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APPLICATION OF GENETIC TECHNOLOGIES IN AQUACULUTRE DEVELOPMENT AND MANAGEMENT

INTRODUCTION

1. The wild harvest of fish, invertebrates (mainly molluscs and crustaceans), and aquatic plants (mainly seaweeds), has provided human populations across the globe with important sources of nutrition from ancient times. Today aquaculture and capture fisheries directly employ over 180 million people, supporting the livelihood of 8 percent of the world's population, and each sector provides about 50 percent of the world's aquatic food supply.[1] There are more than 31 000 species of finfish, 85 000 species of mollusk, 47 000 species of crustacean and 13 000 species of seaweed, with more than 5000 species accessed in wild fisheries and about 400 species used in aquaculture. Aquatic genetic resources underpin the productivity and sustainability of world aquaculture and capture fisheries, and the essential services provided by aquatic ecosystems in marine, brackish and freshwaters.

2. The application of genetic principles to aquatic species used in aquaculture is a relatively recent phenomenon and the sector has not yet made full use of available technologies to increase production as other food producing sectors have done. Indeed it is only over the past two decades that there has been widespread acceptance that genetic improvement and the application of biotechnologies has an important role to play in aquaculture development and that very significant genetic gains can be achieved through the appropriate application of well planned genetic breeding programmes for aquatic species.

3. This document accompanies working document COFI:AQ/VI/2012/9 – *Genetic resources and technologies in aquaculture development: opportunities and challenges* and summarizes current and future applications of long-term and short-term genetic technologies in aquaculture production, and briefly touches upon other applications for the characterization and management of aquatic genetic resources and their increasing importance for traceability of fish and fish products.

[1] FAO 2010. The state of world fisheries and aquaculture 2010. FAO, Rome. 197p.

APPLICATION OF GENETIC TECHNOLOGIES IN AQUACULTURE PRODUCTION

4. Genetic technologies can be utilized in aquaculture for a variety of reasons, although the main use is to improve production. Improvements in marketability, disease resistance, body shape, color, culturability, and the conservation of natural resources can be facilitated by the appropriate genetic technology. Genetic improvement programmes can be used to provide short-term or long-term gains. The short term gains are usually immediate, within two generations, and generally not cumulative (unless combined with other long-term programmes), whereas the long term programmes such as selective breeding produce gains that accumulate each generation.[2]

Long-term genetic improvement strategies

5. Domestication and the full potential for the utilization of aquatic genetic resources will only be realized through long-term breeding programmes. The aquaculture sector lags far behind the crop and livestock sectors with regard to the development of domesticated and genetically improved strains.

Selective breeding

6. Growth rate is the characteristic most often improved in selective breeding programmes and increases of up to 20% per generation have been reported. Other traits have been shown to have additive genetic variance and therefore, amenable to improvement. Traits such as disease and stress resistance, timing of maturity and flesh quality are now being increasingly included in selective breeding programmes. Breeding programmes have been expanded and their design optimized, and new ones initiated. Examples of species used in recent breeding programmes include Atlantic cod, Atlantic salmon, common carp, gilthead seabream, hybrid striped bass, Lake Malawi tilapia, Mediterranean sea bass, Nile tilapia, red sea bream and rohu carp.

7. On disease resistance, the adoption of domesticated and genetically improved whiteleg shrimp *Penaeus vannamei* resulted in a drastic increase in shrimp aquaculture output but also posed serious risks of persistent infections, e.g. with viral pathogens that can be passed from broodstock to post-larvae. The use of specific pathogen free (SPF) domesticated shrimp should be supported by robust biosecurity as a prime consideration[3].

8. Another potential application of genetic selection techniques is in the area of enhancing feed utilization, i.e. to determine whether carnivorous fish with natural capacity for protein utilization as main energy source can be genetically selected[4].

9. Classic selective breeding programmes will continue to be the main engine driving the global finfish aquaculture industry forward.[5]

Genetic engineering

10. Genetic engineering technology is now beginning to find application in the production of aquaculture feed to assist in reducing the dependency on fishmeal and fish oil and to improve the

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[2] Bartley D.M. 1998. Genetics and breeding in aquaculture: current status and trends, pp. 13-30. In D.M. Bartley and B. Basurco (eds), Genetics and Breeding of Mediterranean Aquaculture Species Cahiers OPTIONS Vol. 34. 297p.

[3] Hine, M. et al. 2011. Expert Panel Presentation III.3. Improving biosecurity: a necessity for aquaculture sustainability, pp. xx–xx. Book of Abstracts, Global Conference on Aquaculture 2010, 22–25 September 2010. FAO/NACA/Thailand Department of Fisheries. Phuket, Thailand.

[4] Rana, K.J. et al. 2009**.** Impact of rising feed ingredient prices on aquafeeds and aquaculture production. *FAO Fisheries and Aquaculture Technical Paper*. No. 541. Rome, FAO. 63p.

[5] Hulata, G. 2009. Genetic improvement of finfish, p.55-86. In Burnell, G. and G. Allan (eds.). New technologies in aquaculture. CRC Press. 1191p.

terrestrial animal- and plant-based feed ingredients. Examples[6],[7] include: (1) genetically engineered yeast for production of important feed ingredients such as fish growth hormone and carotenoid pigments; (2) pre-processing techniques of plant material to reduce the effects of antinutritional factors, (3) breeding of plants with a better amino acid profile and less antinutritional factors, and (4) converting low grade land animal by-products into high-value protein.

11. Transgenic fish has been produced since the mid 1980s with most research focused on the transfer of growth hormone genes[8]. In several cases, significant increases in growth have been reported. Currently, no transgenic fish have been approved for commercial release as food for humans.

Short term genetic improvement strategies

12. Short-term genetic improvement techniques may not require the same level of record keeping nor management as long-term projects and can impart significant gains with simple technologies in a short period of time.

Hybridization and crossbreeding

13. Crossbreeding and hybridization can be utilized to combine favourable qualities from two genetically different groups and to take advantage of hybrid vigour (heterosis). Interspecific hybridization has resulted in fish with improved growth rates, manipulated sex ratios, sterile animals, improved flesh quality, increased disease resistance, improved tolerance to environmental extremes and other altered traits.[9]

Chromosome set manipulation

14. Manipulation of chromosome-sets (polyploidization) has been accomplished for many aquatic species through thermal and chemical shocks to developing embryos. Triploid organisms are useful because they are sterile and therefore able to put more energy into the growth process rather than into maturation and reproduction. Whilst chromosome-set manipulations have not resulted in many commercial applications for finfish, the use of triploids has become an important part of the oyster farming industry and may have similar potential in other shellfish. For example, triploid Pacific oysters have shown 14 - 159% growth improvement over diploid controls[10]. At the same time, sterility reduces the risk of breeding with native species which may be of importance in stocking programmes such as the use of grass carp for vegetation control or to address environmental impacts of fish escaping from farms.

Sex manipulation

15. Manipulation of sex can be of advantage in species with sexual dimorphism in important traits or when reduced chance of reproduction is desired. Monosex male stocks have considerable commercial benefit in a number of species, most notably in tilapia due to problems of both precocious maturation and unwanted reproduction within the production system exhibited by this species. Also, female trout and salmon grow better and female sturgeon produce caviar. The sex of fish can be easily

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[6] Ukibe, K. et al. 2009. Metabolic engineering of *Saccharomyces cerevisiae* for astaxanthin production and oxidative stress tolerance. Applied and Environmental Microbiology 75:7205-7211.

[7] Rana, K.J. et al. 2009**.** Impact of rising feed ingredient prices on aquafeeds and aquaculture production. *FAO Fisheries and Aquaculture Technical Paper*. No. 541. Rome, FAO. 63p.

[8] reviewed by Kapuscinski, A., 2005. Current scientific understanding of the environmental biosafety of transgenic fish and shellfish. Rev. Sci. Tech. Off. Int. Epiz. 24(1), 309-322.

[9] Bartley, D.M. et al. 2001. The use of inter-specific hybrids in aquaculture and fisheries Reviews in Fish Biology and Fisheries 10: 325–337.

[10] Guo et al. 2009. Chromosome set manipulation in shellfish, pp. 165-194. In Burnell, G. and G. Allan (eds.). New technologies in aquaculture. CRC Press. 1191p.

manipulated using hormonal treatments, but there has been concern about the use of hormones in animal production resulting in an increased use of other biotechnologies in those developing countries whose production goes to export markets.

Emerging technologies

16. A number of new genetic technologies are now beginning to be applied in cultured aquatic species. Genome technologies include DNA marker, novel sequencing, gene discovery, genome mapping (showing the relative positions of genes along a chromosome) and genome expression technologies that examine how genes actually function in the organisms. These technologies will be useful to find important genes affecting traits such as disease resistance, growth rate and sex determination, allowing more precisely targeted selection to improve aquaculture performance.

Other applications

17. The application of genetic technologies for the characterization of genetic resources has different applications in aquaculture ranging from identification of valuable genetic resources for genetic improvement programmes, management of farmed broodstocks, and discrimination between wild and cultured specimens, to monitoring of genetic effects of aquaculture escapees on wild populations[11].

18. The broad spectrum of applicability and high resolution of genetic markers can help to increase value in post-harvest and trade applications for fish and fish products. Traceability is a key aspect of aquaculture certification schemes[12]. Genetic markers provide an extremely sensitive means to identify samples of fish which could not be identified by other means, including frozen material, fillets, and early life history stages, e.g. eggs and larvae. Molecular genetic diagnoses of fish and fish products have already identified cases of mislabelling, consumer fraud and have helped convict offending parties[13].

19. Immunodiagnostic and molecular technologies are widely applied in pathogen screening and detection, elucidation of pathogenicity and disease diagnosis and have played an important role in health management due their high sensitivity, specificity, and ability for rapid diagnosis[14].

20. Linking the use of genetic technologies in fishing and aquaculture will increase efficiency and efficacy of the technologies. However, it should be noted that many of these technologies require specialized equipment and highly skilled staff.

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[11] Lidder, et al. 2011. Biotechnologies for the Management of Genetic Resources for Food and Agriculture. CGRFA Background Study Paper No. 52, FAO, 2011.

[12] FAO 2011. Technical Guidelines on Aquaculture Certification Version approved by the 29th Session of Committee on Fisheries (COFI) Rome, Italy. FAO, Rome.

[13] Martinsohn, J. 2011. Deterring Illegal Activities in the Fisheries Sector - Genetics, Genomics, Chemistry and Forensics to Fight IUU Fishing and in Support of Fish Product Traceability. JRC European Commission Reference Report.

[14] Hine, M., et al. 2011. Expert Panel Presentation III.3. Improving biosecurity: a necessity for aquaculture sustainability, pp. xx–xx. Book of Abstracts, Global Conference on Aquaculture 2010, 22–25 September 2010. FAO/NACA/Thailand Department of Fisheries. Phuket, Thailand.