A comparative growth performance and survival of different genetic strains of Nile tilapia (*Oreochromis niloticus)* and Red tilapia *(Oreochromis* spp.*)* in a floating net cage culture farming in the Cirata Lake, West Java, Indonesia

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ABSTRACT

This investigation was conducted to evaluate growth performance and survival rate between 3 cultivated and 1 genetically improved strains of Nile tilapia *(Oreochromis niloticus*) and Red tilapia (*Oreochromis* spp.), which were cultured in a floating net cage system in the Cirata Lake, West Java, Indonesia. Two thousand sex-reversed fingerlings of Nile tilapia (34.8 ± 11.7 g) and Red tilapia (42.4 ± 13.9 g) were stocked in two replicate net cages (7m width × 7m length × 2.5m height). All fish were individually tagged and cultured with similar conditions in the net cages for a period of 183 days. Growth performance, survival, morphology, and skin (or scale) color were individually recorded. The statistical model considered the initial weight as covariate, the replicate cages as block, and the genetic strains as treatment. The least square means ranged from 709.4 ± 15.5 g to 877.7 ± 14.2 g for harvest weight and 38.0 ± 2.2% to 43.6 ± 2.2% for survival rate of Nile tilapia, and from 682.2 ± 12.3 g to 758.7 ± 12.9 g for harvest weight and 39.2 ± 2.2% to 51.2 ± 2.2% for survival rate of Red tilapia. The genetically improved strain (IG-SB) had the highest ($P < 0.05$) harvest weight and highest average daily gain for both Nile and Red tilapia. All tested Nile tilapia strains had no significant difference for survival rate. However, the genetically improved strains tended to have higher survival than the other strains. The cultivated Nile tilapia strains had shorter ($P < 0.05$) standard length, head length, and body width than the genetically improved strain. While the genetically improved Red tilapia strain had outstanding thickness and greater skin pigmentation than the other strains. The genetically improved strain achieved 26.5% better average biomass among the tested tilapia strains in both species. These results stress the economic advantage of using genetically improved tilapia strains to enhance a sustainable cage culture farming.

Keywords: Cirata Lake, cage culture, performance test, tilapia, genetic strains

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INTRODUCTION

Indonesia is an archipelagic country with an approximate coastline of 81,000 km and has a vast potential for aquaculture. The production volume of the inland capture fisheries in Indonesia was approximately 737 thousand metric tons in 2019 (Statista, 2019). Cage culture of Nile (*Oreochromis niloticus*) and Red (*Oreochromis* spp.) tilapias in rivers, irrigation canals, and lakes/reservoirs is prevalent in Indonesia and Thailand, utilizing semi-intensive and intensive methods. Tilapia is the most-produced aquaculture product in Indonesia, surpassing shrimp, milkfish, *Clarias* spp. catfish, carp, *Pangasius* spp. catfish, and groupers. (Phillips *et al.*, 2015). Tilapia cage culture is predominantly prevalent in West Java, South Sumatra, Kalimantan, and Jambi, according to Guerrero (2002). As the fourth most populous country in the world with a 270.2M population, West Java has the highest populated province (48.3M; Latief, 2021). To meet future fish demand, Indonesia's fishery sector must expand. Currently, nearly 38% of aquatic production is destined for export, making the seafood trade an important source of income for Indonesia. Aquatic food products thus contribute to food and nutrition security, employment, and national economic growth (Phillips *et al.*, 2015).

The Cirata Lake has the largest source of tilapia produced particularly in West Java, Indonesia. It was built in 1987 with a covered area of approximately 62 km^2, originally intended as the hydropower source to provide support for the national electricity needs. Eventually, it was also utilized for intensive cage culture farming. Cage culture in Cirata Lake has contributed to fulfil freshwater fish consumption in West Java. Fresh water aquaculture at Cirata Lake is the largest in Indonesia with an average production volume of 6,450 tons of fish per month or 39.5% of all floating net production in West Java (Widiyati *et al*., 2009). According to the Ministry of Environment and Forestry (Kementrian Lingkungan Hidup Republik Indonesia) 2012 data, the water quality of lakes and rivers in Indonesia is generally poor. West and Central Java were reported as one of the most heavily polluted areas (ADB, 2016). A good water condition is crucial for the growth performance and survival of the population since the entire life process of the fish is entirely dependent on the quality of its environment. However, success is not greatly dependent upon the suitability of the reservoir's water quality, aside from environmental parameters there are several factors attributed such as quality and quantity of feeds used, management, cage position, and density of stocks including the quality of strain to use. The shortage of qualified seed supply and availability in Indonesia was mentioned as one of the primary challenges during The Aquaculture Roundtable Series (TARS) 2017, combined with a lack of water resource regulation and management and pollution (USSEC, 2017).

Nandlal and Mather (2018) reported that numbers of successful stock improvement programs in Asia and the Pacific region (and elsewhere) have not been successful over the long-term simply because the local capacity to maintain and extend the programs was not addressed at the time. As an example, there have been several attempts by both government and private producers to develop improved strains of farmed Nile tilapia in Malaysia and Indonesia that was initially successful, later failed due to poor stock management or a lack of ongoing support from fish breeders with an appropriate background in stock improvement technologies and approaches. There are studies that aquatic animal species can benefit from genetic enhancement projects in the same way that cattle and crops have (Gjedrem, 1998; 2000; Hulata, 2001). Different commercial strains of tilapia are available around the world, including Indonesia, and provide adequate genetic resources that are customized or tailored to the needs of aquaculture producers. Genetically improved strains of Nile (Super Black; SB) and Red (Super Red; SR) tilapia are products from a long-term continuous selective breeding program of the Manit Genetics. They have been performance and progeny tested for growth, survival, and other economically important traits under Thai environmental conditions from generations to generations, and their fingerlings have been preferred by producers within and outside the country (Leungnaruemitchai *et al*., 2020).

There are several studies contributed to evaluate water quality status in Cirata Lake using local cultivated strains of tilapia. However, almost none to find a comparative study between cultivated and genetically improved (Nile and Red) tilapia strains in Cirata Lake, which could provide information that can be beneficial to enhancing sustainable aquaculture production. Assessing the impacts of using the most suitable genetic strains under the target environmental condition is challenging due to the presence of various difficulties and numerous complexities of the environment. Thus, the objectives of this investigation were to evaluate and compare growth performance, survival rate, morphology, and other traits between the local cultivated and the genetically improved Nile *(Oreochromis niloticus*) and Red tilapia (*Oreochromis* spp.) strains cultured in a floating net cage culture farming in the Cirata Lake, West Java, Indonesia.

MATERIALS AND METHODS

Experimental Design and Test Environments

This study was conducted in a commercial floating net cage culture farming system in the Cirata Lake/ Waduk Cirata, Cianjur West Java, Indonesia (Figure 1; 6°43′51.6″S 107°16′33.1″E). The experiment was conducted within a period of 183 days from May to November 2017. The investigation employed the use of four net cages in total, two replicate cages for Nile and Red tilapia. The size of each cage was 7m width × 7m length × 2.5m height. The net cages were attached on a bamboo frame and floated by empty metal barrels, with the inner and outer netting for security. Sex-reversed fingerlings of Nile and Red tilapia (23–25 days old; body weight ranged from 0.3 to 0.5 g) were collected from the cultivated genetic strains of the 3 commercial sources sold in Indonesia for Nile tilapia (CGN 1, CGN 2, and CGN 3) and for Red tilapia (CGR 1, CGR 2, and CGR 3) and the genetically improved strains from the Manit Genetics for Nile tilapia (Super Black; SB) and for Red tilapia (Super Red; SR), which were imported from Thailand. A randomized complete block design (RCBD) was performed for this study.

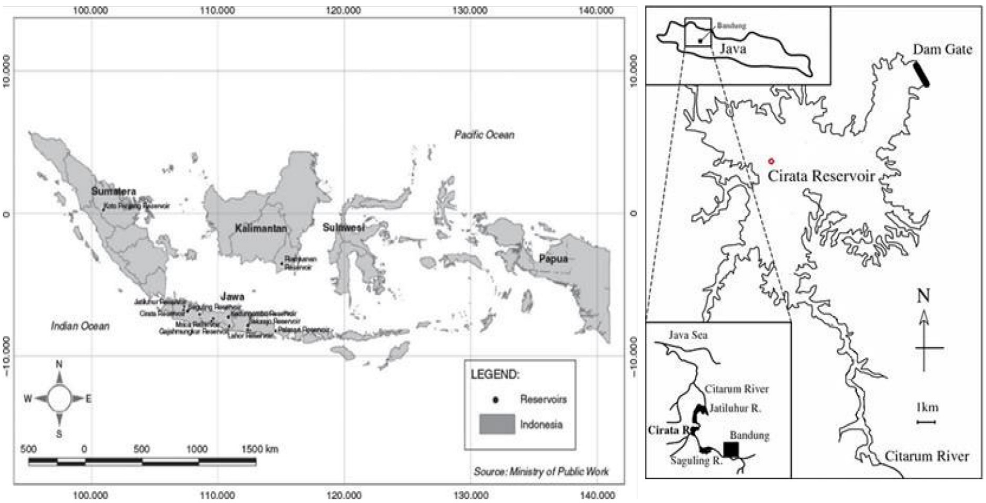

Figure 1 Location of the experimental site for net cage culture system at the Cirata Lake, West Java, Indonesia (Source: Ministry of Public Work, Indonesia)

Ten thousand fish stocks per strain and species were collected simultaneously to avoid bias on age and size. The collected stocks were nursed and reared on separated units to avoid feed and space competition. After quarantine and nursing phases, upon reaching 5 g of the average weight, the fish were transferred to the Cirata Lake for the second nursing and acclimation. Size grading was conducted at a weight of 20 g to eliminate any potential bias in selection during tagging that could be attributed to differences in initial weight. The size grading process began with a random sampling of 30 fish per genetic strain to determine mean of the initial weight of each strain.

Two hundred fifty juveniles from each strain per species (Nile and Red tilapia) and per replicate (sampling and trial) cages have been randomly chosen and individually tagged using a radio frequency identification (RFID) or the Biomark PIT tags (ISO HDX12, Biomark USA). Visually obvious biggest and smallest fish on each genetic strain were discarded to avoid bias on initial weight. Stocking density of 1,000 juveniles/replicate cage, which were all males from the same cohort Nile and Red tilapia (Table 1). Stocked fish were fed with commercially available tilapia floating feeds (30% crude protein) based on commercial feeding practice, the frequency of feeding was three times daily (at 08:00, 11:00, and 15:00 hours). *Ad libitum* feeding was practiced once a week to observe the feeding response of the fish. Nets were checked and cleaned on a regular basis to prevent stock escape and net clogging.

Mortality was collected and recorded every day for RFID tag retrieval. Water quality parameters (i.e., water temperature, dissolved oxygen, pH, ammonia, nitrite, sulfide, and alkalinity) at different euphotic depths of the lake were monthly monitored to evaluate the effects of water quality on cultured stocks (Table 2). Temperature and dissolved oxygen were monitored using YSI 550A (Yellow Springs Instrument, OH, USA). The samples were collected to analyzed other water quality parameters and sent to the laboratory at Animal Health Service, Technical Research and Development Division (PT Central Proteina Prima Tbk (CP Prima), Indonesia).

Table 1 Number and weight (g) of the stocked fish per genetic strains and replicates (sampling and trial) cages of Nile and Red tilapia

Genetic strains	Sampling cage			Trial cage		
	Number	Weight (g)	CV (%)	Number	Weight (g)	CV (%)
Nile tilapia						
CGN 1	250	35.1 ± 10.5*	29.9	250	34.2 ± 9.9	28.9
CGN 2	250	36.3 ± 9.9	27.3	250	37.6 ± 10.3	27.4
CGN 3	250	27.8 ± 10.7	38.5	250	25.4 ± 10.3	40.6
IG-SB	250	40.9 ± 10.9	26.6	250	41.4 ± 11.1	26.8
Total	1,000	35.0 ± 11.5	32.6	1,000	34.6 ± 11.9	34.4
Red tilapia						
CGR 1	250	37.2 ± 10.8	29.0	250	38.6 ± 10.6	27.5
CGR 2	250	37.4 ± 11.7	31.3	250	38.4 ± 11.2	29.2
CGR 3	250	39.4 ± 11.0	27.9	250	41.2 ± 12.5	30.3
IG-SR	250	52.8 ± 15.5	29.4	250	53.8 ± 14.8	27.5
Total	1,000	41.7 ± 14.0	33.6	1,000	43.0 ± 13.9	32.3

Note: * Mean ± standard deviation, CV = coefficient of variation, CGN = cultivated genetic strains of Nile tilapia, IG-SB = genetically improved strain-Super Black, CGR = cultivated genetic strains of Red tilapia, IG-SR = genetically improved strain-Super Red

Table 2 Monthly water quality monitoring data during commercial test period

Sampling date	Water temperature (°C)	Dissolved oxygen (mg/L)	pH	TAN/ ammonia (ppm)	Nitrite (ppm)	Sulfide (ppm)	Alkalinity (ppm)
26 May 2017	29.1	1.84	7.8	0	0	0.80	75
07 June 2017	29.6	3.43	7.5	0	0	0.16	75
18 July 2017	28.8	2.57	7.8	0	0	0.16	75
22 August 2017	29.0	4.34	7.8	0	0	0.20	75
Average	29.1	3.04	7.7	0	0	0.33	75

Note : Provided information by the Animal Health Service, Technical Research and Development Division, Pt. Central Proteina Prima, Tbk, Indonesia

Data Collection

Growth assessment of the tested fish stocks in the sampling cage was performed on monthly basis by individually weighing all stocks from each cage on both species to determine growth performance of different genetic strains. The trial cage served as a reference on the impact of handling during monthly sampling. Individual weight (g), survival percentage, and average daily gain (ADG) of each genetic strain were measured to determine growth in each genetic strain (treatment) over the course of the experiment, as described below.

Weight gain (g) = Final weight – Initial weight ------- (1)

Survival rate (%) = (Number of fish harvested / Initial number of fish stocked) × 100 ------- (2)

ADG (g/fish/day) = (Final weight – Initial weight) / Number of days cultured ------- (3)

At the end of the experiment, all tested fish stocks from cages were harvested. Individual weight and traditional morphometric data based on linear measurements between reference points (standard length, body width, head length, and thickness) were measured. The total population size of harvested fish stocks, number of test fish survived, and biomass in each genetic strain were computed based on the formula:

Total biomass at harvest = (Average weight at harvest × Survival rate) / 1,000 ------- (4)

Individual color categorization of all genetic strains of Red tilapia from both replicate cages were measured at harvest. A customized coding technique developed by Akvaforsk Genetics Center (AFGC) was used to define color categorization on each fish stock. The fin and skin/scale color of harvested stocks from both replicated cages were classified using three criteria: the proportion percentage of (1) black spots, (2) skin/scale color, and the intensity percentage of (3) pigmented area covering the body of the fish. The comprehensive methods used to color coding for Red tilapia genetic strains in this study was from Thodesen *et al.* (2013).

Statistics Analyses

The dataset was analyzed using a linear model in R-studio software (version 1.3; https://www.rstudio.com; MA, USA). The one-way analysis of variance was done separately for Nile tilapia and Red tilapia to test the effect of genetic strains of tilapia on growth performance, survival rate, and morphological or skin/scale color. The statistical model considered the initial weight (at stocking age), replicate cages as block, and genetic strains as treatment. The least square means (LSM) for the considered traits of different genetic strains of tilapia were calculated and compared using Tukey-Kramer Test at 95% of confidence interval.

RESULTS AND DISCUSSION

Growth Performance

Under similar environmental conditions within the Cirata Lake, Nile tilapia genetic strains had generally better growth performance than Red tilapia genetic strains (Table 3). Differences in growth performance between strains were more visible starting from the third month onwards. The Nile tilapia had a larger range for body weight among genetic strains for 56 days (199 g *vs* 146 g), 91 days (410 g *vs* 287 g), 126 days (633 g *vs* 424 g) and 183 days (999 g *vs* 645 g) of the tested period (Table 3). Larger variations were found at older ages in all strains of both Nile and Red tilapia. Range of body weight at the final recording (183 days of the test period; 263 days old) was from 709.4 ± 15.5 g (CGN 3) to 877.7 ± 14.2 g (IG-SB) for Nile tilapia, and from 682.2 ± 12.3 g (CGR 3) to 758.7 ± 12.9 g (CGR 1) for Red tilapia (Table 4). The genetically improved strains show the first rank on growth performance for Nile tilapia (IG-SB) and rank second for Red tilapia (IG-SR). The difference between LSM of the improved genetic strain and LSM of the heaviest cultivated genetic strain was 61 g (7.5% better) for Nile tilapia and no significant difference for Red tilapia. The CGN 3 and CGR 3 had the lowest final weight compared to the other strains.

Table 3 Mean and standard deviation for body weight (g) of different genetic strains of Nile tilapia (*Oreochromis niloticus*) and Red tilapia (*Oreochromis* spp.) cultured in a floating net cage farming system in the Cirata Lake, West Java, Indonesia

Genetic strains	Stocking		56 days		91 days		126 days		183 days	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Nile tilapia										
CGN 1	35.1	10.5	180.5	44.4	351.4	92.4	496.8	139.1	732.5	229.1
CGN 2	36.3	9.9	198.8	43.5	394.0	79.9	570.1	127.2	830.7	199.4
CGN 3	27.8	10.7	145.7	49.0	286.9	93.6	424.3	141.1	645.3	214.3
IG-SB	40.9	10.9	195.4	51.0	410.0	107.7	632.8	176.5	998.6	252.9
Red tilapia										
CGR 1	37.2	10.8	167.2	52.9	318.8	87.8	501.5	134.6	740.4	199.8
CGR 2	37.4	11.7	160.0	42.5	299.8	78.7	461.1	120.0	686.5	176.6
CGR 3	39.4	11.0	160.1	42.8	296.2	84.8	449.3	133.6	648.5	192.9
IG-SR	52.8	15.5	175.6	50.3	321.2	105.9	494.1	164.6	769.6	217.1

Note: CGN = cultivated genetic strains of Nile tilapia, IG-SB = genetically improved strain-Super Black, CGR = cultivated genetic strains of Red tilapia, IG-SR = genetically improved strain-Super Red

For the test period, the LSM for average daily gain was the highest for IG-SB (4.9 ± 0.5 g/day) and then followed by CGN 2 (4.3 ± 0.1 g/day), CGN 1 (3.9 ± 0.1 g/day) and CGN 3 (3.3 ± 0.1 g/day), respectively, for Nile tilapia, and was the highest for IG-SR (4.0 ± 0.7 g/day) and then followed by CGR 1 (3.8 ± 0.7 g/day), CGR 2 (3.6 ± 0.7 g/day), and CGR 3 (3.4 ± 0.7 g/day), respectively, for Red tilapia (Table 4). Within similar conditions in the Cirata Lake, the genetically improved strains of Nile (IG-SB) and Red tilapia (IG-SR) would have capability to express their genetic potential in utilizing the diet for growth performance. Based on observations, they were more active and voracious feeders compared to other strains. Because digestion requires more oxygen, when oxygen levels in the reservoir were optimal, the fish ate better and digest the food more efficiently. Oxygen is required for respiration and metabolism in all animals. The concentration of oxygen in the rearing environment has a significant impact on the metabolic rate of fish. Respiration and feeding activities reduce when the dissolved oxygen concentration falls. During the study, water was most often stagnant, fish was observed gasping on the water surface. Extended depletion of dissolved oxygen (DO) concentration in water (hypoxia) causes significant stress in fish (Abdel-Tawwab *et al*., 2019). Furthermore, fish reduced their feed intake, resulted in a decrease in growth. Hypoxia may slow fish growth, feed utilization, and health status. The fish may use a variety of mechanisms to adapt for a decrease in DO uptake.

Table 4 Least square mean and standard error for the final weight, average daily gain, survival rate, and morphological traits of the different genetic strains of Nile and Red tilapia cultured in a floating net cage farming system in the Cirata Lake, West Java, Indonesia

Genetic strains	Final weight (g)	Average daily gain (g/fish/day)	Survival rate (%)	Standard length (cm)	Head length (cm)	Body width (cm)	Body thickness (cm)
Nile tilapia							
CGN 1	753.3 ± 15.5^{c}	3.9 ± 0.1^{c}	39.0 ± 2.2	25.5 ± 0.2^{c}	7.8 ± 0.1^{c}	10.9 ± 0.1^{b}	4.5 ± 0.0^{b}
CGN 2	816.7 ± 14.1^{b}	4.3 ± 0.1^{b}	41.8 ± 2.2	26.5 ± 0.2^{b}	8.1 ± 0.1^{b}	11.1 ± 0.1^{b}	4.7 ± 0.0^{a}
CGN 3	709.4 ± 15.5^{c}	3.3 ± 0.1^{d}	38.0 ± 2.2	24.7 ± 0.2^{d}	7.4 ± 0.1^{d}	10.1 ± 0.1^{c}	4.3 ± 0.0^{c}
IG-SB	877.7 ± 14.2^{a}	4.9 ± 0.5^{a}	43.6 ± 2.2	27.5 ± 0.2^{a}	8.3 ± 0.1^{a}	11.6 ± 0.1^{a}	4.7 ± 0.0^{a}
Red tilapia							
CGR 1	758.7 ± 12.9^{a}	3.8 ± 0.7^{ab}	41.4 ± 2.2^{b}	26.4 ± 0.2^{a}	7.9 ± 0.1^{a}	10.8 ± 0.1^{ab}	4.4 ± 0.0^{b}
CGR 2	721.9 ± 13.4^{ab}	3.6 ± 0.7^{bc}	39.2 ± 2.2^{b}	25.5 ± 0.2^{b}	7.6 ± 0.1^{b}	10.5 ± 0.1^{bc}	4.4 ± 0.0^{b}
CGR 3	682.2 ± 12.3^{b}	3.4 ± 0.7^{c}	44.8 ± 2.2^{ab}	25.1 ± 0.2^{b}	7.7 ± 0.1^{ab}	10.5 ± 0.1^{bc}	4.3 ± 0.0^{b}
IG-SR	732.8 ± 12.6^{a}	4.0 ± 0.7^{a}	51.2 ± 2.2^{a}	26.4 ± 0.2^{a}	7.7 ± 0.1^{ab}	10.9 ± 0.1^{a}	4.6 ± 0.0^{a}

Note : $^{a, b, c, d}$ Least square means in the same column of the Nile or Red tilapia with different superscript were significantly different ($P < 0.05$). CGN = cultivated genetic strains of Nile tilapia, IG-SB = genetically improved strain-Super Black, CGR = cultivated genetic strains of Red tilapia, IG-SR = genetically improved strain-Super Red

The genetic improvement for both IG-SB and IG-SR have not been done by selective breeding program utilizing performance records of progenies or relatives tested in the environments like those of the Cirata Lake, but their ancestors were proved based on records of relatives tested in various environments in Thailand (Leungnaruemitchai *et al*., 2020). Better growth performance of those genetically improved strains compared to the cultivated genetic strains in this investigation (Figure 2 and Table 4) stressed the benefit of a selective breeding program that could help enhancing the sustainability of tilapia productions and business competition.

Survival Rate

All Nile tilapia genetic strains had not significantly difference for survival rate. The range LSM was from 38.0 ± 2.2% (CGN 3) to 43.6 ± 2.2% (IG-SB). While significant difference was found among Red tilapia genetic strains ($P < 0.05$). The IG-SR (51.2 ± 2.2%) had similar survival rate with CGR 3 (44.8 ± 2.2%) but had more survival rate than CGR 1 (41.4 ± 2.2%) and CGR 2 (39.2 ± 2.2%), respectively (Table 4). Ranks for survival rate among genetic strains were different between Nile and Red tilapia.

Although tilapias generally are known for acceptance to a wider range of environmental factors, such as temperature and low dissolved oxygen levels (El-Sayed, 2019), warm water species (e.g., tilapia and catfish) requires DO concentration of 4 mg/L or higher to maintain good health and feed conversion (Masser, 1997). According to the findings of this study, there was no significant difference in survival regardless of the strain or species involved. The relatively low survival results at harvest were probably due to the poor environmental condition in the experiment site. It should also be noted that test cages are situated in highly localized areas in the reservoir and are in congested conditions. Even though spontaneous mortality in test cages was rare, it occurred regularly over long periods until the harvest, resulting in significant accumulated mortality and low survival at the end of the study. There were also reported occurrences of mass mortality in Cirata Lake largely attributed to its structural nature and the extreme density of cages and fish stocks (Effendie *et al.*, 2005). Also, disease mortalities related to low dissolved oxygen levels at the reservoir were observed. Clinical signs such as inappetence, disorientation, swirling swimming activity, and exophthalmia were observed and finally died. These clinical signs are comparable to those described in studies by Najiah *et al.* (2012), Asencios *et al*. (2016), and Sun *et al.* (2016), and on streptococcal infection in *Oreochromis niloticus*. This type of bacterial infection is frequently linked to a high bacterial load in the water as well as the high stocking density used in cage aquaculture.

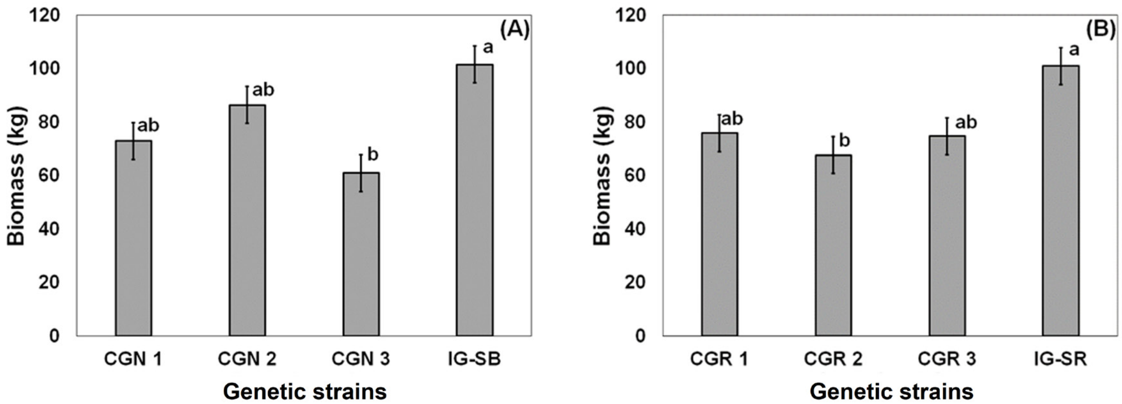

Figure 2 Biomass at harvest from different genetic strains of (A) Nile tilapia (*Oreochromis niloticus*) and (B) Red tilapia (*Oreochromis* spp.) cultured in a floating net cage farming system in the Cirata Lake, West Java, Indonesia. Each bar represents the mean of replicate cage (sampling and trial cage). Superscript letters indicate significant differences between groups ($P < 0.05$). CGN = cultivated genetic strains of Nile tilapia, IG-SB = genetically improved strain-Super Black, CGR = cultivated genetic strains of Red tilapia, IG-SR = genetically improved strain-Super Red

A high significant difference in Nile strains was observed among body weights at later period, specifically 120 days onwards. At harvest, the results demonstrated that genetically improved strains (IG-SB and IG-SR) achieved 26.5% better yield from the average biomass among genetic strains on both species and replicate cages. Biomass harvested in Nile tilapia was highest in IG-SB at 101.6 ± 6.9 kg which was significantly higher than CGN 3 with 61.0 ± 6.9 kg. However, there was no significant difference found in biomass at harvest between IG-SB and CGN 1 and CGN 2 (Figure 2A). For Red tilapia, biomass at harvest in IG-SR (101.0 ± 5.0 kg) was significantly higher than CGR 2 (67.7 ± 5.0 kg) but was not statistically different from CGR 1 (75.9 ± 5.0 kg) and CGR 3 (74.7 ± 5.0 kg; Figure 2B). Moreover, the harvest size variation of improved genetic strains (IG-SB and IG-SR) demonstrated an above-average percentage of good-sized fish (44.5% for above 1,000 g in Nile tilapia and 51.2% for 800 g and more in Red tilapia; Figure 3). Other cultivated genetic strains from both species resulted in smaller size distribution and lower growth performance at harvest, mostly less than 800 g.

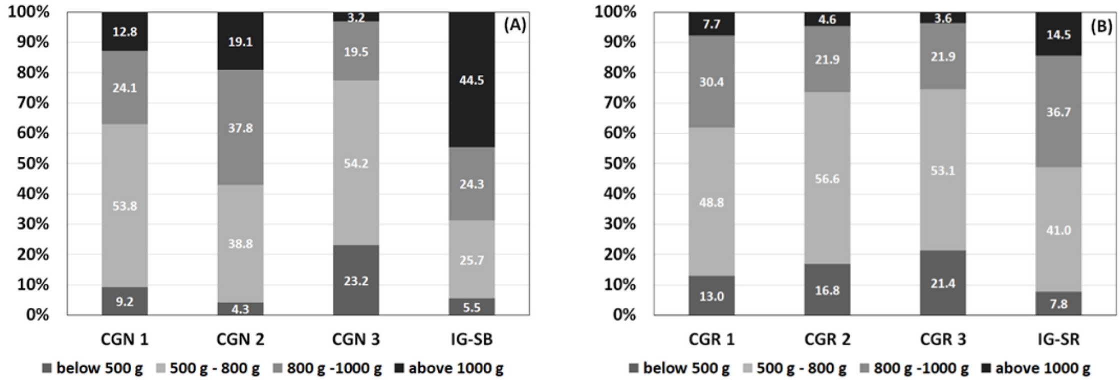

Figure 3 Distribution of weight size at harvest (183 days) of different genetic strains (A) Nile tilapia (*Oreochromis niloticus*) and (B) Red tilapia (*Oreochromis* spp.) cultured in a floating net cage farming system in the Cirata Lake, West Java, Indonesia. CGN = cultivated genetic strains of Nile tilapia, IG-SB = genetically improved strain-Super Black, CGR = cultivated genetic strains of Red tilapia, IG-SR = genetically improved strain-Super Red

Morphometric Differences

Fish size, fillet quality, and other traditional traits are no longer the only factors that influence consumer choice at the point of sale, especially when fish are sold whole. Body shape and skin pigmentation have also become valuable appearance traits in commercial markets, owing to rising market sophistication. For morphological traits of Nile tilapia, the IG-SB had significantly ($P < 0.05$) the longest standard length (27.5 ± 0.2 cm), head length (8.3 ± 0.1 cm), and body width (11.6 ± 0.1 cm), and similar body thickness with CGN 2 (Table 4). In contrast, for Red tilapia, the IG-SR (26.4 ± 0.2 cm) had a similar standard length with CGR 1 but they were significantly larger than CGR 2 (25.5 ± 0.2 cm) and CGR 3 (25.1 ± 0.2 cm). The CGR 1 (7.9 ± 0.1cm) had a longer head length than CGR 2 and CGR 3. The IG-SR was the largest perform for body width and thickness (10.9 ± 0.1 cm and 4.6 ± 0.0 cm, respectively) while CGR 1 was not significantly different from CGR 2 and there were no significant differences between genetic strains CGR 1, CGR 2, and CGR 3 for body thickness (4.4 ± 0.0 cm, 4.4 ± 0.0 cm and 4.3 ± 0.0 cm, respectively).

Differences in morphology between farmed populations are also of great concern for selective breeding because the shape is a commercially important trait that contributes to the market value of the product (de Oliveira *et al.*, 2016). Our results provide a clear indication that different genetic strains of tilapia display significant differences in body shape. Growth traits (body weight and average daily gain) have positive genetic correlations with depth ratio and thickness (Rutten *et al*., 2005). Long-term selection for growth and high daily gain tended to create rotund fish, even at a slow rate, indicating that long-term selection for growth and high daily gain tended to produce rotund fish.

Skin Color Differentiation

Skin (or scale) color and pigmentation in Red tilapia have also become valuable appearance traits in commercial markets, owing to rising market sophistication. Consumers associate the red color with a variety of marine fishes that have similar coloration and a high market value. It is favored by consumers due to its color and market value. It is also one of the economically important traits that was included in the long-term selective breeding program in Thailand. In this study, all genetic strains of Red tilapia were also color categorized; pigmented area (given score 5 as highly/full pigmentation; body dominated by red skin color without black spots; lower score means lesser black spots/blotches). The results facilitated understanding the validity of genetic improvement on skin pigmentation differentiation in Red tilapia and highlight the advancement of the genetically improved strain. The distribution of color traits between genetic strains was summarized in Figure 4. The CGR 1 has more black spots in general having a wide range within population, less pigmented area (highest percentage on score 1) with red dominating yellow skin color. The CGR 2 in general has fewer black spots (high percentage on scores 0 to 2), less pigmented area (highest percentage on score 1), and scale color is majority red dominating yellow. The CGR 3 has fewer black spots in general. There were a few numbers of animals which has many black spots, many pigmented areas with red dominating yellow scale color. Lastly, the IG-SR population has a short range of black spots, highly pigmented with red dominating yellow scale color.

Genetically Improved and Cultivated Strains

The genetically improved strains performed better for many traits compared to those cultivated genetic strains. Results from this investigation stressed that using genetically improved stocks can overcome limiting factors and improve production cost-efficiency (Gjedrem, 2002). As the rate of growth increases, production time and maintenance requirements will automatically decrease, while feed conversion rate will improve. Genetically improved tilapia strains may be able to contribute to food security in a significant way. More meat is produced per kilogram of feed, liter of water, and unit of land area as production increases to meet the increasing demands of growing populations (Gjedrem and Baranski, 2009). Utilizing genetically improved farmed fish strains can fulfill rapidly increasing fish demand by increasing production gains (Acosta and Gupta, 2010), improving disease resistance (Houston, 2017), and improving the socioeconomic and welfare performance of related aquaculture systems (Dey, 2008). Growing improved strains of tilapia in the Philippines, according to Yosef (2009), also results in significant cost savings for farmers. Improved strains are 32% to 35% less expensive to produce than non-improved strains, depending on the production environment. According to Toledo *et al.* (2008), the development of improved tilapia strains is a major factor that has fueled the growth of the tilapia industry in the Philippines.

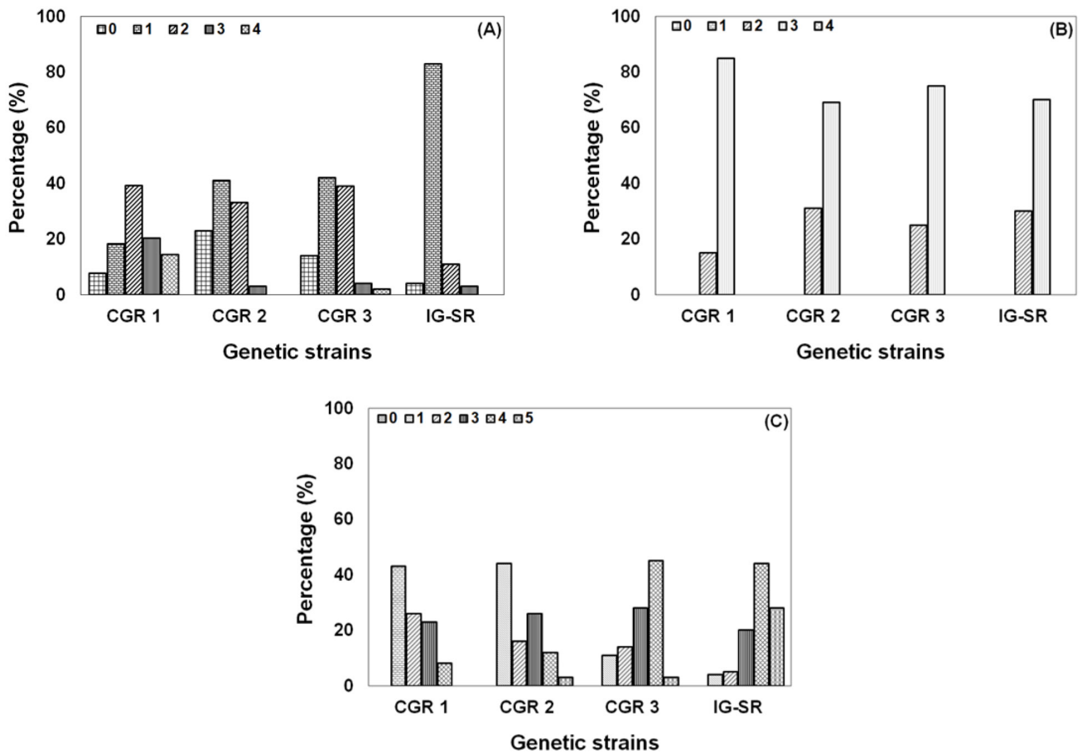

Figure 4 Distribution of color traits in different genetic strains of Red tilapia (*Oreochromis* spp.) cultured in a floating net cage farming system in the Cirata Lake, West Java, Indonesia: (A) black spots, (B) skin/scale color, (C) pigmented area. CGN = cultivated genetic strains of Nile tilapia, IG-SB = genetically improved strain-Super Black, CGR = cultivated genetic strains of Red tilapia, IG-SR = genetically improved strain-Super Red

Tilapia has established itself as a low-cost, high-yielding, and profitable fish over the last three decades. The tilapia sector has provided immediate, measurable benefits in terms of nutrition, employment, and income generation, as well as indirect benefits such as improved availability of fish in local rural and urban markets at an affordable cost to meet expanding consumer demand. The results found in this study suggested a possibility of greater profitability on using genetically improved strains could aid in augmenting cage culture farmers. There is an opportunity to extend the productivity border by encouraging farmers to use better management practices such as proper cage positioning, decreasing densities within localized areas, and proper feeding management to avoid feed waste and maximize feed utilization. This will allow for sustainable fish production and will also help to improve productivity. During the period 2014 to 2017, Indonesian tilapia products outperformed Chinese tilapia products in the US market (Dai *et al.*, 2020). The findings further indicate significant impacts on using genetically improved strains, specifically on the export market. A higher average yield and profitability at harvest may also increase in other favorable culture farming systems using genetically improved strains. This is a necessary condition for improving welfare and obtaining the economic, social, and environmental gains that come with it. Likewise, just importing genetically improved strains for farming is at best, only likely to have local and short-term impacts if the technical capacity to manage and continue to improve the strains is not in place.

CONCLUSIONS

This study had two significant practical implications. Firstly, relative comparisons and variations of growth, survival rate, morphology, and other economically important traits of the local cultivated and the genetically improved Nile and Red tilapia cultured in a floating net cage culture farming in the Cirata Lake, Indonesia. Secondly, the genetically improved strains showed the best performance and provided more biomass compared to those cultivated genetic strains under a similar environmental condition of a commercial cage culture farming system in Cirata Lake. The investigated results stressed the advantages of selective breeding program over traditional cultivation and also implied the economic advantage from using genetically improved tilapia strains for both stainability of tilapia production and business competition.

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