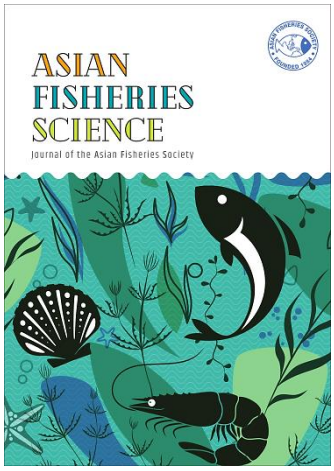

Red Hybrid Tilapia (*Oreochromis* spp.) Broodstock Development Programme in Malaysia: Status, Challenges and Prospects for Future Development

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Abstract

The red hybrid tilapia (*Oreochromis* spp.) and the black tilapia, including the genetically improved farmed tilapia (GIFT) (*Oreochromis niloticus* (Linnaeus, 1758)) collectively contributed to about 30.7 % of the total freshwater aquaculture production in Malaysia in 2018. The red hybrid tilapia is the most important, accounting for 94 % of total tilapia production. Among the major problems encountered in tilapia farming is the inconsistent supply of quality and adequate seeds, which could be solved through systematic breeding programmes. Among the major problems encountered in tilapia species farming is the inconsistent supply of quality and adequate seeds, which could be solved through systematic breeding programmes. This paper discusses the status of the red hybrid tilapia breeding programme in Malaysia, including issues and future perspectives. In brief, the first systematic breeding programme was initiated by the Fisheries Research Institute (FRI) in 2008. Selected founder stocks from Malaysia, Taiwan and Thailand were used to establish a base population for the programme. In this programme, the combined selection was practised which produced six generations of selection and successfully improved 12.5 % of harvest body weight per generation. The 6th generation was used as one of the founder stocks, apart from FRI Glami Lemi, Negeri Sembilan and Pahang populations to improve resistance to *Streptococcus agalactiae*. In 2017, the scope of the programme was expanded to include molecular tool in identifying markers for growth. Ten SNP markers associated with high growth performance traits were discovered. The provision of better breeding stocks for the aquaculture industry and the development of safe and productive operations are expected to result in more stable fish production and an improved income for farmers.

Keywords: *Oreochromis* spp., broodstock development, aquaculture, genetics

Introduction

Tilapia is a hardy and an ideal fish for farming because of the relatively short culture period of about 6 months. It has good tolerance to high stocking density, high productivity rates and is adaptable to a wide range of culture systems. They grow rapidly on formulated feeds with low protein content and can tolerate high carbohydrate levels. These qualities translate to a relatively inexpensive product as compared to marine fish. In Malaysia, tilapia aquaculture refers to red hybrid tilapia (*Oreochromis* spp.) and black tilapia species, including the genetically improved farmed tilapia (GIFT) (*Oreochromis niloticus* (Linnaeus, 1758)). Tilapia is the second most farmed freshwater fish in Malaysia after the African catfish, *Clarias gariepinus* (Burchell, 1822) with red hybrid tilapia as the preferably cultured by the fish farmers and they account for more than 94 % of the total tilapia production (Fig. 1).

Although Malaysia started farming red hybrid tilapia many years ago, the current production is still not very promising. There was a decreasing trend in the production of red hybrid tilapia from 2012 (39,581 MT) to 2017 (25,975 MT) and black tilapia species since 2016 (9,715 MT) to 2018 (5,790 MT) (Department of Fisheries Malaysia, 2020). Currently, the retail price of red hybrid tilapia in Malaysia is approximately RM13.00.kg^{-1} (US$3.2), which is slightly higher than black tilapia species sold at RM11.00.kg^{-1} (US$2.7) (Department of Fisheries Malaysia, 2020). This makes tilapia the

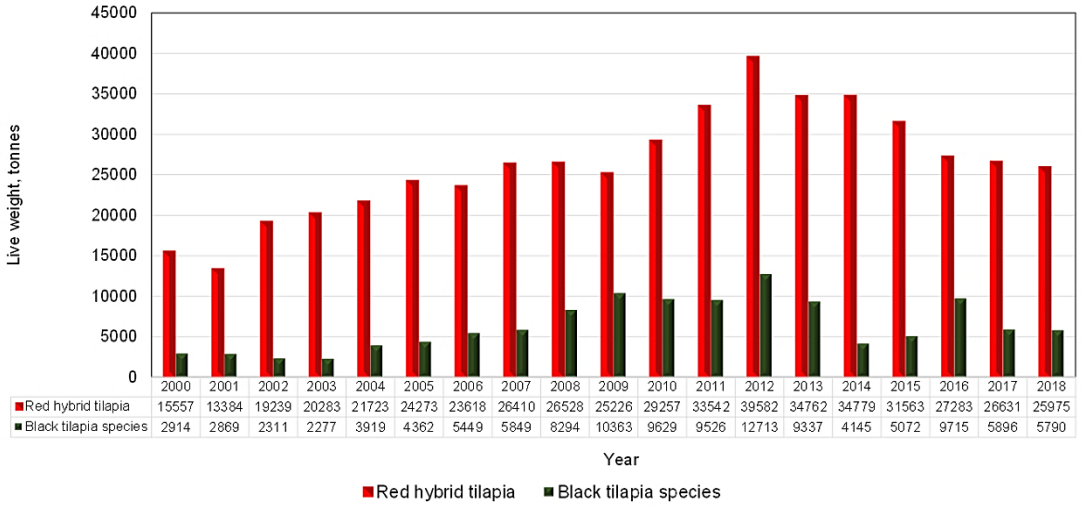

Fig. 1. Production of red hybrid tilapia (*Oreochromis* spp.) and black tilapia species (including the genetically improved farmed tilapia (GIFT) *Oreochromis niloticus* in Malaysia from 2000–2018 (Department of Fisheries Malaysia, 2020).

cheapest fish in the market after the African catfish, thus qualifying itself as the best candidate as "fish for the people".

Red hybrid tilapia is not a true species of tilapia. They are produced from selected tilapia species of the genus *Oreochromis* which has an attractive red colouration as a result of continuous selective breeding. The Taiwanese (Galman and Avtalion, 1983), Florida (Behrends et al., 1982) and Israel strains (Hulata et al., 1995) are examples of some red hybrid tilapia strains produced through selective breeding. Mutant reddish-orange female *Oreochromis mossambicus* (Peters, 1852) and normal male *O. niloticus* crosses have been used to produce the Taiwanese strain while a normal coloured *Oreochromis urolepis* (Norman, 1922) female was crossed with a red-gold male *O. mossambicus* to yield a Florida strain. Red Nile tilapia originating from Egypt was crossed with wild-type blue tilapia, *Oreochromis aureus* (Steindachner, 1864) to produce an Israel strain. Due to its characteristic colour resemblance to premium marine species such as the sea bream (*Pagrus major* (Temminck & Schlegel, 1843)) and red snapper (*Lutjanus argentimaculatus* (Forsskål, 1775)) along with its fast growth and high market demand, the red hybrid tilapia has inevitably become more popular. Most red hybrid tilapia farmers in Malaysia tend to use unimproved species and strains without any information regarding their origin, genetic background, growth performance and pedigree information (Hamzah et al., 2017). Most of the hatchery operators practise mass selection methods to produce fast growing individuals for grow-out. This method seemed to be readily adopted; however, fish performance usually decreases after two or three generations due to inbreeding. Tilapia farming will not be sustainable if the sector solely relies on unimproved stocks for seed production and grow-out. The aquaculture industry worldwide faces this problem as less than 10 % of aquaculture production is derived from selectively bred stocks (Gjedrem et al., 2012). To overcome this problem, production and dissemination of sufficient quality seeds to the farmers are crucial and could be supported through appropriate and systematic breeding programme.

The Department of Fisheries Malaysia (DOF) initiated a systematic tilapia broodstock development programme since the 9th Malaysian Plan (RMK-9). The breeding programme was aimed to improve certain economically important traits (such as growth and survival) in a population. A number of activities are involved in a programme such as setting up a breeding goal, performance evaluation, collecting information on phenotypes, estimation of genetic parameters, selecting potential broodstock, systematic mating and production of progenies and dissemination of improved broodstock to fish farmers. A well-managed programme could achieve a permanent selection response for each generation's targeted traits, contributing to increased production at harvest. This paper aims to present the R&D on red hybrid tilapia broodstock development programme conducted in Malaysia, particularly on the status, challenges and prospects for future development.

R&D on Red Hybrid Tilapia Broodstocks Development Programme

Nile tilapia (*O. niloticus*) was introduced to Malaysia from Thailand in 1979 and a year later, the red hybrid tilapia was introduced from Taiwan (Ang et al., 1989). As red hybrid tilapia gained more consumer attraction than the black tilapia species, an attempt was made in 2008 to conduct a breeding programme to genetically improve the red hybrid tilapia strain in Malaysia. Generally, the programme was carried out based on the well-known GIFT tilapia strain methodology. Firstly, the strain performance evaluation on a number of available red hybrid tilapia strains in

Malaysia was carried out by the Fisheries Research Institute (FRI) Glami Lemi, Negeri Sembilan. In this study, 1900 broodstocks were collected from a number of farms within Peninsular Malaysia. Fingerlings produced from each strain of broodstock were nursed until they attained a suitable size for identification. Passive integrated transponder (PIT) tags were applied to mark each strain before performance evaluation was carried out in grow-out ponds. The best four strains in terms of growth were selected and transferred to the Aquaculture Extension Centre (PPA) in Jitra, Kedah, where the second phase of the programme was initiated together with the WorldFish.

At PPA Jitra, strains from Taiwan and Thailand were procured from the Aquaculture Genetics Research Institute, Thailand. Subsequently, a strain evaluation experiments on the Malaysian (the selected stock received from FRI Glami Lemi), Taiwan and Thailand strains were carried out. Results showed genetic differences in growth and survival among the three strains (Hamzah et al., 2008). The best breeders from these strains (200 females and males per strain with an average body weight of 237 and 285 g, respectively) were used in a complete 3 × 3 diallel cross which successfully produced 101 full-sib families. The best performing individuals (highest estimated breeding value) were used as a synthetic base population (G_0) for this breeding programme. In subsequent generations, the selection had been practised within and between families based on the estimated breeding value ranking for body weight at harvest. Matings were carried out among genetically unrelated broodstock based on their pedigree. The same selection and mating procedures were repeated for all generations.

This programme indicated significant progress in the development of genetically improved red hybrid tilapia strain in Malaysia as the cumulative improvement achieved for body weight at harvest was 12.5 % per generation when the gain was expressed as a percentage of the base population (Hamzah et al., 2017). Selection for body weight had also resulted in correlated increase in body length, width, depth and survival rate. In 2014, the sixth generation of the red hybrid tilapia strain was successfully produced. Fingerlings from the improved breed were produced and disseminated to local farmers.

From 2017 onwards, the red hybrid tilapia broodstock development activity was slowly shifted from PPA Jitra to FRI Glami Lemi. Besides looking at the growth genes, this programme also identified potential broodstock that were resistant to *Streptococcus agalactiae*. The scope of the programme was expanded to include molecular techniques in identifying markers for growth which required relatively less time to identify genes and trait linked markers compared to the traditional selective breeding technique.

Determination of molecular marker for fast-growth characteristic

The molecular aspect of this project was carried out in collaboration with the Centre for Marker Discovery and Validation (CMDV), Malaysian Agricultural Research and Development Institute (MARDI). Since there was no genome sequencing database available for red hybrid tilapia, the CMDV had initially developed a draft genome to assess and mine the potential single nucleotide polymorphisms (SNPs) markers that were linked to the fast-growth characteristics. In order to execute this, a total of 32 potential samples were chosen to be used for genome sequencing based on their estimated breeding value (EBV) provided by the WorldFish. DNA from all samples were extracted and pooled into four pools for sequencing purposes. DNA concentration of each sample was measured using the Qbil platform before mixing into four pools of libraries and sequenced by Illumina Hi-Seq 2000. Four high quality sequenced readings (30 × coverage) which ranged from 25.88 to 35.6 gigabyte in size, were successfully produced for each pool. The quality of sequence reads was filtered and mapped after that to assemble tilapia genome Orenil 1.0 with 13.517 scaffolds. SNPs discovery was done within pools 1 and 3 for high performance male and pool 2 for high performance female. Around 1.6 million SNPs were mined for female high performance. A total of 2,000 SNPs from each group were chosen randomly from several scaffolds for validation. Due to the restricted budget, only 100 SNPs located close to each other were chosen for the first phase of the marker validation (Mohd-Azwan et al., 2020).

For marker validation, two extreme groups of red hybrid tilapia (the largest and smallest), aged about 3 months from 3 different culture systems (pond, tank and cage) were sampled. The samples consisted of 123 individual large fish and 130 small size fish. A total of 100 SNPs was successfully designed into 4 iPlex except for 4 SNPs which failed. The remaining 96 SNPs were used for genotyping 253 tilapia samples collected using the Agena® MassArray. All data on genotypes produced were scored using the Typer 4 software associated with the platform.

Out of 96 SNPs markers that were used for genotyping 253 samples, only 10 SNPs markers exhibited stable genotypes across all the systems between two extreme phenotypes and was predicted to be associated with high growth performance traits of red hybrid tilapia (Table 1).

This finding marked the first attempt to molecularly characterise the genes in fish broodstock development in Malaysia. It is hoped that this will help increase the effectiveness of the broodstock selection. However, this information was not fully incorporated into the existing programme at the FRI Glami Lemi due to some technical issues. Thus, the

Table 1. Candidate of single nucleotide polymorphism (SNP) loci associated with high growth performance in red hybrid tilapia *Oreochromis* spp.

Location	PF00790.16	PF00305.16	PF00400.29	PF00105.15	PF13432.3	PF06701.10
Big fish	GA	A	A	TC	TA	GA
Small fish	A	AT	AC	T	T	A

A: Adenine; G: Guanine, C: Cytosine; T: Thymine

selective breeding under the red hybrid tilapia broodstock development programme at FRI Glami Lemi has to be continued with the conventional method deployed with GIFT. Similar hurdles were encountered by other tilapia producers in Asia, such as the Philippines.

Broodstock collection

FRI Glami Lemi started with the establishment of a founder stock that consisted of three populations, i.e. the sixth red hybrid tilapia generation from PPA Jitra (generated from the collaborative work between Worldfish and DOF), Pahang and FRI Glami Lemi, Jelebu, Negeri Sembilan. The selection of founder stock was based on broodstock availability and guided by the previous findings of Karuppannan et al. (2012), which assessed the red hybrid tilapia stocks from Sungai Buloh of Selangor state, Bentong of Pahang state, Enggor of Perak state and Simpang Pertang of Negeri Sembilan state in Malaysia using microsatellite markers. The results revealed that heterozygosity values among the populations studied were more than 50 %, indicating the presence of moderately high genetic variability. The populations from Bentong clustered the furthest with the highest genetic distance from the other populations. Thus, this study thus suggests that the four populations from the states of Selangor, Pahang, Perak and Negeri Sembilan are suitable for a selective breeding programme.

Transfer and quarantine procedure

Broodstock from Aquaculture Extension Centre, Jitra (600 individuals), Pahang (500 individuals) and FRI Glami Lemi (800 individuals) were procured and transferred to FRI to be used as founder stocks in establishing a synthetic base population for this programme. They were quarantined in 10 m^3 fibreglass tanks with a stocking density of 5 fish.m^{-3} isolated based on their origin for three weeks before being used for mating. Prior to stocking in the tanks, fin samples of individuals from each population were clipped for DNA analysis. Random samples of individuals from each population were also screened for *S. agalactiae* infection. During the quarantine period, they were fed twice a day with formulated feeds at 5 % of their biomass.

Strain evaluation

After 2 weeks of the quarantine period, the progenies of each population were produced using 50 males and 100 females through mass spawning in a separate 20 m^3 tank. The progenies were nursed in 1 m^3 tank separately at a density of 100 fry.m^{-3} for 2 months before being tagged. In total, 1,000 progenies of each population were tagged and stocked in the pond for communal growth performance evaluation. The performance evaluation showed that there were genetic differences in growth among the three populations. The best broodstock from these populations (200 females and males per population) were used in a complete 3 × 3 diallel cross.

Establishment of synthetic base population

Prior to the cross to create a synthetic base population, the male and female broodstock were stocked separately in 20 m^3 tanks for 2 weeks. During this period, the selected broodstock were individually tagged for identification. The tail fin samples were also taken for DNA extraction to identify the fish with fast growth based on the molecular markers. The broodstock were mated using full diallel procedure to produce families (Table 2). The selected broodstocks were mated at a ratio of one male to two females in 2 m^3 tanks. Ten replicates were set for each cross combination to produce 90 families which will be used as a base population in this programme.

Table 2. Diallel mating design to create a base population of red hybrid tilapia for the broodstocks development programme in Malaysia.

		Male (♂)		
		P	J	C
Female (♀)	P	PP	JP	CP
	J	PJ	JJ	CJ
	C	PC	JC	CC

P: Pahang; J: Jitra; C: FRI Glami Lemi.

Observation on female breeders was initiated on day 18 to day 21 after mating. Mature eggs in the females' mouths were removed manually and incubated in hatching jars until they hatched. Hatched eggs or free-swimming fry were nursed in 1 m^3 hapa (300 pieces.hapa^{-1}) for a month. They were then transferred into 2 m^3 tanks for further rearing (1 month) before relocating into 5 m^3 tanks for another 1 month. After 3 months, each individual fish was PIT

tagged and transferred into circular cement ponds (400 m^3). They were fed commercial starter feed (about 2-3 % body weight), twice a day. Only 52 families were successfully produced despite the intended target of 90 families to form a base population.

Communal rearing and assessment of the base population (F_0) performance

The base population comprising of 52 tagged families, were cultured in a circular cement pond with a total water capacity of 400 m^3. The cement ponds were divided into two sections by netting in order to culture fish by batches (grouping based on the date of birth). The fish were stocked at a density of 5 individual per cubic metre and cultured for 5 months. Each fish was sampled for body weight (g), standard length (SL), body weight (BW), body width (Bwid) and head length (HL) at the initial stocking stage and at the final harvest. During the last sampling, sexes and the appearance of black spots or stripes were also recorded. Fish with black spot or strip were eliminated during the selection for production of first-generation, F_1.

Resistance test against Streptococcus

The fish were divided into four groups or batches based on the harvesting period. A total of 780 fish with weight ranging between 20.2 g to 238.4 g were used. Fish free from *S. agalactiae* were incorporated in the challenge test. A total of 10 to 30 fish from 42 families of base population were exposed to *S. agalactiae* to determine their resistance towards *Streptococcus* infection. An inoculum of *S. agalactiae* (10^8 CFU.mL^{-1}) was intraperitoneally injected into each fish according to weight (0.1 mL inoculum for 50 g body weight). The control fish were injected with approximately the same volume of culture medium. After injection, the fish were placed in a treatment tank in a secured wet laboratory.

The fish were monitored daily for up to 14 days for any unusual behaviour, clinical symptoms or deaths and observations were recorded. Of the 42 families tested, only 14 families showed survival rates of 50 % or more (Fig. 2).

Production of first generation F_1

Mortality occurred during the tagging and mating processes. In addition, the elimination of fish with black spots had tremendously reduced the number of available fishes for selection to produce the first generation. Thus, the selection intensity was approximately 10 %. This was relatively comparable to what had been achieved for many terrestrial animals raised for food and had only a few offspring (Gjedrem and Robinson, 2014). The selection of broodstock to produce the first generation (F_1) was based on the results of the highest survival rate achieved after being exposed to *Streptococcus* infection and their estimated breeding value (EBV) for body weight at harvest. The estimated heritability for body weight was 0.10 ± 0.09, indicating that there is scope for further improvement in the population. A total of 30 families were selected in the mating process to produce the first generation (F_1). The best family was ranked based on their EBV as family 1 followed by family 2, family 3 and so on. The mate allocations were conducted by assigning the males from the best or high ranked family with the females from the best family. To date, a total of 31 F_1 families have been produced.

Issues and Challenges

There are many issues and challenges faced by the FRI in implementing the red hybrid tilapia broodstock development programme. Among them are:

Broodstock resources

The major challenges were finding the right candidate to establish the founder population, especially tilapia broodstock with high genetic variation. Besides

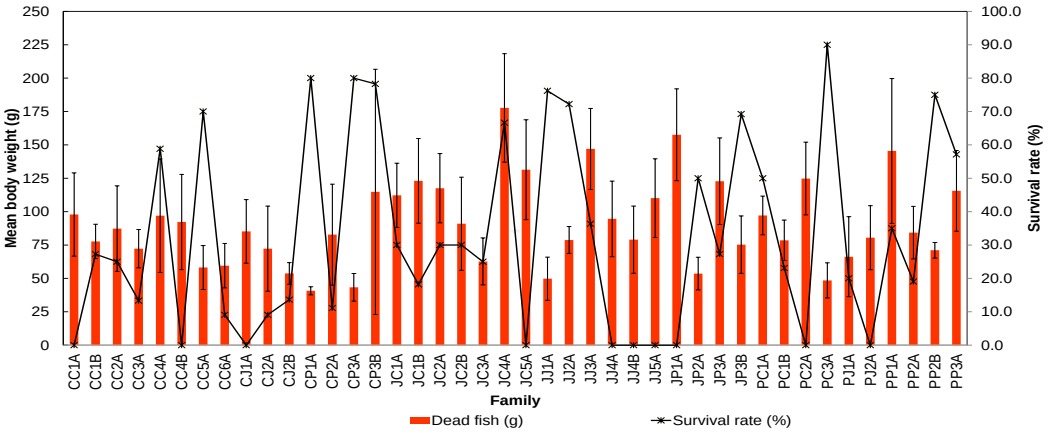

Fig. 2. Cumulative of red hybrid tilapia survival rate and mean body weight of dead fish during challenge test with *Streptococcus agalactiae* for 42 families.

quality, there were not sufficient numbers of broodstock for this purpose.

Research and knowledge gaps

There is still a wide gap in our researcher's understanding and skills in executing this programme. A lot of pertinent information regarding our broodstocks is still not available and not well comprehended. Data from the study on the maturation diet to improve gonad development in Nile tilapia broodstock (El-Sayed and Kawanna, 2008) and the influence of protein content of Nile tilapia broodstock diets on larval quality and performance (Gunasekera et al., 1996) should be further investigated and verified with the broodstocks in the current study. The understanding of the exogenous and endogenous mechanisms controlling gametogenesis and spawning is also minimal. Furthermore, the lack of knowledge on the immune system of the fish restricts possible treatment regimes. In conclusion, the current information needs to be enhanced, and knowledge in managing this programme must be enriched.

Modern biotechnology is becoming more accessible and is a valuable tool in genetic improvement of broodstock by pedigree analysis of DNA, gene mapping and the identification of genetic markers or specific genes associated with desirable traits. The application of such techniques has led to promising results in genetically modified individuals of the mud loach, *Misgurnus mizolepis* Günther, 1888 (Nam et al., 2001), black tiger shrimp *Penaeus monodon* Fabricius, 1798 (Yazawa et al., 2005) and Atlantic salmon *Salmo salar* Linnaeus, 1758 (AquaBounty, 2020). In the present study, the molecular markers developed by CMDV had not been fully utilised in the programme because of some technical issues. Therefore, the conventional method for selective breeding was applied instead of the marker-assisted method. Other tools such as the quantitative trait loci (QTL) and genomic selection (GS) have been widely adopted in other countries to assist in the genetic improvement of broodstock. However, these approaches have not been attempted here because of the high cost involved.

High operational cost

The development of broodstock is a slow and high-risk process hence making the programme very costly. This is why most of these programmes were being funded by public funds (Niera, 2010). This was also the case for the project at FRI Glami Lemi. The execution of this project requires high budget input for the development, operation and maintenance of the hatchery which cannot be compromised.

Inadequate infrastructure

Maintaining pedigree information is crucial in a breeding programme. However, it is not possible to tag the small-sized fingerlings after hatching. Therefore, sufficient numbers of tanks, hapas or ponds are crucial to maintaining them separately until they are suitable to be tagged. This will increase the infrastructure development and operational cost and induces environmental (i.e. hapa, tank or pond) effects in the families produced. One of the solutions to this constraint is by using DNA markers for parentage assignment. In this method, genetic tagging could be done after hatching and all families can be communally reared in tank or pond. This will, in turn, reduce the environmental effects on the families. However, as mentioned earlier, these approaches have not been attempted due to the restriction of infrastructure and the cost involved. At present, FRI Glami Lemi faces a shortage of ponds and tanks to accommodate the families that have been successfully bred. Ideally, it would be great to possess complete operation facilities for broodstock holding, spawning, egg hatching, live feed production, nursing ponds and adequate and consistent supply of water. To complement this, a functional bio-secure system and measures should also be in place. Although FRI Glami Lemi facilities for the tilapia broodstock programme have adequate bio-secure systems, there is still a shortage of tanks and ponds due to other on-going research and broodstock development programmes such as the Malaysian Mahseer, *Tor* spp. and *Pangasius nasutus* (Bleeker, 1863).

Extension services

Besides the issues and challenges faced in the execution of the broodstock development programme, there are also problems pertaining to the dissemination of the potential broodstock to hatchery operators. Currently, seed dissemination is disorganised and needs a significant revamp. Sometimes, it is difficult to find a taker for the broodstock that has been developed. Takers here are referred to as committed private hatcheries with adequate bio-secure facilities to serve as broodstock multiplication centres (BMCs).

Future Perspective

The future of red hybrid tilapia aquaculture looks very promising and will remain a lucrative business with good demand and stable price. With this motivation and other advantages of red hybrid tilapia as mentioned in the earlier part of this paper, Malaysia has to step up its efforts in order to meet the Third National Agrofood Policy 3 (NAP3) target or, better still, to turn into a significant producer of red hybrid tilapia in the future.

For this purpose, the red hybrid tilapia broodstock development programme must be sustained. The existing programme should be improvised so that the headway made in the 9th, 10th and 11th Malaysia Plan

could be converted into an increase in tilapia production for Malaysia in the future. Besides that, both FRI and DOF have further roles (Table 3) to play in complementing the broodstock development programme that has been initiated so that it could be more impactful to the nation.

Malaysia also needs to establish the supply chain for red hybrid tilapia production to serve as a reference to all stakeholders involved. Figure 3 represents the proposed model for red hybrid tilapia broodstock development, dissemination and control of seed production in Malaysia. Although the proposed model looks simple, it is in accordance with the current practise in Malaysia.

The broodstock development programme and proper support system alone will not help in increasing tilapia production in Malaysia. There are other aspects too that need to be addressed in order to increase production. Table 4 presents examples of other factors that are equally important in achieving high tilapia production besides having a good broodstock development programme. Malaysia needs to manoeuvre these factors too, in order to achieve the NAP3 target and become one of the top tilapia producers.

One of the strengths that Malaysia has is the support of the government on aquaculture investments and operations. Besides that, with an inventory of 90 lakes and reservoirs covering a total area and volume of 1,095 km^2 and 30,400 $Mm^{3,}$ respectively (Omar, 2010), Malaysia has a great potential for aquaculture production if properly planned and managed. In other countries such as Bangladesh and Egypt, fish production from lakes and reservoir were very significant (Samy-Kamal, 2015; Roy et al., 2018). For example, in the Northern lakes of Egypt (Manzala, Burullus, Mariout and Edko Lake) which cover an area of 1,430 km^2, production was up to 127,525 tonnes or 89 tonnes.km^{-2}. However, in comparison, the production of fish in Malaysia from the available water bodies was relatively small where the production of fish was only about 12.7 tonnes per 1 km^2 area (Department of Fisheries Malaysia, 2020).

Conclusion

Malaysia has a lot of catching up to do before it can be considered a major tilapia producing country. History has proven that investments in broodstock development programmes have resulted in great returns to the aquaculture industry and R&D should continue selecting desirable traits in fish.

Table 3. Comprehensive roles of Fisheries Research Institute (FRI) and Department of Fisheries (DOF) in ensuring the success of red hybrid tilapia (*Oreochromis* spp.) broodstock development programme in Malaysia.

FRI	DOF
a. Serve as the nucleus breeding centre (NBC) with the objective of continuously improving the broodstock development through R&D. b. Disseminate quality broods for BMCs equipped with bio secure systems and facilities. c. Produce standard operating procedures (SOPs) and manuals for BMCs, hatchery operators and be made available to them. d. Produce brief, attractive and easy to understand information on breed management for BMCs, hatchery operators and farmers in the forms of posters or leaflets. e. Provides training, advice and regular visits to BMCs. f. Refinement of existing knowledge and management protocols.	a. Identify private entrepreneurs who are committed to serve as broodstock multiplication centres (BMC). These BMC will have to adhere to the SOPs developed by the FRI. b. Accredit the BMC through certification and regular monitoring by certified auditors so that aquaculture entrepreneurs and farmers would feel confident in the seed that the BMC produces. c. Establish a framework and guidelines for accreditation of BMCS and standard for seed quality. d. Establish at least one BMC in every state. e. Establish BMC in every Intensive Aquaculture Zone (IAZ) to ensure enough supply of seeds and reduce chances of disease outbreak through import/ bringing of seeds from outside. f. Form a network for researcher and private BMCs to facilitate and standardise the information sharing and technology transfer. g. Encourage formal cooperation between FRI and private entrepreneurs with specific targeted and outputs and outcomes.

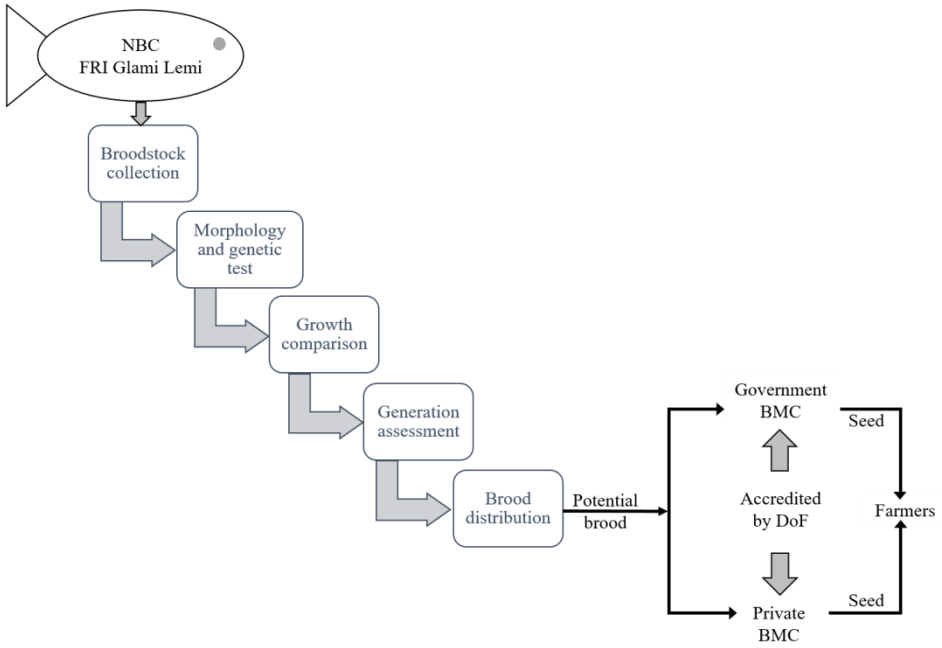

Fig. 3. Proposed model for red hybrid tilapia broodstock development, dissemination and control of seed production in Malaysia.

Table 4. Factors contributing to high tilapia production in the top producing countries (Mapfumo, 2018).

Country	Factors
Egypt	Cage and pond farming, rice-tilapia, polyculture in brackish and freshwater systems
Indonesia	Cage culture, polyculture, rice culture
Bangladesh	Government support and private sector investment
Brazil	Lots of available water, labour, land, feed
Thailand	Better reporting
Mexico	Continued intensification, some government support, large and small private investments
Sub-Saharan Africa	Commercialisation, small farms

Incorporating genomic selection along with the conventional selective breeding of the red hybrid tilapia is a good option to be explored. It is the latest molecular approach in modern breeding schemes and offers substantial improvements in selection accuracy over pedigree-based methods as has been applied for yellowtail kingfish *Seriola lalandi* Valenciennes, 1833, Atlantic salmon (*S. salar*), Pacific white shrimp, *Penaeus vannamei* (Boone, 1931) and common carp (*Cyprinus carpio* Linnaeus, 1758). Tilapia broodstock management is a field of active study but challenges are multidisciplinary with integrated and collaborative research approaches needed.

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