Tilapia Genetic R&D in the Philippines:
Challenges and Prospects for Future Development

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Tilapias (*Oreochromis* spp.) are important aquaculture commodities that have been constantly studied in aquaculture genetic research and development (R&D). Specifically, genetic technologies including sex and chromosome-set manipulations, DNA markers, and transgenesis have created practical applications in tilapia culture. Recent advances in computing and sequencing technologies have facilitated the genetic and genomic studies in tilapia, making this commodity one of the most studied aquaculture species with robust available genomic-scale data. After dedicating efforts to the implementation of breeding programs that aim to improve the performance of farmed tilapia stocks, the Philippine tilapia aquaculture industry had rapidly developed and made substantial impacts on the country's total fish production. Success in such endeavors has changed the status of the country's tilapia aquaculture industry into a more productive one, shifting the Philippine perspective of becoming a globally-competitive tilapia producer. Nevertheless, despite the success in producing novel strains of tilapia with improved qualities, the tilapia aquaculture industry of the Philippines still continues to face challenges particularly in the area of genetic R&D.

During the past decades, genetic technologies including sex and chromosome-set manipulations, genome mapping, DNA markers, transgenesis, and marker-assisted selection (MAS) have already found their way for new and practical applications in aquaculture. However, results of the application of these modern technologies, especially gene transfer and manipulation, and DNA marker technique, have not yet made much impact on the aquaculture industry. It is believed that verification of the former although holding much promise has been constrained by inadequate resources while the latter has allegedly led to not very positive effects, thus, its adoption has been restricted to certain extent (Hulata, 2001). Nonetheless, many genetic tools are now continuously being applied to the aquaculture of a wide range of commodities, *e.g.* salmon, trout, catfish, common carp, tilapia, and ornamental fishes.

Tilapia (*Oreochromis* spp.) is not only economically valuable but has also been considered scientifically important for research studies on aquaculture genetics from the classical selective breeding and hybridization to drafting its recently released whole genome sequence (*http://www.broadinstitute.org*). Through the traditional breeding programs of the Philippines, benefits from genetic applications in tilapia R&D including the development of various genetically improved tilapia species have been reaped. The country's project on Genetic Improvement of Farmed Tilapia (GIFT), the first selective breeding initiative launched in the Philippines, served as a starting point for tropical fish genetic improvement programs around the world (Gupta and Acosta, 2004) and was recognized as the first project to formulate a selective breeding program for *O. niloticus* (Eknath *et al*., 1993). The introduction of GIFT and other improved tilapia stocks to the aquaculture industry since 1998 resulted in the rapid boost of tilapia production not only in the Philippines (Toledo *et al*., 2009) but also in other Southeast Asian countries (**Table 1**). However, despite successes in genetic enhancement of tilapia, the country's efforts to apply modern tools and techniques such as DNA marker technology in tilapia genetic research continue to be insufficient.

Table 1. Tilapia production (in metric tons: MT) of Southeast Asia

Southeast Asian countries	2006	2007	2008	2009	2010
Brunei Darussalam	50	...	...	...	6
Cambodia	600	600	...	...	...
Indonesia	95,699	97,085	328,831	...	458,152
Lao PDR	...	...	...	...	...
Malaysia	28,887	32,024	34,823	35,583	38,886
Myanmar	10,000	3,300	30,938	34,860	85,848
Philippines	190,043	228,748	...	260,911	258,638
Singapore	5	3	...	...	40
Thailand	205,568	213,800	217,200	209,141	179,355
Vietnam	...	...	50,000	...	...
TOTAL	**530,852**	**575,560**	**661,792**	**540,495**	**1,020,925**

Note: Some countries were unable to provide updated data during the reporting periods (SEAFDEC, 2009-2012)

Genetic Applications in Tilapia Aquaculture

Various commodities have been used in carrying out genetic improvement of stocks for the aquaculture industry. Specifically for tilapia, selective breeding, hybridization, and chromosome set manipulation, also known as traditional

genetic improvement techniques have been adopted to improve the stocks (McAndrew and Napier, 2011). Later, the application of wide range of techniques such as the molecular-based approaches (*e.g.* genetic markers, genetic mapping and functional genomics, transgenesis) followed suit not only for tilapia but also for other aquatic organisms.

Genetic markers for monitoring and management

In aquaculture, good quality seeds are results of proper broodstock selection and management while poor stock management practices are potential causes of reduced stocks performance (Eknath *et al*., 1991; Hulata *et al*., 1986; Macaranas *et al*., 1995). Therefore, in order to increase production, improvement of stocks is necessary including sound inferences on the monitoring and management processes that are not solely based on selective breeding and the culture methods used, but also on the genetic characteristics of the stocks. The use of DNA markers as genetic tools for aquaculture monitoring and management have become a significant trend in tilapia culture operations. While markers and microsatellites have seen notable impacts in genetic aquaculture research, markers have also been very effective in addressing a wide array of concerns in tilapia aquaculture and are used to provide more accurate information on the genetic diversity of natural stocks (Agnese *et al*., 1997).

Genetic mapping and functional genomics

With recent advances in computational and sequencing technology, assembly of large genomic resources for many aquatic organisms including non-model species had become easier and faster, making the required data readily available. From various sequencing innovations, tilapia has become one of the major aquaculture species with the most robust genomic-scale data available where genomes (genetic materials of an organism) had already been documented from karyotypes (chromosomes of a cell displayed in systematized and paired arrangement) of various tilapias down to their genome (Majumdar and McAndrew, 1986; Guyon *et al*., 2012). While several sets of genetic markers to determine the genetic linkage maps of tilapia had been charted, *e.g.* microsatellite-based linkage maps, the bacterial artificial chromosome (BAC)-based physical map of tilapia genome has also been generated (Katagiri *et al*., 2005). Such feat has significantly contributed to the establishment of more comprehensive genetic and physical maps of tilapia which became useful in subsequent genetic studies.

Recently, genomic data from tilapia had increased but studies focusing on genome scan for tilapia are presently very few. Nevertheless, it is apparent that next generation sequencing (NGS) technology is probably the most efficient method for identifying genetic markers (*e.g.* microsatellites and single-nucleotide polymorphisms (SNPs) and genetic linkage and physical map construction. Developing genetic and physical maps of tilapia also represent a valuable resource to support the identification and isolation of genes or quantitative trait loci (QTLs) which control the economically-important traits of the species for comparative genomic studies (*e.g.* genome evolution) and further interventions (*e.g.* marker-assisted selection (MAS)). Aside from growth and body weight-related markers, one of the interesting aspects in tilapia genetic mapping studies is the identification and mapping of markers and QTL alleles associated with sex-linkage (Ezaz *et al*., 2004; Shirak *et al*., 2006; Cnaani *et al*., 2008; Liu *et al*., 2013). These data have immediate uses for tracking sex-linked haplotypes in breeding programs aimed at controlling the sex of fingerlings for commercial production of monosex populations (Lee *et al*., 2004). Extensive mapping has also been carried out for the other commercially-important traits of tilapia such as cold and salt-tolerance.

Functional genomics has also been considered an important research area for aquaculture, and their applications include investigation of the relationship of somatic growth and different factors as reflected in the levels of expression of certain genes. This is useful for the development or rearing of strains with enhanced growth. In tilapia, Vera Cruz *et al*. (2006) established a positive correlation between the levels of hepatic insulin-like growth factor-I (IGF-I) and growth rate, suggesting that measurement of IGF-I could prove useful as a rapid and direct indicator of growth in tilapia. In addition, at optimum combination of temperature and dietary protein, enhanced growth rate and feed utilization could be attained from the increased expression of somatotropic genes including pituitary growth hormone (GH), hepatic growth-hormone receptor 1 (GHR1) and IGF-I mRNA (Qiang *et al*., 2012). Therefore, the levels of expression of somatotropic genes could be used to assess the growth of tilapia species.

Transgenic tilapia

Transgenesis is defined in textbooks as the introduction of exogenous gene or transgene to a living organism in order for it to acquire new property that could be transmitted to its offspring. The availability of fish gene sequences has made a remarkable impact in transgenesis of cultured fish species including tilapia, where much focus in transgenic research had been placed on the development of strains capable of accelerating growth as well as germ cell transplantation (Farlora *et al*., 2009) and turning into potential biofactories for valuable pharmaceutical products (Maclean *et al*., 2002), among others. Furthermore, generations of cold-resistant and saline-tolerant transgenic tilapia lines are also currently being developed through transgenesis (He *et al*., 2013). Although transgenic fish technology offers a promising contribution to aquaculture advancements, it still needs to be experimentally refined. Nevertheless, in order to improve the efficiency in producing transgenic tilapia, research studies

have made focus on the application of different gene transfer techniques.

Guillen *et al*. (1999) conducted a study to address health risk concerns from consumption of transgenic tilapia, where transgenic hybrid *Oreochromis urolepis hornorum* that contained an expressed tilapia GH transgene were given to 22 persons for five (5) consecutive days, twice daily. After the evaluation, results showed that consumption of the transgenic tilapia showed no effect on any clinical or biochemical parameters consequently confirming that the fish GH is not bioactive in primates. However, there is still no authenticated release of transgenic fish for aquaculture because of difficulties in assessing the environmental risk of escapees if culture is made outside experimental laboratories (McAndrew and Napier, 2011). Therefore, sterility in transgenic fish has been used as a control measure to contain transgenic tilapia, especially when completely secured land-locked facilities are not available (Maclean *et al*., 2002) since transgenic technology could be exploited and thus, risks associated with rearing transgenic tilapia and genetically modified (GM) fish in general, could be minimized.

Tilapia Genetic Research in the Philippines

In the Philippines, the culture of tilapia began in 1950s with the introduction of the Mozambique tilapia species (*Oreochromis mossambicus* Peters 1852), but culture of this so-called "wonder fish" failed to promote commercial production because of its unwanted characteristics such as early maturation resulting in overpopulation in fishponds, stunted growth, small size at harvest, becoming "pests" in brackishwater ponds, and unappealing dark color (Bolivar, 1993; Guerrero, 1994). This led to the launching of a research program at the Freshwater Aquaculture Center of the Central Luzon State University (FAC-CLSU) in the Philippines in 1974 on monosex male culture and sex reversal of females through hormone treatment of tilapia fry (Guerrero, 1994). This was the earliest genetic application to improve tilapia production in the country that also marked the emergence of a line of technologies for commercial tilapia production that were developed over the succeeding decades (Yosef, 2009).

In 1970s, different strains of Nile tilapia (*Oreochromis niloticus* L.) were introduced in the Philippines from various origins (Guerrero and Tayamen, 1988; Bolivar, 1993). These strains rapidly gained popularity with farmers and consumers because of better characteristics (*e.g.* lighter color, faster growth, and high tolerance to various environmental conditions) over the Mozambique tilapia. However, problems were encountered later on the culture of these species.

Early on, major constraints in tilapia culture (and tropical fishes in general) that confront many developing countries include inadequate supply of seeds and poor genetic quality of cultured stocks compared to the wild population because of inbreeding depression (Pullin and Capili, 1988; Eknath *et al*., 1993; Acosta *et al*., 2006). In fact, tilapia production began to decline in 1980s due to the deterioration of genetic quality of tilapia stocks that led to significant reduction in performance of farmed Nile tilapia. Thus, the public sector, national institutions and international organizations based in the Philippines initiated in 1986 several programs on selective breeding and development of other technologies for genetic improvement using the Nile tilapia (Bolivar, 1993; Acosta *et al*., 2006).

Various agencies in the Philippines embarked on R&D programs to improve tilapia strains for aquaculture through genetics and biotechnology to make the aquaculture industry of the Philippines more profitable and sustainable (DA-BAR, 2001), such as the Aquaculture Research Development and Extension Division of the Department of Agriculture-Bureau of Agricultural Research (DA-BAR) and the Philippine Council for Aquatic and Marine Research Development [(PCAMRD), now the Philippine Council for Agriculture and Aquatic Resources Research and Development (PCAARD)]. While the potentials for increased aquaculture production were seen through better farm management, it was deemed necessary to increase the supply to meet the demand, which could be achieved through the use of genetically improved breeds/strains. Therefore, several genetic techniques for stock enhancement have been applied to increase the country's global competitiveness in the production of tilapia and other aquatic commodities that could provide better quality of life for fish farmers and fisherfolk (Abella, 2006).

At present, tilapia is the second most important food fish for domestic consumption in the Philippines (Lopez *et al*., 2005; BFAR, 2010) after milkfish (*Chanos chanos* Forsskal 1775). This national scenario emanated from increased tilapia production brought about largely by various efforts in tilapia genetics R&D that resulted in significant advances in the genetic improvement specifically in Nile tilapia. While the main focus of most of early research studies was to improve growth performance (Eknath *et al*., 1993; Basiao *et al*., 1996; Bolivar and Newkirk, 2002; Tayamen *et al*., 2006), this had shifted later to initiatives that aimed to produce strains that would perform well in different culture environments such as in farms with low-temperature or high-saline levels (Romana-Eguia and Eguia, 1999; Tayamen *et al*., 2002; Rosario *et al*., 2004). Such tilapia breeding programs have not only led to the tremendous progress in terms of increased tilapia production in the Philippines but also highlighted the

application of genetics for various aquaculture commodities in the country.

Products of Tilapia Breeding Programs

In the Philippines, different tilapia strains were produced from the various breeding programs as shown in **Table 2**, through multi-institutional collaboration among government institutions, agencies and international organizations with funds coming from both national and international donor agencies (Abella, 2006). The various strains developed and generated from such programs, *i.e.* GIFT, FaST, YY-male and GMT, GET EXCEL, GST™, SST, Salt-tolerant strains (Molobicus and BEST), and Cold-tolerant, are described in **Box 1**.

Table 2. Genetic breeding programs carried out in the Philippines (Modified from Abella (2006) and Acosta (2009))

Strain Developed	Research Project	Project Year	Implementing institutions	Donor(s)/Funding institution(s)	Significant Results	Producers	Commercial Distribution
FAC-selected Tilapia (FaST or "IDRC" strain)	Fish Genetics Project	1986-1996	FAC-CLSU	International Development Research Centre (IDRC)	Produced fast-growing strains of *O. niloticus*	hatcheries that purchase broodstock from FAC-CLSU	1993
Genetically Improved Farmed Tilapia (GIFT)	Genetic Improvement of Farmed Tilapia	1988-1997	Institute of Aquaculture Research, AKVAFORSK, Norway, FAC-CLSU, ICLARM, BFAR-NFFTC, UPMSI	Asian Development Bank and United Nations Development Programme	Produced fast-growing strains of *O. niloticus* and demonstrated that *O. niloticus* respond positively to selection	GIFT (Genetically Improved Farmed Tilapia)	1997
GenoMar Supreme Tilapia (GST™)		1999-2002		GenoMar	Application of DNA genotyping technology, selection differential increased, and total genetic gain on growth rate was 40% higher than the ninth-generation GIFT	GenoMar Philippines, Inc.	2002
Genetically Male Tilapia also called "YY" (YY male/ GMT)	Genetic Manipulation for the Improvement of Tilapias	1988-1997	University of Wales, Swansea, FAC-CLSU, BFAR-National Freshwater Fisheries Technology Center (NFFTC)	Overseas Development Administration (ODA)	Produced genetically male tilapia for grow-out and YY breeders for fingerling production	Produced by Fishgen Ltd. and by Phil-Fishgen and its accredited hatcheries in the Philippines	1995
Genetically Enhanced Tilapia - Excellent (GET-EXCEL)		2002	BFAR-NFFTC	DA-BAR	Combining strain crosses and adopting within family selection of four different strains of *O. niloticus*	produced by NFFTC and its accredited multipliers	2000
Brackishwater Enhanced Selected Tilapia (BEST) Cold-tolerant tilapia (COLD)	Development of Saline and Cold tolerant Tilapia	1998-present	FAC-CLSU, BFAR-NFFTC, University of the Philippines-Visayas	DA-BAR	Formed a base population from four different *Oreochromis* species by combining best performing purebreds and crossbreeds after rigid evaluation in different environments	produced by NFFTC and its accredited multipliers	2003 2005
Molobicus	Development of Saline Tolerant Tilapia Hybrid (Molobicus Program)	1998-present	BFAR-National Integrated Fisheries Technology Development Center (BFAR-NIFTDC)	Philippine Council for Aquatic Marine Resources and Development (PCAMRD) and Centre de Cooperation Internationale en Recherche Agronomique pour le Development (CIRAD)	Developed saline tilapia hybrids through hybridization using *O. niloticus* and *O. mossambicus*	produced by NIFTDC and its accredited multipliers	?
(SEAFDEC-Selected Strain (SST)		1999-?	Southeast Asian Fisheries Development Center - Aquaculture Department (SEAFDEC/ AQD)		Produced fast growing strain of *O. niloticus* (Chitralada stock) from modified mass selection technique with collimation technique and developed a small-farm, low-cost selection program	SEAFDEC-AQD	?

Box 1. Strains generated from the various tilapia breeding programs in the Philippines

FaST strain

FAC-CLSU which is responsible for the development of FaST or FAC-Selected Tilapia (or FAC-selected and IDRC) collaborated with two Canadian institutions, the International Development Research Centre (IDRC) and University of Dalhousie to produce a fast-growing tilapia using within family selection, starting with available strains of Nile tilapia (known as "Taiwan", "Singapore", "Thailand", and "Israel" which are generally referred to as "Philippine strain" (Bolivar *et al.*, 1994)). Selection for the nineteen full sib groups was based on body weights at 16 weeks of age, and the heaviest individuals from separate families were mated (1 male: two females). An estimated genetic gain in body weight of 12% per generation was observed after 12 generations of selection. Comparison of the growth rate of FaST and GIFT (Bolivar and Newkirk, 2002; Ridha, 2006) showed no significant difference between both strains, but in terms of survival rate, GIFT was found to have higher (23%) survival (Ridha, 2004). Overall, FaST and GIFT strains had better growth rate, feed conversion ratio and production rates than the non-improved strains (Ridha, 2006). FaST was the first improved tilapia to be commercially disseminated, and was initially distributed in 1993 as the International Development Research Centre (IDRC)-selected tilapia, a reference to the funding agency supporting the research project that resulted in its development (Abella, 2006).

GIFT strain

The need to develop low-cost and improved breed of Nile tilapia (*O. niloticus*) in different agro-ecological conditions and farming systems in the Philippines opened the avenue for the collaboration of ICLARM (now WorldFish Center) with other institutions such as the Philippine-based BFAR, CLSU and Marine Science Institute of the University of the Philippines (UP-MSI), and Norwegian Institute of Aquaculture Research (AKVAFORSK) giving rise to the GIFT Project which started in 1988. Launched as a starting point for tropical fish genetic improvement around the world (Gupta and Acosta, 2004), this project was the first to formulate a selective breeding program for *O. niloticus* at the national and international levels (Eknath *et al.*, 1993) for improved breeds of Nile tilapia, and developed the capacity of national institutions in aquaculture genetics research. After the performance assessment of pure bred and crossbred groups among the eight strains (imported wild strains and commercially-farmed strains) from various sources, 25 best-performing groups were selected to construct a synthetic base population, successfully producing a generation that had higher growth and survival performance under on-farm and on-station conditions compared to the local strains farmed in the Philippines. Eknath and Acosta (1998) reported a 12-17% gain over five generations of fish or a 60-85% cumulative increase over the base population. Result of an evaluation of the performance in different agro-ecological countries indicated that the GIFT strain outperformed the non-GIFT strains in terms of growth both in pond and cage culture systems (Dey *et al.*, 2000). The development of GIFT favored an interchange of essential information as well as collaborative research among developing countries across Asia, and among scientific institutes, international organizations, and the private sector (Yosef, 2009). In the Philippines, the development of GIFT led to the creation of other genetically enhanced strains which were referred to as "sons of GIFT" using the GIFT strain as one of the base populations.

YY-male and GMT

Simultaneous with the GIFT project was the development of YY-male and GMT producing broodstock under the Genetic Manipulation for the Improvement of Tilapias (GMIT) Program through the collaboration of the University of Wales Swansea (UWS), FAC-CLSU and BFAR-National Freshwater Fisheries Technology Center (BFAR-NFFTC). YY-male technology was conceptualized as a breeding program that generates monosex tilapia (with YY genotypes instead of XY for normal males) providing an alternative to hormonal sex reversal and hybridization. Also known as genetically male tilapia (GMT), the YY-males are called "supermales" with unique capability of siring only genetically male progeny when crossed with normal female with mean progeny sex ratio of 95% male (Mair *et al.*, 1997a). Phil-Fishgen, established at CLSU in 1985, was tasked to disseminate the outputs of the technology (under the registered trade name of GMT licensed by Fishgen Ltd.) and to generate income for the financial sustainability of future FGBP (FishGen Breeding Program) research activities (Tayamen *et al.*, 2006). The YY-male technology provided an effective solution to the problems of early sexual maturation before reaching market size, stunting and overpopulation in tilapia culture systems trough the application of mixed-sex culture system. It also generally solved genetic deterioration in farmed tilapia strains which was then a significant constraint in tilapia production (Mair *et al.*, 1995; Tuan *et al.*, 1998; Abucay *et al.*, 1997). GMT performed much better than the sex-reversed male tilapia in terms of yield, survivability, and food conversion ratios. Moreover, YY/GMT culture is relatively environment-friendly because no hormones are applied while hormone application to broodstock is low (Dunham *et al.*, 2000). Although this technology addressed some of the problems such as early sexual maturation and unwanted reproduction during grow-out that reduces yield, certain issues emerged. Ponzoni *et al.* (2008) pointed out that the hormones used in masculinization pose concerns on food safety since it takes three generations to produce YY-males by the time they are ready for use, the strain could lag behind in terms of genetic gain by 20-45%, and a laboratory with modern facilities to sustain this technology might not be available in many developing countries.

GET EXCEL

As envisioned in the Philippine National Tilapia Breeding Program, BFAR-NFFTC continued to develop fast growing GIFT strain, known as Genetically Enhanced Tilapia or GET 2000. BFAR-NFFTC also completed the selection of genetically enhanced base population from the GET 2000 parent line, resulting in the GET 2002 EXCEL. The new strain was a product of a selection program that combined strain crosses and within-family selection with rotational mating using four parent lines: 8th Generation GIFT, 13th Generation FaST, *O. niloticus* Egypt strain, and Kenya strain (Tayamen, 2005). The superior breed of tilapia dubbed as "EXCEL" (short for EXCELlent strain) had comparable advantages over other tilapia strains for entrepreneurial livelihood. Compared to the 8th generation GIFT fish, EXCEL had higher survival, more disease resistant, can withstand temperature fluctuations and enhance growth. To produce additional weight gain of 38 g to every 100 g of the GIFT strain (Ng, 2004), the improved GET EXCEL 2010 was introduced by NFFTC with an estimated 48 g higher growth gain than the origininal GET 2000, that prompted the launching of the "Nationwide Dissemination of GET EXCEL Tilapia" (Tayamen, 2005).

GST™

The GST™ strain originated from the "GIFT Super Tilapia" or the fifth generation strain that was developed through the GIFT project. After the project ended in 1999, a nonprofit private foundation known as the GIFT Foundation International (GFI) was established through partnerships with private sector hatcheries in the Philippines (Acosta *et al.*, 2006) to carry out tilapia seed production programs. In order to expand its market GFI contracted GenoMar ASA, a private Norwegian company involved in aquaculture biotechnology, for the development of GIFT Super Tilapia strain (Gjoen, 2001). This commercial alliance enabled GFI to receive an equity position in GenoMar as well as certain rights to produce and distribute improved tilapia strains developed by GenoMar. Since then, GenoMar has conducted selections for three more generations through DNA typing as a replacement to physical tagging (GenoMar, 2008). With this state-of-the art breeding technology, the selection differential has increased very significantly per generation in terms of genetic gain. This improved strain from GenoMar was launched in late 2002 and is believed to have 40% higher genetic gain (in terms of growth) compared to GIFT 9th generation (Gjoen, 2001). In 2003, GenoMar developed the 14th generation of GIFT-derived strains (Yosef, 2009), and continues to produce new generations every nine months with annual genetic gain estimated at more than 15% of the growth (GenoMar, 2008). Experiments have also shown that these improved strains grow faster, more than twice as fast as the local strains (Acosta and Gupta, 2010).

Box 1. Strains generated from the various tilapia breeding programs in the Philippines (Cont'd)

Salt-tolerant strains: Molobicus and BEST

BFAR-NIFTDC collaborated with PCAMRD and the Centre de Cooperation Internationale en Recherche Agronomique pour le Development (CIRAD), a French scientific organization specializing in development-oriented agricultural research for the tropics and sub-tropics, and launched the Molobicus Program to culture fast-growing tilapia in brackishwater ponds, rivers and estuaries, involving the development of highly saline-tolerant tilapia. Known as Molobicus (combination of *O. mossambicus* and *O. niloticus*), its selection scheme for the first phase involved repeated backcrossing of progenies of *O. niloticus* and the hypersaline *O. mossambicus* to develop hybrids (Rosario *et al.*, 2004), and the next phase comprised selection of fast-growing characteristics from interspecific hybrid population. This rotational crossing scheme was done to preserve genetic variability of the individuals (Camacho *et al.*, 2001; Rosario *et al.*, 2004). Another salt-tolerant hybrid, the Brackishwater Enhanced Selected Tilapia (BEST) was developed by BFAR-NFFTC in collaboration with FAC-CLSU and the University of the Philippines Visayas (UPV) from 1998 to 2005. The BEST strain was developed using three euryhaline tilapia species (*O. mossambicus*, *O. aureus* Steindachner 1864, and *O. spilurus* Günther 1894) and three genetically improved Nile tilapia strains (GIFT, YY/GMT and FAST) as founder stocks. Products of the selection resulted in growth gains of about 86% compared to F_1 pure cross of *O. mossambicus* and 24% compared to F_1 of *O. mossambicus* x *O. niloticus* Egypt strain. Survival also increased by 24% compared to pure *O. mossambicus* cross and 35% compared to the cross of *O. mossambicus* x *O. niloticus* Egypt strain (Tayamen *et al.*, 2002). The latest stock produced by NFFTC was named "BEST 2010".

Selective breeding of salinity-tolerant strain of Nile tilapia hybrid was also implemented by SEAFDEC/AQD involving hybridization of *O. niloticus* with *O. mossambicus* followed by repeated backcrossing of the hybrid with *O. niloticus* (Basiao, 2001). On the other hand, BEST and *Molobicus* strains were evaluated (Danting pers. comm., 2012) to assess the advantages of these strains. One of the possible advantages is the suitability of the strains to brackishwater environments which could serve as an alternate culture species for shrimps and milkfish when seedstocks of the latter commodities are not available or could be grown in polyculture with other farmed brackishwater species. Another interesting development is on the use of saline-tolerant tilapia for the "greenwater technology" to control Vibriosis disease in shrimp (*Penaeus monodon* Fabricius 1798) farming in brackishwater ponds. The use of saline tilapia was considered bioremediation factor since the greenwater produced by tilapia prevents the occurence of diseases in shrimp farms and helps in controling unwanted weeds.

Cold-tolerant tilapia

The inability of tilapia to tolerate low temperatures is a serious concern for commercial aquaculture in colder regions of the Philippines. The optimal temperature for tilapia growth is between 25° and 28°C (Charo-Karisa *et al*, 2005), while numerous adverse effects could include high mortality due to low temperature at 10-12°C, cessation of feeding activity below 16-17°C, and reproductive inhibition below 20°C (Yadav, 2006). Thus, the project on "Development of Cold Tolerant Tilapia" was initiated by BFAR-NFFTC to develop a breed of tilapia which could withstand cold temperatures in northern Philippines like in the Cordillera Autonomous Region (CAR), and in other areas with relatively cooler temperatures (ranging from 10° to 22°C) during the country's cold season. The project envisions to maximize these areas in order to produce additional supply of marketable size tilapia. The base population of the COLD Tilapia as it is now called, is composed of *Oreochromis* species, namely: *O. aureus*, *O. spilurus* and the two improved breeds of Nile tilapia, namely: the 8th Generation GIFT and FaST. The project was implemented in five consecutive years following rigorious evaluation in ponds, tanks and cages under different environments following the communal stocking scheme.

SST

The Aquaculture Department of the Southeast Asian Fisheries Development Center (SEAFDEC/AQD) based in the Philippines developed its own growth-enhanced strain starting in 1999, through a simple farm-based size-specific mass selection on previously size graded stock. This was aimed at developing tilapia broodstock improvement program that is low-cost, small-scale, and could be applied under very practical conditions (Lutz, 2004). The SEAFDEC-selected strain or SST was produced from 100 pairs of domesticated Thai Nile tilapia (NIFI) stock, known as Chitralada. SST was developed through a simple mass selection to improve the growth of cage-reared Nile tilapia. Response to selection after one generation of size-specific mass selection was noted at 3%, while the realized heretability was estimated at 16%, a projected improvement of 34% over a 5-year period (Basiao and Doyle, 1999). However, this strain has not been extensively distributed as the other more popular strains such as GET-EXCEL, GST™, GMT and FaST.

Impacts of Improved Tilapia Strains in the Aquaculture Production of the Philippines

Tilapia has been widely adopted as a substitute for all kinds of wild-caught fishes pushing the global demand for tilapia to yearly increases despite world-wide recessions (Fitzsimmons *et al*., 2011). In the Philippines, the continuous effort of enhancing the overall quality of tilapias by fish breeding institutions has contributed to increased demand for tilapia products in the market (Toledo *et al*., 2009). As a result, farmed tilapia costs much cheaper than chicken, becoming an important fish and protein source in the diet of poor Filipinos who had been consuming less milkfish, round-scad (*Decapterus* spp.) and other native freshwater fishes (Edwards, 2006; ADB, 2005). Moreover, the affordability and stable market price of tilapia coupled with income elasticity of demand among poorer populations in the Philippines make it a significant food fish to financially-challenged Filipinos (Yosef, 2009). As a matter of fact, after the introduction of enhanced tilapia strains that led to increased production, the average per capita consumption of tilapia in the Philippines had risen by 474% from 0.66 kg (before the introduction) to 3.13 kg per year in 2010 (Yosef, 2009; BAS, 2012). Figures have shown that in the past decade from 2002 to 2012, tilapia production achieved a remarkable 50% growth with maximum production of 303,169 metric tons (MT) in 2012, accounting for about 6% of the country's total fisheries production in the same year (BAS, 2012). This phenomenon could be attributed to fish farmers' access to wide range of tilapia strains, and increased resources and labor force since tilapia farming operations became widespread. Since 68% of the total tilapia seeds produced in the country in 2003 comprised GIFT and GIFT-derived tilapia strains (ADB, 2005), this validates the significant contribution of this genetic improvement to the growth of the country's tilapia production that was recorded at 145,869 MT in 2004, making the Philippines third among the top tilapia producers of the world.

In 2011 however, other countries especially Indonesia and Thailand have remarkably increased their tilapia production pushing the Philippines behind at the top five. In this connection, the Philippines developed its Master Plan for the Tilapia Industry that included a target to increase tilapia production from 122,000 MT in 2002 to 250,000 MT in 2010 (DA, 2002), and in 2008, the expected volume had been exceeded. Nonetheless, increases in Philippine tilapia production had not been as pronounced as in other Asian countries due to various management obstacles encountered (Yosef, 2009). Although many Filipinos have benefited from improved tilapia strains, gains could not be measured in terms of the number of consumers only but also on the number of Filipinos who have benefited from the tilapia industry (CGIAR, 2006).

Other Applications of Tilapia Genetic R&D

In genetic research of tilapia, most studies used technologies such as DNA markers for genetic characterization, gene mapping, and functional genomics, while molecular-based knowledge in tilapia genetics and stock management have been confined to some developed and developing countries in Asia, including the Philippines (Galman-Omitogun, 2005). Despite being recognized as one of the most successful countries to apply traditional genetic R&D in its breeding programs, the Philippines has yet to boost its effort in the area of genetic applications in aquaculture. Until now, the country still lacks the capacity to utilize advanced genetic technologies as tools for management and monitoring, and for exploring the potentials of tilapia genetic resources for production enhancements. Development of novel strains and improvement of stocks through genetics and biotechnology is a vital aspect in tilapia aquaculture that should be addressed to secure its sustainability and profitability. Under the National Integrated Research Development and Extension Program (Aquaculture) of the Philippines and in the formulation of the Aquaculture Research Development and Extension Agenda of DA-BAR and PCAARRD (DA-BAR, 2001), earlier genetic works were centralized in creating improved tilapia strains through genetic improvement from simple species-crossing to organized selection programs, to enhance their viability, reproductive fitness, and adaptability to environmental changes and stress (Kuo and Abella, 1982). While improved tilapia strains have been produced through traditional selective breeding, hybridization, cross-breeding, sex reversal or combination of these techniques, most of these programs, *i.e.* selective breeding, have been conducted typically in favorable environments where growth is expected to be high and results that bring forth additive genetic variables exploited from such programs (Tran *et al*., 2011).

From the previous experimental breeding programs conducted in the Philippines, tilapia research during the past three decades were mostly based on the growth performance of tilapia in different farm environments (Galman *et al*., 1988; Basiao *et al*., 1996; Mair *et al*., 1997b; Romana-Eguia and Eguia, 1999; Basiao *et al*., 2005; Romana-Eguia *et al*., 2010), and on the development and determination of strains suitable for saline waters (Villegas, 1990; Romana-Eguia and Eguia, 1999; Rosario *et al*., 2004; Tayamen *et al*., 2002). In addition, the use of more powerful molecular techniques was also recently started although other protein markers were already used in few studies in the previous years. Some of the genetic researches on tilapia in the Philippines are shown in **Table 3** which includes only the studies conducted by or in collaboration with, government or national institutions, and those studies which used different strains in the methodologies, specifically the strains developed in the Philippines. While the table summarizes the available information, all experiments on genetic technologies in tilapia aquaculture R&D might not have been necessarily enumerated. Nonetheless, **Table 3** would provide valuable information for various aspects of aquaculture practices with special highlight in selective breeding programs and genetic improvements of aquaculture stocks.

It should be recalled that in the beginning, efforts of the Philippines in analyzing the genetic aspects of tilapia focused on two areas, *i.e.* genetic differentiation of cultured tilapia stocks using morphometric and meristic characters (Pante *et al*., 1988) as well as biochemical or protein markers for allozyme analysis (Pante and Macaranas, 1989; Macaranas *et al*., 1993, 1995), and genetic characterization of stocks to basically address the problems of deteriorating quality of tilapia fingerlings and reduced performance of farmed tilapias in 1980s (Taniguchi *et al*., 1985; Macaranas *et al*., 1986) using allozyme electrophoresis which was widely used for genetic characterization during that period. The results revealed the founder and bottleneck effects in cultured tilapia stocks as well as widespread introgression of genes from the less desirable species *O. mossambicus* to the commercial Nile tilapia. This finding actually signaled

Table 3. Genetic researches on tilapia in the Philippines in the past 20 years

Research areas/titles	Technology	References
Genetic enhancement of tilapia thru breeding program	Selective breeding techniques, hybridization, crossbreeding	Eknath *et al.* (1993)
Genetic characteristics of food fishes		
Introgressive hybridization in cultured tilapia stocks in the Philippines	Allozyme genotyping	Taniguchi *et al.* (1985)
Electrophoretic evidence for extensive hybridization gene introgression into commercial *O. niloticus* stocks in the Philippines	Allozyme genotyping	Macaranas *et al.* (1986)
A preliminary study on the use of canonical discriminant analysis of morphometric and meristic characters to identify cultured tilapias	Morphometric and meristic analysis	Pante *et al.* (1988)
Documentation and genetic characterization of different tilapia strains	Allozyme genotyping	Macaranas *et al.* (1993); Pante and Macaranas (1989)
Genetic improvement of farmed tilapias: biochemical characterization of strain differences in Nile tilapia	Allozyme genotyping	Macaranas *et al.* (1995)
YY male technology	Sex manipulation	Abucay *et al.* (1997); Mair *et al.* (1997a, 1997b)
Multilocus DNA fingerprinting and RAPD reveal similar genetic relationships between strains of *Oreochromis niloticus* (Pisces: Cichlidae)	DNA markers (minisatellites, RAPD)	Naish *et al.* (1995)
Genetic Diversity in farmed Asian Nile and Red Hybrid Tilapia stocks evaluated from microsatellite and mitochondrial DNA analysis	DNA markers (microsatellites, RFLP)	Romana-Eguia *et al.* (2004)
Genetic changes during mass selection for growth in Nile tilapia, *Oreochromis niloticus* (L.), assessed by microsatellites	DNA markers (microsatellites)	Romana-Eguia *et al.* (2004)
DNA barcoding of different tilapia strains in the Philippines*	DNA barcoding (mitochondrial DNA, nuclear DNA)	
Mining molecular markers in the gene of cultured Nile tilapia associated with disease resistance**	DNA markers	

* On-going project of the National Fisheries Research and Development Institute, Philippine Bureau of Fisheries and Aquatic Resources
** On-going project of Central Luzon State University, Nueva Ecija, Philippines

the start of research on the genetic improvement of tilapia in the Philippines.

Nevertheless, very few research studies employed the polymerase chain reaction (PCR)-based methods, where the earliest record used multilocus DNA fingerprinting (mini-satellite markers) and random amplified polymorphic DNA (RAPD) analysis to detect the genetic relationship of cultured strains of *O. niloticus* found in the Philippines (Naish *et al.*, 1995). A subsequent PCR-based study was performed a decade after by Romana-Eguia *et al.* (2004) using more powerful DNA markers such as mitochondrial-restriction fragment length polymorphism (mitochondrial-RFLP) and microsatellites to estimate the probable genetic variability and possible erosion of the gene pool of different tilapia stocks found in the Philippines. The results revealed that Nile tilapia stocks were slightly divergent from red tilapia stocks with improved Nile tilapia stocks being more diverse compared to strains not subjected to any breeding program.

Although not strictly a genetic technology, gamete cryopreservation has a potential role in genetic conservation of wild, endangered wild or cultured stocks (Hulata, 2001). Cryopreservation and the establishment of 'Tilapia Sperm Bank' were started by BFAR-NFFTC in 2003 with technical assistance from the Institute of Aquaculture, University of Stirling, UK. Now, the gene bank has a collection of different strains of tilapia founder stocks from different countries, 281 straws from the founder stocks, and 480 straws of fish samples from selective breeding programs (De la Rosa, 2003; ADB, 2005). Breeding trials conducted by the WorldFish Center to determine the precise magnitude of genetic gains achieved during the development of GIFT made use of the semen from GIFT founder stocks that were deposited in the Sperm Bank (ADB, 2005). Results of experiments that utilized cryopreserved tilapia spermatozoa showed that accumulative genetic gain in growth rate of GIFT strain is still high (at least 64%) in the progeny produced from spermatozoa of the ninth generation (produced in Malaysia) compared to the progeny produced from cryopreserved spermatozoa of the base population (generation zero produced in the Philippines), confirming that GIFT is a superior Nile tilapia strain (Khaw *et al.*, 2008). Despite the abundant collection of tilapia sperm at BFAR-NFFTC Tilapia Sperm Bank, this resource has not yet been adequately used or tested under local initiatives.

Advocators of Philippine Tilapia Genetic Research

Molecular-based genetic approaches in Philippine tilapia aquaculture are still in its infancy due to insufficient financial resources and/or limited human resources with capacity or

expertise impeding further development of the country's tilapia genetic R&D. Over the past decades, various institutions from the government and private sector have been active in conducting fisheries and aquaculture research, specifically spearheading aquaculture genetic studies, *e.g.* BFAR-NFFTC, CLSU, UPV in Iloilo, and SEAFDEC/AQD. At present, tilapia breeding and genetic improvement are performed only by agencies with the human resource, expertise and facilities required, and mandates to develop and distribute improved tilapia strains to farmers (Tayamen *et al*., 2006). The main government institutions such as BFAR-NFFTC and FAC-CLSU are responsible not only in the production and dissemination but also in the depository (*i.e.* Tilapia Sperm Bank) and genetic management of tilapia species and strains for genetic diversity maintenance. While FAC-CLSU is mandated to do R&D works on tilapia genetics, NFRDI has the mandate of ensuring the welfare of the fisheries sector through fisheries R&D, and in management, conservation, and protection of the country's aquatic resources. Nevertheless, continuous improvement of tilapia strains is still conducted by FAC-CLSU, BFAR-NFFTC, and SEAFDEC/AQD with performance evaluation still the most prevalent activity in tilapia aquaculture. At SEAFDEC/AQD, different tilapia strains are used to determine the most suitable for brackishwater environments, while on-farm performance comparisons are being carried out by BFAR-NFFTC. The tilapia road map charted by NFRDI includes the conduct of genetic-related studies that would expedite the growth of tilapia production and aid in developing more efficient management and monitoring practices and strategies that subsequently contribute to achieving the industry's goal of sustainability. At present, NFRDI is working on DNA markers for farmed tilapias and suitable genetic markers to differentiate the commercially-used strains for genetic protection and conservation purposes. FAC-CLSU also focuses on genetic studies to determine the molecular markers associated with disease resistance in farmed tilapia.

Challenges and Future Prospects

The recent decade marks the period where increasing numbers of projects explore the applications of molecular approaches in economically-important aquaculture species, which could be greatly attributed to the increasing number of scientists with expertise in fish genetics. Thus, with increasing human resources, genetic research in farmed tilapia could expand and progress well. Simultaneous with the selection programs is the utilization of molecular genetics techniques, such as molecular markers for science-based stock monitoring, assessment and management in tilapia aquaculture, and DNA marker-assisted selection. Nonetheless, success of future aquaculture breeding programs would mainly come from the pool genetic information compiled to be integrated into specific programs. One of the current trends in aquaculture genetic research is the discovery and mapping of quantitative trait loci (QTLs) or genes coding for characters with important productive value that could be subsequently used to speed up genetic gain of a target species through MAS breeding programs. Preliminary works on the development of new tilapia strains based on mapping QTLs using molecular markers such as microsatellites and anonymous fragment length polymorphism (AFLP) had been initiated as early as 1995. Based on the current capability level of the Philippines in terms of aquaculture research, performing high-level and more expensive technologies such as QTL identification would be very challenging. In tilapia genetic research at present, venturing into this technology might not be practical but will certainly be needed in the future. Thus, future molecular-based researches should focus on more tangible objectives that are urgent and equally important (Acosta *et al*., 2006; Toledo *et al*., 2009) although some insights were inferred from the present program framework implemented in two main breeding nuclei in the country (*i.e.* BFAR-NFFTC and FAC-CLSU).

Therefore programs that aim to ensure the maintenance of genetic integrity of improved tilapia stocks should be developed, and a prerequisite of establishing good culture program is having stocks with relatively high genetic variation. Assessing the diversity of existing tilapia genetic resources is essential not only in the development of effective management schemes but also in protecting and conserving the economic traits (*e.g.* growth rate, survival, and disease and temperature resistance) of improved stocks. Genetic gains established during the breeding programs can be negatively impacted when genetic variability reduction occurs. Determining the genetic variation in cultured stocks is also important in preventing the release of mixed hatchery-produced seeds which could not be detected by the appearance of the fish (An *et al*., 2011). Application of molecular markers, especially microsatellite DNA, is useful in addressing numerous aquaculture problems such as discrimination of wild and hatchery stocks (Ha *et al*., 2009), detection of inbreeding or genetic introgression in cultured stocks (Sukmanomon *et al*., 2012), strain evaluation for broodstock selection (Brown *et al*., 2007), and determination of genetic status and loss of genetic diversity of cultured stocks (Wang *et al*., 2012). The only detailed information available on genetic diversity of Philippine tilapia stocks was from Romana-Eguia *et al*. (2004), which indicated that Nile tilapia stocks such as GIFT, GMT, and FaST strains have high genetic diversity. However, this information was released almost a decade ago and no subsequent reports ensued while genetic monitoring of tilapia seeds and broodstocks in the country's breeding nuclei (*i.e.* BFAR-NFFTC and FAC-CLSU) are currently not performed. Therefore, a program that promotes the

conduct of continuous follow-ups and routine monitoring (*e.g.* checking of selection response, detecting signs of inbreeding depression, assessing stocks with valuable source of genes for future mitigation of genetic erosion) by national institutions, especially the country's tilapia breeding nuclei, would greatly help in maintaining tilapia genetic resources. Moreover, the efficiency of breeding programs in implementing quality checking schemes, an important issue that needs to be frequently addressed, could also be assessed. Genetic diversity monitoring should be a top priority and integrated in present monitoring programs as this would contribute to the baseline for science-based plans and actions such as preventing possible reductions in genetic variation of present healthy stocks and developing measures to counter possible consequences elicited by genetic deterioration.

The introduced and invasive blackchin tilapia (*Sarotherodon melanotheron*), locally known as "tilapiang Gloria", had been infesting fishponds and other water tributaries in Bulacan and Bataan Provinces of the Philippines (Ordoñez *et al*., 2014) and regarded as pests in these provinces. Invasion of blackchin tilapia or any other invasive species in different water systems would not only pose serious threats to fisherfolk's livelihoods and the aquatic ecosystem but could also bring about possible undesirable effects on the genetic makeup of natural tilapia populations. Interspecific hybridization resulting to genetic introgression could lead to genetic degradation and poor quality of tilapia stocks, which already happened in the 1980s (Taniguchi *et al*., 1985; Macaranas *et al*., 1986). Therefore, the application of genetic analysis using DNA markers (*e.g.* microsatellites) would address such concerns, especially in detecting the presence of hybrids of *S. melanotheron* and *Oreochromis* spp. and the extent of introgression between such species in a certain population. Assessing the ecological impacts of new strains after escaping to the wild should also be part of monitoring programs. Ecological risks in tidal ponds, open water cages and offshore ocean culture systems are relatively high because of the direct contact between the farm and natural waters (Leung and Dudgeon, 2008). Mitigating risks is important considering that vast brackishwater areas are now being targeted for the expansion of tilapia farming and the introduced species could become invaders of food and space, transmit diseases and cause inbreeding with wild species.

In Lake Buhi of the Philippines, the introduction of tilapia in freshwater aquaculture systems was reported to have caused the near extinction of the indigenous sinarapan (*Mistichthys luzonensis* Smith 1902) populations (Yap *et al*., 1983) and also resulted in significant ecological and economic impacts in the tropics and subtropics (Canonico *et al*., 2005). Efficient tools for tracing the stocks from the origins of escaped individuals could include the application of genetic techniques such as genetic analysis using microsatellite markers or SNPs. Once the source of escapees has been pinpointed, actions to prevent further introduction of farmed fish stocks to natural habitats could be taken. This investigative strategy makes it possible to come up with better risk assessment and management schemes. However, the release of non-native tilapia and carp species in Southeast Asian freshwater systems had substantially added to total fish community biomass with at best, mild impacts on native fish communities as reported by Arthur *et al*. (2010). Another practical and immediate application of genetic markers is parentage assignment (Norris *et al*., 2000) since determining the stock parentage by pedigree tracking is critical to avoid the offspring of few individuals from dominating the replacement broodstocks (McAndrew and Napier, 2011). In BFAR-NFFTC, the tedious work of physical tagging is still done which could be very difficult when tagging individuals at their early stages (Subasinghe *et al*., 2003). Using DNA microsatellite markers to serve as "genetic tags" could assist and facilitate tracking and identifying pedigrees in breeding programs thus, avoiding the risk incorporating physical tags in the human food chain (McAndrew and Napier, 2011).

Therefore, the development of "genetic tags" or "barcodes" would be useful in protecting the intellectual property rights (IPR) of the breeders' products. To date, only trademarks are effectively protectable (as in GST™ and GMT) and there is no policy that restricts breeders' products from being utilized in other research works (Acosta *et al*., 2006). In the advent of whole-genome sequencing technologies, identifying strain-specific markers (*e.g.* SNPs) has become more efficient, cheaper, and relatively easier to undertake. Identification of genetic tags could serve as scientific basis for IPR policies and help prevent intellectual property theft. In the Philippines, tilapia is still not included or covered by existing Philippine laws on fish export/import and regulations that concern protection of aquatic biodiversity. Given the wide research areas, investments to support such efforts should be intensified to ensure that the gains which have been achieved are sustained (Sevilleja, 2006). Income generating projects of public sector might not suffice the activities' heavy demands so that support should also be sought from the private sector. Thus, private-public partnership can play a vital role in keeping these R&D activities running through collaborative arrangements to ensure sustainable financial resources for genetics research (Acosta *et al*., 2006). With the creation of the DA-Biotech Program, a government program that aims to modernize Philippine agriculture through biotechnology, projects exploring genetics and genomics in aquaculture species are expected to increase in the coming years. Again, these activities are only possible if there is sufficient manpower with the needed technical

skills. Once proven to be successful, these researches could lead to successful tilapia aquaculture management, ensuring that production of high-quality tilapia could be sustained for food security of the country.

Conclusion and Way Forward

Genetic and genomic techniques have benefited tilapia aquaculture in many ways. Most of the applications involve the use of DNA markers for monitoring and management but a considerable portion of these researches paid attention to genome mapping. With the generation of genome-scale data becoming easier and more efficient, genomic and transcriptomic data of tilapia has been rapidly emerging. The tremendous amount of data compiled through the use of next generation technologies would provide invaluable information for future marker-assisted breeding and transgenesis of tilapia. There is no doubt that success of the tilapia industry in the Philippines has been largely attributed to the development of genetics-based applications. Utilizing genetic principles and tools in various breeding programs enabled the improvement of stock quality and performance, contributing to the steady increase of the country's tilapia production.

However, despite successes in producing novel strains with improved qualities, the country's tilapia aquaculture sector continues to face challenges particularly in the area of genetic research that could contribute to the sustainability and advancement of the whole industry. The bottlenecks include inadequate monitoring of the genetic status of present farmed stocks and limited technical persons with genetic research background and skills. Although genetic studies in tilapia aquaculture has already started in the Philippines, but this is still far from marking their significant impacts on the sector's performance. Furthermore, advanced DNA-based studies like MAS breeding for Philippine tilapia research would strongly rely on scientific information that can only be produced using DNA fingerprinting technologies. Once such efforts become successful, knowledge could be transferred to other breeding programs, which in turn would contribute to ensuring the prosperity and stability of the country's entire aquaculture sector.

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