage[2, 12]. So a common gene transplant is that of antifreeze protein genes where the intent is to develop fish that have an increased adaptability (particularly salmonids) to very cold waters[9, 14]. Atlantic salmon cannot tolerate low temperatures due to the absence of the AFP or AFGP gene in its genome, which is a problem for sea pen culture in cold waters, eg. in the Northwest Atlantic. Therefore, there is great interest in developing a new strain of freeze tolerant salmon in these areas.

Disease resistance

Diseases are the main cause of economic loss in the fish farming industry. The application of transgenic technology can effectively improve the disease resistance of fish to substantially reduce economic losses. The high densities in which fish are farmed make them susceptible to diseases caused by viruses, bacteria, fungi and protozoa. Improving the natural disease resistance of farmed fish would increase profitability[15]. Yet no gene transfers to resist disease and parasitism have been reported for fishes[1]. However, research is under way on the relevant major genes[16, 17, 18] and one such example is the antibacterial enzyme lysozyme[14]. This enzyme is effective in the mucous of fish against a range of bacterial pathogens[19] and attempts to increase its concentration might prove beneficial. Another avenue is the development of vaccines using gene technology. Recombinant DNA vaccines are being developed for infectious hematopoietic necrosis virus (IHNV), a fish rhabdovirus responsible for massive mortalities of chinook salmon and rainbow trout[9]

There are also a number of other target phenotypes for which transgenics offer considerable potential. These include salinity tolerance, sterility, control of sexual phenotype, disease resistance to specific pathogens and behavioural modifications. One interesting possibility is that of modifying the genome to allow greater production of omega-3 fatty acids[4]. There are, as yet, few concrete data which can be reported but clearly there are very promising areas of work which could bring substantial benefits to aquaculture. The introduction of a transgene is intrinsically unlikely to have only one effect on the phenotype and possible pleiotropic effects need to be considered.

Commercial significance

The demand for fish is increasing year on year and the yield from capture fisheries is declining. Thus, although aquaculture production is increasing the market for further expansion in aquacultural production is likely to be very good for many years to come. An OECD (1995) view was that the time scale from 1995 for GMOs in salmon to be commercialized would be 15 years and that for tilapia would be five years. As matters stand at present the estimates for both species would lie between the two figures given. It is reported[20] that Atlantic salmon transgenic for a Chinook salmon GH gene are being considered for approval in aquaculture in the USA. The data available on GH transgenics suggest that the monetary benefits to be obtained from use of these fish will be large. For comparison, the use of the single step genetic change represented by monosex genetically male tilapia (GMT) in Nile tilapia (though this is not a GMO) increased production by almost 30 percent and effectively doubled the net income, from this source, of Philippine farmers growing it[21].

Other: Other transgenic work on fish has studied gene regulation and function, developmental genetics, and the use of animals for production of human hormones such as insulin[13].

Future possibilities

Possible future applications include[10, 14, 22, 23]:

- Raising marine fish in fresh water
- Manipulating the length of reproductive cycles
- Increasing the tolerance of aquaculture species to wider ranges of environmental conditions
- Enhancing nutritional qualities and taste
- Controlling sexual maturation to prevent carcass deterioration as fish age
- Using transgenic fish as pollution monitors
- Creating fish that act as pollution monitors
- Enabling fish to use plants as a source of protein
- Using fish to produce pharmaceutical products
- Improving host resistance to a variety of pathogens, such as Infectious Haematopoietic Necrosis Virus (IHNV), Bacterial Kidney Disease (BKD) and furunculosis.

POTENTIAL RISKS

Ecological Risks

The current facilities used in aquaculture farms do not ensure complete containment of stock, with many fish escaping from farms into the wild. If transgenic fish were bred in current aquaculture facilities, some fish would escape and interact with their wild counterparts and the rest of the aquatic community. It is difficult to predict their impact on ecological systems because of experimental difficulties.

The scale and frequency of introductions of transgenic fish into a particular environment will greatly influence the degree of ecological risk involved[9]. The type and degree of ecological risk will vary depending on a number of factors. These are as follows[9, 13, 24, 25]:

- the type of transgenic fish, namely the overall phenotypic effect of the transgene
- the adaptive ability of the transgenic animals to the local environment
- the fitness of the transgenic fish
- the health of local populations
- the normal ecological role of the host species
- the potential for dispersal and persistence
- the local environment itself

The effects of escaped transgenic fish on wild ecosystems can be divided into two types: **intraspecific** (mainly 'genetic') and **interspecific** (mainly 'ecological') levels[26]. Other aspects such as the introduction of diseases and effects on population size may have an effect at both the inter- and intraspecific level[26].

Intraspecific interactions: One of the biggest ecological risks associated with growing GM fish is their likely impacts on the native population if they escape from aquaculture facilities. If transgenic fish enter an ecosystem that contains the same species, the genetics of that population will change if they interbreed. The population will acquire a new gene or set of genes that could alter the fitness of that population (e.g. reduced antipredator response) [27].

Interspecific interactions: Another ecological risk associated with the escape of transgenic fish into wild populations is the potential impacts on the broader aquatic community. Released transgenic fish stocks are thought to pose a risk to other species through niche expansion and even speciation[9]. Interspecific interactions would be in the form of competition for space, food and cover. Such interference competition is primarily mediated through aggressive behaviour towards other individuals.

The number of accidentally released fish from aquaculture operations is considerable; in many spawning populations, released fish now outnumber wild fish[28]. Below is some empirical evidence of interactions between cultured and wild fish:

- escaped farmed Atlantic salmon can spawn successfully in rivers in the North Atlantic and the Northeast Pacific;
- escaped farmed Atlantic and Pacific Salmon have destroyed the egg nests constructed by wild salmon;
- the breeding performance of farmed Atlantic salmon, particularly males, can be inferior to that of wild salmon; and
- as juveniles, the progeny of farmed Atlantic Salmon can compete successfully with, and potentially competitively displace, the progeny of wild Atlantic salmon[13].

Human health risks

One of the major concerns by the public about GMOs is whether or not they are safe for human consumption. Many reports state that GM fish are as safe to eat as conventionally bred fish[22, 29]. Concerns may arise for two reasons: (a) if the DNA is sourced from an allergenic protein; (b) if the transgene causes an inactive toxin gene to be expressed[22]. These dangers could be mitigated by a regulatory assessment procedure of the introduced gene on a case-by-case basis.

An allergenicity risk exists if the DNA is sourced from a protein that is known to cause an allergic reaction in some people. An example is transferring a shellfish protein to a teleost fish, which could cause an anaphylactic reaction in people allergic to shellfish[22].

Toxic effects may result from the insertion of a transgene into the host genome[29]. Insertion of a transgene could possibly cause an inactive toxin gene to be expressed in a normally safe species of fish. The development of transgenic fish might activate the expression of a gene that is not normally expressed, resulting in increased levels of a toxin.

There are other issues not necessarily of health interest but more issues of consumer satisfaction. Increased growth rates caused by transgenesis may have an effect on meat and nutritional quality. Changes in the levels of muscle enzymes PFK and Cytox affect metabolism, which can lead to changes in meat quality[22, 29].

Commercial Risks

A primary issue of producing novel strains of transgenic fish is their eventual demand by the aquaculture industry and consumers. Public backlash may be so fierce that, even if transgenic fish are produced, they do not sell. Commercial risks include market access restrictions, price discounts and dominance of large multinational companies. At present, the commercial use of transgenic fish has not yet started and it is difficult to gauge the likely public reaction. In addition, some animal rights groups also did not support genetic engineering stating that animals will physically suffer as a result of genes being transferred into their genetic code[30]

CONCLUSION

Gene technology can provide many potential benefits for the aquaculture industry, including increased growth rates, increased temperature tolerance, and improved disease resistance. It is anticipated that further interest will develop in the future for using this tool to improve economic efficiency for the aquaculture industry as well as reduce pressures on wild stocks. There are, however, some associated risks with the application of gene technology in aquaculture. The potential effects on wild ecosystems from escaped farmed transgenic fish, human health safety and the reputation and viability of industries adopting this practice all have to be considered. Therefore, before the application of gene technology in aquaculture can be readily endorsed, the potential risks need to be thoroughly assessed and the necessary risk aversion measures developed and applied.

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