Octa Journal of Biosciences
International peer-reviewed journal
Octa. J. Biosci. Vol. 3(1):34-36

ISSN 2321 – 3663
Jun. 2015

Octa Journal of Biosciences

journal homepage: www.sciencebeingjournal.com

Environmental Impact of Genetically Modified Fish – A Review

Satimehin, F.P.D., and Olufeagba S.O.

Department of Fisheries and Aquaculture, University of Agriculture, Makurdi, Benue State, Nigeria

ARTICLE INFO

Received 12 May 2015
Revised 5 June 2015
Accepted 15 June 2015
Available online 30 June 2015

Keywords: GM fish , Environment , Aquaculture, Gene technology

Email: folajimidaniel@gamil.com

ABSTRACT

This is an overview of current research into the use of modern biotechnology in aquaculture. It is directed to policy and decision makers to give an indication of issues relevant to research into and the potential for commercialisation of genetically modified (GM) organisms in the seafood industry. Application of gene technology in fish to improve production efficiency has many potential benefits. Research on GM fish has primarily focused on 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 resistance so important to high-density aquaculture. Whilst the potential benefits of GM fish are plenty, 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. These genetically enhanced fish 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. Preventative measures include sterilisation of all transgenic fish, and better aquaculture infrastructure to ensure secure containment of fish, neither of which yet is fully effective.

INTRODUCTION

About sixty to seventy percent of the world's fisheries are threatened by over-fishing according to United Nations Food and Agricultural Organisation (FAO, 2001). Aquaculture has been proposed as the only way to sustainably increase production on a global scale. The United Nations Food and Agricultural Organisation estimates that at some point between 2015 and 2025, half of all fish consumed in the world will be farmed (FAO, 2001).

Due to the rapidly increasing focus on aquaculture farming, the industry is continually looking at measures for improving efficiency and is starting to explore modern biotechnological avenues (Hew and Fletcher, 2001).Various genetic technologies are emerging ranging from genetic modification, enhance growth efficiency, resistance to freezing and disease, polyploidy manipulation to control reproduction.

Biotechnology is the term given to the range of agricultural, mechanical and industrial technologies that make use of the natural processes or products of living organisms. Gene technology covers techniques used to alter or move the genetic material of microorganisms, plants and animals, either within the organism or between different organisms.

It allows genetic material to be transferred between completely unrelated species thus giving breeders greater options to incorporate characteristics into organisms that are not normally available to them. Gene technology has also been utilised in research of genetically modified plants and animals, including fish, the topic of this report.

A genetically modified fish (GM Fish) is a fish whose genetic material has been altered using genetic engineering techniques. Genetic modification involves the mutation, insertion, or deletion of genes. Inserted genes usually come from a different species in a form of horizontal gene-transfer.

Naturally, this can occur when exogenous DNA penetrates the cell membrane. To do this artificially may require; attaching the genes to a virus, physically inserting the extra DNA into the nucleus of the intended host using micro injector, Electroporation (is the process of introducing DNA from one organism into the cell of another by use of an electric pulse), With very small particles fired from a gene gun.

Humans have been domesticating plants and animals since around 12,000 BC through the process of selective breeding, in which organisms with desired traits are used to breed the next generation and organisms lacking the trait are not bred, is the oldest form of genetic modification. Genetic engineering was first accomplished by Herbert Boyer and Stanley Cohen, that when genetic material from a different species is added, the resulting DNA is called recombinant DNA and the organism is called a transgenic organism. The first recombinant DNA molecules were produced by Paul Berg in 1972.

Some examples of Genetically Modified aquatic animals, Royal Society of Canada (RSC 2001): Abalone (Haliotis diversicolor), African catfish (Clarias gariepinus), Arctic char (Salvelinus alpines) Crustacean (Artemia franciscana), Brown trout (Salmo trutta), Common carp (Cyprinus carpio), Goldfish (Carasius auratus), Japanese medaka (Oryzias latipes), Kuruma prawn (Penaeus japonicas), Milkfish (Chanos chanos), Tilapia (Oreochromis niloticus) etc.

The highly technical nature of genetic engineering means that it can only be performed in a private biotechnology research laboratory, a government-run hatchery or a university. The animals produced in these labs may then be sold on to fish farmers where they can breed a stock of genetically altered fish. Genetic modifications are being used to (Hew and Fletcher 2001):

Increase growth rates; enable adaptation to extreme environments, such as through freeze/cold resistance; increase disease resistance; control sexual maturation, fertility and sex differentiation; enhance nutritional qualities and; improve food utilisation.

GM fish is likely to play a primary role in the expansion of the aquaculture industry according to the Bureau of Rural Sciences. The technology, however, is likely to improve the profitability of aquaculture through reduced time to market and improved harvest quality (BRS 1998).

Benefit of genetically modified fish

Increasing the growth rate of fish by adding a growth hormone inducing gene is a common area of research for GM fish (Devlin et al. 1995; Devlin 1999). The commercial incentive for growth hormone (GH) technology is the opportunity to rear fish to market-sizes faster. 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. A promoter is a sequence at the beginning of a gene that determines how often the gene is "switched on" to produce growth hormone. Various promoters are used in transgenic fish to drive growth hormone genes. These promoters includes Metallothionein promoter, Antifreeze protein (AFP) promoter. Other fish promoters used includes trout and salmon metallothionein, carp B actin, salmon histone, and protamine from fish species.

The most widespread genetic manipulation in aquaculture worldwide is sterilisation, which is achieved through polyploidy manipulation. These techniques are used to induce animals to carry additional copies of their chromosomes, which results in sterility. The advantage of sterile organisms is that they use their energy to continually add to flesh, rather than seasonally shifting to the production of sperm and eggs.

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 (Kapuscinski and Hallerman 1991; Maclean 1998).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. Therefore, there is great interest in developing a new strain of freeze tolerant salmon in these areas. The relevant genes have been isolated from a number of different species, including winter flounder, sea raven and ocean pout.

The high densities in which fish are farmed make them susceptible to diseases caused by viruses, bacteria, fungi and parasites. Improving the natural disease resistance of farmed fish would increase profitability (Fjalestad et al. 1993). No gene transfers to resist disease and parasitism have yet been reported for fishes (Hew and Fletcher 2001). However, research is under way on the relevant major genes that can be used to resist diseases. These include the antibacterial enzyme lysozyme (Maclean 1998). This enzyme is effective in the mucous of fish against a range of bacterial pathogens (Grinde 1989) 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 (Kapuscinski and Hallerman 1991).

A possible future application of GM fishes

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/or taste; controlling sexual maturation to prevent carcass deterioration as fish age; using transgenic fish as pollution monitors; controlling sex differentiation and sterility; enabling fish to use plants as a source of protein; using fish to produce pharmaceutical products; “imprinting" fish with marker DNA sequences in order to facilitate population studies in the wild; and Improving host resistance to a variety of pathogens, such as Infectious Haematopoietic Necrosis Virus (IHNV), Bacterial Kidney Disease (BKD) and furunculosis.

Ecological Impact of Genetically Modified Fish

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 (RSC 2001). The effects of escaped transgenic fish on wild ecosystems can be divided into two types namely:

Intra-specific Interaction

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, Behaviours involved in reproduction, feeding, and territorial defence, spatial or temporary habitat distributions, or other life history features could be affected leading to unpredictable changes in population dynamics and perhaps even destabilisation of the community (Gutrich and Whiteman 1998).

Another ecological risk associated with the escape of transgenic fish into wild populations is the potential for transgenic fish to displace indigenous stocks. Transgenic organisms are capable of reproduction, and they have the potential to establish themselves in the environment as persistent populations, or to introduce transgenes into existing populations through introgression or other means (Bruggeman 1993). Much of this is reliant on the mating success rate of the transgenic fish and when it comes to GH fish, they might be at an advantage.

Factors That Likely Reduces Intra-Specific Impact Of Genetically Modified Fish

Whilst there are some serious potential risks to native populations through the release of transgenic varieties, studies have reported that transgenic fish may not be fit enough to out compete their native equivalents.

GH fish have a reduced anti-predator response. In fish, anti-predator responses have a genetic basis but can be modified (Magurran 1990). Predator-vulnerable risky phenotypes may not be selected again in farmed environments because the food supply is constant and predictable, and natural predators are lacking (Kohane and Parsons 1989). Growth hormone increases the energy demand and thereby the feeding motivation of an animal, however it can also reduce the anti-predator response as a result. One study on brown trout showed that both hatchery selection and GH injection consistently reduced anti-predator behavioural responses in juveniles in the presence of a trout predator (Johnsson et al. 1996).

In combination with the reduced predator avoidance behaviour, genetic engineering can affect the overall shape of transgenic fish, which can lead to a reduced swimming ability. A reduced swimming ability would be expected to increase vulnerability to predators. Swimming speeds of transgenic Coho salmon has been reported as being significantly lower than those of non-transgenic controls of the same size and age (Devlin et al. 1999). Reduced swimming speeds may be caused by ontogenetic delay or from disruption of the locomotor muscles and/or their associated respiratory, circulatory and nervous systems (Farrell et al. 1997).

Therefore, fish that exhibit reduced anti-predator responses may not survive in wild environments and so cannot out compete their wild counterparts.

Inter-Specific 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 (Kapuscinski and Hallerman 1990, 1991) and even speciation (Knibb 1997). Even if they do not spread their genes, transgenic fish could disrupt the ecology of streams by competing with native fish for resources (Hallerman and Kapuscinski 1995; Gutrich and Whiteman 1998; Reichhardt 2000; RSC 2001).

Inter-specific interactions would be in the form of competition for space, food and cover. Such competition is primarily mediated through aggressive behaviour towards other individuals. Size-related competitive ability of GH fish may be a mechanism by which it gains a competitive advantage over another species (Hindar 1995). Cultured GH fish, if comparatively large, may prey upon smaller, wild fish (Gutrich and Whiteman 1998; RSC 2001).

Escaped transgenic fish, which are larger than normal at a given age, may lead to increases in the size of their selected prey (Kapuscinski and Hallerman 1991). They could also have bigger appetites (Weatherly and Gill 1987; Kapuscinski and Hallerman 1991), which means they have the potential to alter the dynamics of other fish populations that are interconnected in the food web (Devlin et al. (1999) have found that GH transgenic Coho salmon eat nearly three times as much food as their natural counterparts under laboratory conditions. Whether this would still be the case in the wild is uncertain (Reichhardt 2000). Gutrich and Whiteman (1998) suggest that the ecological risk posed by introduced GM fish in the marine environment would be relatively high compared to terrestrial and freshwater environments.

GM aquatic organisms introduced into the ocean environment may have a relatively high rate of establishment because of the comparatively high fecundity of many marine organisms compared to those from freshwater environments.

Measures to reduce environmental Impact of GM fish

Two options to reduce risks associated with GM fish have been proposed which is complete physical containment of GM fish; the development of improved methods for biological containment of GM fish (Smith et al. 2001).

The likelihood of GM fish escaping into the wild can be reduced by moving marine based operations inland where containment can be much more readily achieved (Hindar et al. 1991). Conversely, Smith et al. (2001) and Maclean and Laight (2000) stated that complete physical containment of aquaculture species is not an economically viable option given the high cost of enclosed systems, particularly for sea-based farms. Recirculation systems may be a feasible option, however, the capital costs would be high (Maclean and Laight 2000).

Biological containment requires induction of sterility in transgenic individuals so they cannot breed successfully if they escape into the wild. If cultured fish can be made sterile, it would eliminate the potentially deleterious consequences of interbreeding between wild and cultured fish.

OTHER IMPACT OF GENENTICALLY MODIFIED FISHES

Impact of Genetically Modified Fish on Human Health

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 (Berkowitz and Kryspin-Sorensen 1994; Maclean and Laight 2000). Concerns may arise for two reasons, namely: If the DNA is sourced from an allergenic protein, if the transgene causes an inactive toxin gene to be expressed (Berkowitz and Kryspin-Sorensen 1994). These dangers could be mitigated by a regulatory assessment procedure of the introduced gene on a case-by-case basis (Maclean and Laight, 2000), as is currently performed by government agencies with transgenic crops.

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 (Berkowitz and Kryspin-Sorensen 1994).

Some marine fish are associated with powerful toxins but in well-known edible fish, these toxins are of exogenous origin and are not a product of the fish genome itself (Berkowitz and Kryspin- Sorensen 1994). The cause has always been the incursion of red tides, bacteria, or other causes external to the fish.

None of the common food fishes are known to produce a toxin endogenous to the fish itself. Examples are the mullet and puffer fish which both contain toxins that are produced by marine bacteria that live in a symbiotic relationship with the fish (Tamplin 1990).

Impact of Genetically Modified Fish on Commercial Base

The primary reason for producing 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. In the US, the award of the first patent for a GM animal promoted intense debate. Religious groups questioned the morality of genetic modification stating that moral, social and spiritual issues should be considered more seriously before binding decisions are made on the issue.

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 (Hallerman and Kapuscinski 1991). At present, the commercial use of transgenic fish has not yet started and it is difficult to gauge the likely public reaction. Both Otter Ferry Salmon in Scotland and the New Zealand King Salmon Company scrapped their GM salmon research after unfavourable publicity.

Aqua Bounty Farms, the Canadian arm of a company based in Massachusetts, are still pressing ahead (Reichhardt 2000). They are producing AquAdvantage fish by taking a gene promoter sequence and splicing it to the growth hormone expression system of the salmon. AquAdvantage salmon have year-round expression of their growth hormone rather than just seasonal. The result is fish that grow from 400% to 600% faster than standard fish during the first year of life. These fish do not grow larger than their standard counterparts, and the rapid growth rate diminishes as the fish reach their natural adult size (Entis 1997).

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.

REFERENCES

1. Berkowitz, D. B. and Kryspin-Sorensen, I. K. (1994) Transgenic fish: Safe to eat? A look at the safety considerations regarding food transgenics. *Biotechnology* ,12: 247- 252.
2. BRS (1998) Mini Scenario Workshop on gene technology: Workshop report, Bureau of Rural Sciences, Canberra.
3. Bruggeman, E. P. (1993) Environmental safety issues for genetically modified animals. *Journal of Animal Science* ,71 (suppl. 3): 47-50.
4. Devlin, R. H., Johnsson, J. I., Smailus, D. E., Biagi, C. A., Jonsson, E., Bjornsson, B. T. (1999) Increased ability to compete for food by growth hormone-transgenic coho salmon Oncorhynchuskisutch (Walbaum). *Aquaculture Research,* 30: 479-482.
5. Devlin, R. H., Yesaki, T. Y., Donaldson, E. M., Du, S. J., Hew, C.-L. (1995) Production of germline transgenic Pacific salmonids with dramatically increased growth performance. *Canadian Journal of Fisheries and Aquatic Sciences* , 52:1376- 1384.
6. Entis, E. (1997) AquAdvantage Salmon: Issues in the introduction of transgenic foods. Transgenic Animals and Food Production, Proceedings from an International Workshop in Stockholm, May 1997.
7. FAO (2001) GM solution to overfishing.The United Nations Food and Agricultural Organisation. http://www.biotech2us.com/editorial/features/oct00/f%5F20001002.asp.
8. Farrell, A. P., Bennett, W., Devlin, R. H. (1997) Growth-enhanced transgenic salmon can be inferior swimmers. *Canadian Journal of Zoology* , 75: 335-337.
9. Fjalestad, K. T., Gjedrem, T., Gjerde, B. (1993) Genetic improvement of disease resistance in fish: an overview. *Aquaculture,* 111:65-74.
10. Grinde, B. (1989) Lysozyme from rainbow trout, Salmogairdneri Richardson, as an antibacterial agent against fish pathogens. *Journal of Fish Diseases,* 12, 95-104.
11. Gutrich, J. J. and Whiteman, H. H. (1998) Analysis of the ecological risks associated with genetically engineered marine macroorganisms. In: Genetically Engineered Marine Organisms: Environmental and Economic Risks and Benefits. (eds. Zilinskas and Balint). Kluwer Academic Publishers. Boston, USA.
12. Hew, C.L. and Fletcher, G. L. (2001) the role of aquatic biotechnology in aquaculture. *Aquaculture* 197: 191-204.
13. Hindar, K. (1995) Ecological and genetic effects of transgenic fish. Environmental Encounters Series – *Council of Europe,* 20:233-244.
14. Hindar, K., Ryman, N., Utter. F. (1991) Genetic effects of cultured fish on natural fish populations. *Canadian Journal of Fisheries and Aquatic Sciences,* 48: 945-957.
15. Johnsson, J. I., Petersson, E., Jonsson, E, Bjornsson, B. T. and Jarvie, T. (1996). Domestication and growth hormone alter antipredator behaviour and growth patterns in juvenile brown trout Salmotrutta. *Canadian Journal of Fisheries and Aquatic Sciences*, 53, 1546-1554.
16. Kapuscinski, A. R. and Hallerman, E. M. (1990) Transgenic fish and public policy: anticipating environmental impacts of transgenic fish. *Fisheries* , 15(1): 2-11.
17. Kapuscinski, A. R. and Hallerman, E. M. (1991) Implications of introduction of transgenic fish into natural ecosystems. *Canadian Journal of Fisheries and Aquatic Science,* 48 (suppl. 1): 99-107.
18. Knibb, W. (1997) Risk from genetically engineered and modified marine fish. T*ransgenic Research* , 6: 59-67.
19. Kohane, M. J. and Parsons, P. A. (1989) Domestication: evolutionary change under stress. *Evol. Biology,* 23: 31-48.
20. Maclean, N. (1998) Regulation and exploitation of transgenes in fish. *Mutation Research*, 399: 255-266.
21. Maclean, N. and Laight, R. J. (2000) Transgenic fish: an evaluation of benefits and risks. *Fish and Fisheries,* 1: 146-172.
22. Magurran, A. E. (1990) The inheritance and development of minnow anti-predator behaviour. *Animal Behaviour,* 39: 834-842.
23. Reichhardt, T. (2000) Will souped up+ salmon sink or swim? *Nature* 406: 10-12.
24. RSC (2001) Elements of precaution: Recommendations for the regulation of food biotechnology in Canada. The Royal Society of Canada. http : // www .rsc .ca/food biotechnology/GMreportEN.pdf
25. Smith, T., Breton, B., Prunet, P. (2001) Transgenic fish stay in the pond. European Commission-sponsored Research on Safety of Genetically Modified Organisms – A Review of Results. Available at: http://europa.eu.int/comm/research/quality-of- life/gmo/07-fish/07-intro.htm.
26. Tamplin, M. L. (1990) A bacterial source of tetrodotoxins and saxitoxins in marine toxins: origin, structure and molecular pharmocology (eds. Hall and Strichartz). American Chemical Society, Washington D.C.
27. Weatherly, A. H. and Gill, H. S. (1987) The biology of fish growth (eds. Weatherly and Gill). Academic Press, London, pp. 1-429.