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ESTIMATION OF HERITABILITY AND SELECTION RESPONSE FOR BODY LENGTH OF NEON TETRA (*Paracheirodon innesi*) FROM BOJONGSARI DISTRICT, INDONESIA

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ABSTRACT

The neon tetra (Paracheirodon innesi), a popular South American ornamental fish, has become a key species in Indonesian aquaculture, with production centered in Bojongsari, Depok. However, the industry faces declining genetic quality due to inbreeding. Therefore, implementing a selective breeding program is considered an effective approach to improve genetic quality. This study aimed to estimate the heritability and selection response of the body length trait in the base population of neon tetra fish. Selection was conducted on the entire population using a within-family selection method, specifically employing broodstock from the Curug and Bojongsari populations. A reciprocal breeding design was established using four mating combinations, each comprising 25 pairs of 4- to 5-month-old broodstock (3.28±0.15 cm total length; 0.43±0.06 g body weight) mated at a 1:1 sex ratio. The offspring were reared separately and grown out in an aquarium for 120 days. The results showed that the estimated heritability was 0.42, with a response to selection of 0.13 cm (4.9%). Our finding of moderate heritability implies that this trait can be effectively enhanced through a systematic breeding program. These figures suggest that the selection process for the next generation of neon tetra fish remains viable.

KEYWORDS*:* Genetic gain; ornamental fish; *Paracheirodon innesi*; selective breeding

INTRODUCTION

The neon tetra (*Paracheirodon innesi*) is a freshwater fish belonging to the Characidae family. Originating from South American rivers, it is among the most commercially valuable species in the worldwide ornamental fish industry (Sanaye *et al.*, 2014). In Indonesia, Bojongsari District in Depok City serves as a key hub for both local and export markets, producing about 2 million fish per month (DKP3 Depok, 2018; Kusumah *et al.*, 2022). Although the region's production is significant, it has decreased notably from 25.3 million fish in 2018 to 20.1 million in 2020 (DKP3 Depok, 2020). Consequently, current supplies meet only approximately 50–60% of total market demand.

This production gap is largely attributed to deteriorating genetic quality caused by inbreeding (Nurlaili *et al.*, 2021). In many cases, seed production does not consider the genetic principles, leading to high inbreeding depression. Ralls *et al.* (2014) suggest that inbreeding usually occurs when related broodstock mate without pedigree management, reducing heterozygosity and allelic diversity. This genetic degradation is further exacerbated by small parental populations and unbalanced sex ratios across generations (Frankham, 2008).

Selective breeding programs, whether through individual or family-based selection, are established strategies for improving the genetic quality of offspring (Tave, 1995). Economically, these programs are essential for enhancing production efficiency and reducing costs. The main principle of selection involves utilizing additive genetic effects at specific loci that control quantitative traits (Andersen & Hayes, 2005). Traits such as growth rate, reproductive capacity, and feed conversion efficiency are key factors influencing profitability in aquaculture.

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Successful breeding requires selecting only the best individuals to enhance a family's breeding value. To do this effectively, it is crucial to determine the selection response and heritability values (Nugroho *et al*., 2016; Robisalmi *et al*., 2019). These indicators reflect trait development and help predict the potential progress of the breeding program. This study discusses broad-sense heritability, defined as the ratio of genetic variance to total phenotypic variance (Wray & Visscher, 2008). It measures the extent to which genetic differences contribute to the variation observed in a trait within a population. According to Ranjan & Gautam (2018), knowing heritability estimates is important because they reveal whether a trait is mainly influenced by genetics or environmental factors. This understanding helps ensure that selection procedures can produce reliable and economically valuable genetic improvements.

Although family selection has proven successful in food-fish aquaculture, research on ornamental species remains limited. Extensive studies on food fish reveal notable genetic improvements; for example, the *Cyprinus carpio* Rajadanu F-3 population showed a 51% increase in growth, with a selection response of 14.20 g and a high heritability ($h^2 = 0.60$) (Radona *et al*., 2016). Similarly, Nile tilapia (*Oreochromis niloticus*) raised in saline environments showed a selection response of 10.66–10.92% per generation, with an estimated heritability of body weight of 0.42 ± 0.22 (Robisalmi *et al*., 2019). Furthermore, family selection for growth traits in mandarin fish (*Siniperca chuatsi*) produced genetic gains of 6.94–17.25% (H = 0.17–0.47) (Sun *et al*., 2022). Likewise, research on giant gourami (*Osphronemus goramy*) reported an 11.18% selection response in the F-1 generation, with a high heritability estimate of 0.88 for body weight (Listiyowati *et al*., 2023). These impressive advances in food fish suggest great potential for applying similar selective breeding methods to improve the genetic quality of high-value ornamental species.

Despite the established efficacy of selective breeding in food fish, these methods have yet to be applied to enhance the growth and reproductive performance of neon tetras. Consequently, critical genetic parameters, such as heritability, selection differential, and selection response, remain inadequately understood for this species, thereby impeding the development of systematic breeding protocols. Determining these values is essential for quantifying and monitoring the progress of genetic improvement initiatives. Therefore, the present study aims to estimate the heritability and selection response for body length in a base population of *P. innesi*, thereby establishing a foundation for developing a genetically improved strain.

MATERIAL AND METHODS

The study was conducted from March to September 2024 at the neon tetra ornamental fish farm in Curug Village, Bojongsari Subdistrict, Depok City, West Java, Indonesia. The neon tetra broodstock originated from Curug and Bojongsari, Depok City, West Java (Figure 1).

Broodstock rearing

The fish were reared at a designated aquaculture facility in Curug, selected for its consistent water quality and sufficient breeding infrastructure. Prior to the start of the experiment, the broodstock un-

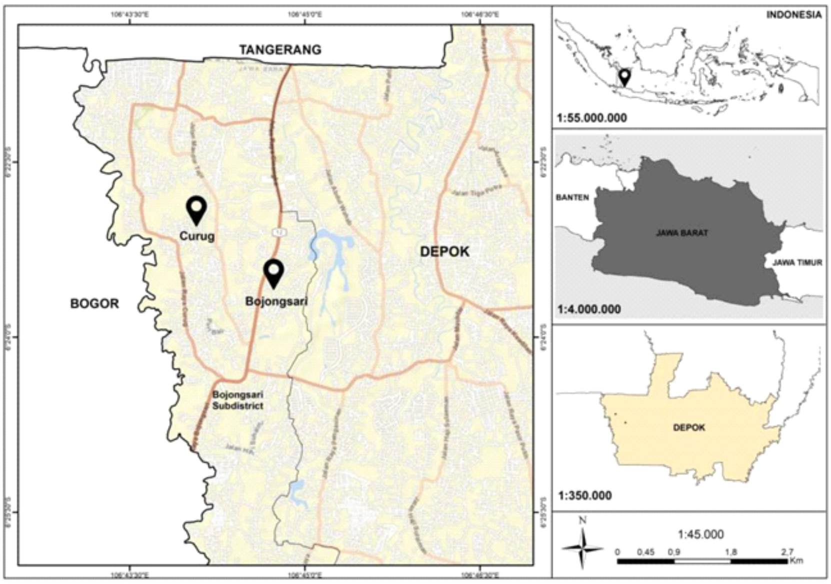

Figure 1. Map of the neon tetra fish collection for the experiment.

derwent a three-week acclimation period at the spawning site. A total of 100 males and 100 females from each source population were maintained separately within aquaria measuring 100 cm x 50 cm x 30 cm, with a water depth of 25 cm. To minimize stress and lower the pH of the rearing environment, 5 dried tropical almond leaves (*Terminalia catappa*) were added to each tank (Ardi *et al*., 2020) along with 250 g of salt and continuous aeration. The broodstock were fed *Moina* sp. or tubifex worms (Tubificidae) ad libitum twice daily. Maintenance protocols included siphoning and 10% water exchanges every two days.

Spawning procedures

Neon tetra broodstock from Curug and Bojongsari were spawned using a reciprocal spawning design to produce the first generation (Minh *et al*., 2022). During natural spawning, one female was fertilized by one male, producing 100 families with 25 pairs per mating (Table 1). The broodstock were 4 to 5 months old, with a total length of 3.28±0.15 cm and a body weight of 0.43±0.06 g. Spawning occurred in a 15 cm x 15 cm x 10 cm aquarium with a water depth of 4 cm, with no aeration.

Larval rearing

After spawning, the broodstock is removed from the spawning container, while the eggs remain until they hatch. Larvae from each mating were reared separately in 33 cm × 25 cm × 30 cm aquaria at a stocking density of 40–50 individuals per tank. Each aquarium was supplemented with 1–2 dried tropical almond leaves (*Terminalia catappa*) to stabilize water conditions. During the initial culture stage, the larvae were fed according to the feeding protocol outlined in Table 2 from 3 to 4 days after hatching (DAH) until they reached an S size (1 cm at total length) at 30 days of age. The feed is provided twice daily (in the morning and evening) using *ad libitum* methods.

Juvenile rearing

Juveniles were randomly assigned to 33 cm × 25 cm × 30 cm tanks and reared separately until reaching the broodstock stage, which occurred 30-120 days after hatching (DAH). At this stage, sex was not considered. The feeding regimen consisted of *Moina* sp. provided *ad libitum* in the morning, followed by commercial pellets in the afternoon. Specifically, from 45 to 70 DAH, fish were fed pellets with particle size < 0.4 mm and a minimum protein content of 40%. From 71 to 120 DAH, PF500 pellets (0.5–0.7 mm, 39% protein) were administered to apparent satiety. Water quality was maintained through twice-daily siphoning or as needed due to waste accumulation, followed by a 25–30% water exchange. Each tank was also equipped with a single sponge filter to provide continuous aeration and biological filtration.

Water quality measurement

Temperature, dissolved oxygen, pH, total dissolved solids (TDS), and conductivity are measured using a multi-parameter water quality meter (Horiba U-53G Multiparameter Water Quality Meter). The titrimetric method is used to measure alkalinity (SNI 06-4581-1998) and hardness (SNI 06-6989.12-2004), and a water quality test kit (Tetra Test Ammonia kit) is used to measure ammonia levels. These measurements were performed monthly as supporting data (Kucharczyk *et al*., 2010; Kusumah *et al*., 2021).

Table 1. Reciprocal spawning diagram of neon tetra broodstock from two selected populations

Population		Male (♂)	
		C	B
Female (♀)	C	(1) C >< C	(3) C >< B
	B	(2) B >< C	(4) B >< B

Description: C = Neon tetra from Curug, B = Neon tetra from Bojongsari. Each cross consisted of 25 pairs.

Table 2. Feeding management of neon tetra fish larvae in the first stage of larval rearing

Type of feed	*Age (day after hatching/DAH)*														
	0	2	4	6	8	10	12	14	17	18	20	22	25	27	30
Yolk sac	*0-4 DAH*														
Artemia nauplii			*4-17 DAH*												
Water fleas (*Moina* sp.)										*18-30 DAH*					

DAH: day after hatching

Selection procedure

The selection process for growth characteristics was conducted using a within-family selection protocol. Each family line was initially isolated through the larval and juvenile stages in separate aquariums to prevent inter-family competition and ensure accurate pedigree tracking. In the initial stage, 100 broodstock pairs were spawned, of which 64 pairs successfully produced larvae. Due to different survival rates during early development, only 26 families maintained a sufficient population size and continued through the rearing period into the selection stage. At the end of the 120-day rearing period, when the juveniles had reached a total length of 2-3 cm, every individual within each family was measured. These length measurements (initial and final) were used to generate size-distribution data and to rank individuals within each family. This ranking established a selection threshold to retain the top 30% of the population from each family line. Finally, the selected best individuals from all families were pooled to constitute the new broodstock to improve the genetic quality of the next generation.

Measurement of growth and genetic performance

At the end of the study (day 120), genetic parameters such as specific growth rate (SGR), coefficient of variation, differential selection, estimated heritability value, and selection response were calculated using the following formula:

a) Specific growth rate (SGR)

$$\text{SGR} = \frac{Ln\ Lt - Ln\ Lo}{t1 - to} \times 100$$

SGR : Specific growth rate (%/day)

Lt : Final total length of seed

Lo : Initial total length of seed

t1 : Final period of experiment

to : Initial period of experiment

b) Coefficient of variation: $\text{CV} = \frac{SD}{X} \times 100$

CV : coefficient of variation (%)

SD : Standard of deviation (cm)

X : Average body length (cm)

c) Differential selection (S) is the difference between the average length of the selected population and the average length of the initial population, calculated using the formula:

$S = x' - x.$

S : Differential selection

X' : Average length of the selected population (cm)

X : Average length of initial population (cm)

(d) Broad sense heritability (H)

Broad sense heritability was calculated for individual fish body length traits within each family by analyzing variance components, using the formula from Singh & Chaudhary (1979).

Broad-sense heritability can be calculated using the formula:

$$H = \frac{\sigma^2{}_G}{\sigma^2{}_p}$$

Description:

H : Heritability value in the broad sense

ó$^{2}_{G}$: Genetic variance

ó$^{2}_{P}$: Phenotypic variance

e) The estimated selection response (R)

R value is the predicted value of genetic improvement expected to be obtained in the next generation as a result of selection activities performed in the previous generation. The selection response value is estimated using the following formula:

$R = S \times H$

Description:

R : Selection response

S : Differential Selection

H : Heritability

Data analysis

All statistical analyses were performed at a 0.05 significance level using IBM SPSS Statistics software (version 27). The normality and homogeneity of the data were evaluated using the Shapiro-Wilk and Levene's tests, respectively. Non-normal or non-homogeneous data were logarithmically transformed, while percentage data were arcsine-transformed. Additionally, a descriptive analysis was used to summarize the conditions of the rearing environment.

RESULT AND DISCUSSION

The growth parameters of the neon tetra broodstock candidates are summarized in Table 3. At 30 days after hatching (DAH), the initial total length (TL) of the fry ranged from 1.09 ± 0.13 to 1.15 ± 0.13 cm. By 120 DAH, the final TL ranged from 2.65 ± 0.24 to 2.76 ± 0.13 cm. Over the four-month rearing period, the Specific Growth Rate (SGR) in total length ranged from 0.93 ± 0.25 to 1 ± 0.10 % per day. Statistical analysis confirmed that the SGR data were normally distributed (Shapiro-Wilk test, $p > 0.05$ for all groups) and that variances were homogeneous (Levene's test, $p = 0.460$). One-way ANOVA revealed no significant differences in SGR among the four crossbreeding groups ($F(3, 16) = 0.422$, $p = 0.740$). Duncan's multiple-range test indicated no significant differences ($P > 0.05$) among the group means, as all experimental groups formed a single homogeneous subset.

The growth rates observed in this study were consistent with established benchmarks for *P. innesi*. Specifically, Sanaye *et al.* (2012) reported that neon tetras fed a combination of live and artificial diets exhibited daily growth rates of 0.98% to 1.20%. The size variation documented in the current study may be attributed to intensified competition for resources. Previous literature suggests that dietary supplementation can exacerbate size disparity by increasing competition for food, particularly when feed is distributed from a localized point (Doupé & Lymbery, 2003; Luan *et al.*, 2020; Valente *et al.*, 2001). Furthermore, the initial variation in body weight likely resulted from competition for both food and space, driven by the constraints of the confined rearing environment during the nursing phase (Charo-Karisa *et al.*, 2006).

Total body length (TL) served as the primary growth metric in this investigation. Although selective breeding in the ornamental fish trade often prioritizes aesthetic traits such as coloration and morphology, the commercial value of the neon tetra is primarily determined by body length. In this species, market pricing is more closely associated with length than with weight, largely because bulk trade requires a uniform large size to meet industry standards. Consequently, breeders prioritize individuals with optimal length growth to ensure consistent quality and maximize economic returns. For these reasons, body length growth was established as the primary criterion for the genetic improvement of this species.

Variation in total length within each family was measured using the Coefficient of Variation (CV), which indicates the standard deviation relative to the mean. Across all experimental groups, CV values ranged from 6.83 ± 1.63% to 8.47 ± 4.34% (see Table 4). Statistical tests showed that the CV data were normally distributed (Shapiro-Wilk test, $p > 0.05$) and had homogeneous variances (Levene's test, $p = 0.182$). One-way ANOVA found no significant differences ($P > 0.05$) in CV among the four crossbreeding groups ($F(3, 22) = 0.488$, $p = 0.693$). Duncan's multiple-range test also confirmed this, grouping all experimental groups into a single homogeneous subset. These results support the idea that crossbreeding is a key strategy to increase genetic variation within a population for selection (Gjedrem, 2010; Yang *et al.*, 2025). Additionally, these results are consistent with a previous study by Musthofa *et al.* (2024), which reported higher genetic diversity in neon tetra populations from the Curug and Bojongsari areas compared to those from other areas.

Table 3. The growth parameters of selected broodstock candidates of neon tetra fish, *Paracheirodon innesi*

Parameters	Mating pairs (♀ >< ♂)				*F, p* value
	C >< C n (family)	B >< C n (family)	C >< B n (family)	B >< B n (family)	
Initial total length (day 30) (cm)	1.09 ± 0.08 (n = 5)	1.14 ± 0.09 (n = 5)	1.15 ± 0.11 (n = 5)	1.13 ± 0.10 (n = 5)	
Final total length (day 120) (cm)	2.68 ± 0.17 (n = 5)	2.65 ± 0.24 (n = 5)	2.76 ± 0.13 (n = 5)	2.75 ± 0.10 (n = 5)	
Specific growth rate (%/day)	1 ± 0.10^{a} (n = 5)	0.93 ± 0.25^{a} (n = 5)	0.97 ± 0.14^{a} (n = 5)	0.99 ± 0.09^{a} (n=5)	$F(3,16) = 0.422$, $p = 0.740$
Coefficient of variation (%)	6.83 ± 1.63^{a} (n=7)	8.47 ± 4.34^{a} (n=5)	8.20 ± 2.58^{a} (n=7)	7.78 ± 2.06^{a} (n=8)	$F(3, 22) = 0.488$, $p = 0.693$

Description: Data are presented as the mean ± standard deviation (SD). C >< C: ♀Curug >< ♂Curug; B >< C: ♀Bojongsari >< ♂Curug; C >< B: ♀Curug >< ♂Bojongsari; B >< B: ♀Bojongsari >< ♂Bojongsari. Values with a common superscript letter are not significantly different ($P > 0.05$).

The total body length distribution of four-month-old neon tetras in the present study is shown in Figure 2. The population follows a normal distribution, with the highest frequency in the 2.5-3 cm range. This bell-shaped distribution is significant because it reflects a quantitative trait influenced by multiple genes and the environment. Such phenotypic diversity provides essential material for genetic improvement through artificial selection (Falconer & Mackay, 1996). In a selective breeding program, the primary objective is to increase the frequency of desirable alleles by selecting and mating the best individuals, specifically those at the upper tail of the length distribution, to serve as the parental generation. This directional selection is intended to shift the population's average size, leading to gradual genetic progress across generations (Gjedrem & Baranski, 2009). The distribution pattern confirms that the population has sufficient phenotypic variation to support a selection program to increase body length in *P. innesi*.

In this study, within-family selection was used to improve desirable genetic traits by carefully selecting individuals. This approach has proven highly successful across various aquaculture species, including Nile tilapia (*Oreochromis niloticus*), with documented multigenerational improvements in growth (Bolivar & Newkirk, 2002). Although widely successful for food fish, there is limited published evidence on growth-focused selection programs in ornamental species, especially those aiming for body length. In this investigation, a within-family selection protocol with a 30% intensity was implemented, retaining only the top-performing individuals from each family based on total length. This threshold was strategically selected to optimize the balance between a robust selection response and adequate genetic diversity. According to Liu *et al.* (2022), a 30% cut-off is an effective compromise that enhances traits while preserving genetic variation for long-term population viability and ongoing population improvement.

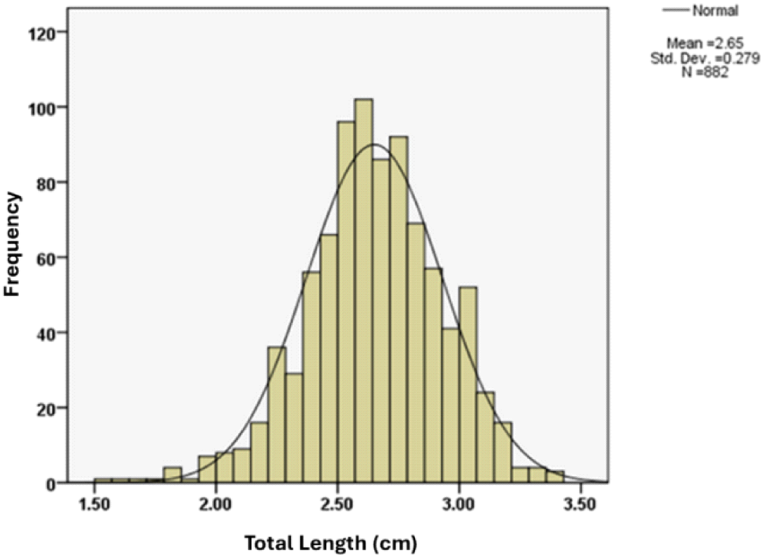

Figure 2. Histogram of the distribution of body length frequency of neon tetra seed derived from within-family selection.

Selection parameters and genetic estimates are shown in Table 4. The average survival rate was 69.57% ± 7.67%, with 882 individuals surviving until the end of the rearing period. Among these, 374 individuals were chosen as superior candidates and kept as the selected population. The average total length (TL) of the base population was 2.65 ± 0.28 cm, while the selected individuals exhibited a higher mean TL of 2.96 ± 0.31 cm. The differential selection (S), defined as the difference between the base population mean and the mean of selected individuals, was 0.31 cm (11.7%) in this study. Although an increment of 0.31 cm may appear modest in absolute terms, its biological and commercial significance is substantial when viewed relative to the species' small size. For an ornamental fish such as the neon tetra, which typically reaches a maximum adult length of only 3–4 cm, an 11.7% improvement represents a meaningful advancement in growth performance. These findings are consistent with established breeding programs for other aquaculture species, including GIFT tilapia and Atlantic salmon. In those instances, sustained selection differentials within a similar range (10–13% per generation) have proven fundamental in driving cumulative genetic gains over successive generations (Gjedrem & Rye, 2016; Hamzah *et al.*, 2014).

In this study, the heritability estimate for neon tetra body length at 4 months was 0.42 (Table 4), classified as moderate (0.20 < h2 < 0.50) according to Stansfield (1991). This value is considerably higher than estimates for growth traits in various tilapia strains, including male GIFT (0.12) (Lozano *et al.*, 2013), pond-reared *O. niloticus* (0.19 ± 0.06) (Luan *et al.*, 2008), and red tilapia (0.33) (Robisalmi & Dewi, 2014), highlighting the strong potential for genetic improvement in this species. Although CV values (Table 3) indicate low phenotypic variation, the moderate heritability suggests a substantial genetic component, making the phenotype a reliable predictor of genotype (Falconer & Mackay, 1996). According to Robisalmi *et al.*, 2019), understanding this parameter is essential for predicting selection response and evaluating breeding program success. Consequently, genetic improvement remains highly feasible through systematic breeding, particularly family-based selection, which remains effective even in populations with limited initial variation (Gjedrem & Baranski, 2009; Gunadi, *et al.*, 2021; Lall *et al.*, 2025).

The predicted response to selection (R), representing genetic gain for the next generation, was 0.13 cm, a 4.9% increase over the initial population mean (Table 4). Falconer & Mackay (1996) suggest that selection is more successful when the base population has high genetic diversity, allowing greater phenotypic variation. Additionally, a higher coefficient of variation (CV) generally results in a larger selection differential, thereby increasing the selection response (Gustiano *et al.*, 2013). Comparing this result with other aquaculture programs is complicated because most focus on body weight, often achieving gains of 10–20% per generation (Gjedrem & Rye, 2016; Ponzoni *et al.*, 2011). However, a relevant comparison based on linear measurements can be made with the Djambal catfish (*Pangasius djambal*), which shows an approximately 4.2% increase in total length due to selection (Tahapari *et al.*, 2020). Therefore, the 4.9% gain observed in *P. innesi*, influenced by its moderate heritability and the applied selection pressure, exceeds the linear increases reported for other species. This demonstrates the effectiveness of the selection protocol used and represents a significant step forward in the genetic improvement of this species.

The findings of this study demonstrate that crossbreeding is a potent strategy for enhancing the genetic potential of neon tetras and serves as a fundamental initial step in establishing a robust base population (Gjedrem, 2010). By hybridizing distinct strains, the resulting population exhibits broader genetic heterogeneity, thereby increasing the likelihood of successful selective breeding (Gustiano *et al.*, 2013). Beyond the immediate advantages for breeding initiatives, such genetic diversity is critical for long-term population resilience. As noted by Dunham (2011) genetically diverse populations possess a wider array of beneficial alleles and genomic combinations, which significantly enhances their capacity for adaptation and survival in response to environmental fluctuations.

Table 4. Population genetic parameters of selected broodstock candidates of neon tetra fish, *Paracheirodon innesi*

Parameters	Value
Survival of the whole population (%)	69.57 ± 7.67
Number of individuals survived (ind)	882
Number of individuals selected (ind)	374
Average total length of population (cm)	2.65 ± 0.28
The average total length of the selected individual (cm)	2.96 ± 0.31
Differential selection (cm)	0.31
Estimated heritability	0.42
Estimated selection responses (cm)	0.13
Estimated selection responses (%)	4.9

Water quality parameters during the study remained within acceptable ranges for rearing *P. innesi* (see Table 5). Temperature (23.9-27.6 °C) and dissolved oxygen (2-4 mg/L) were consistent with the native Amazonian habitats of *P. innesi* (Campos *et al.*, 2016; Chapman,1998). A pH gradient was applied, with acidic conditions (4.5-5.1) for spawning and slightly higher pH (5.1-6.8) during larval rearing, consistent with protocols for successful embryogenesis and growth (Chapman *et al.*, 1998; Kucharczyk *et al.*, 2010). Although conductivity levels during larval and seed rearing were notably higher than those used for spawning, they remained within the species' physiological tolerance. This is supported by broodstock rearing protocols that successfully use conductivity ranges from 31-48 ìS/cm up to 116 ìS/cm without adverse effects (Chapman *et al.*, 1998; Kucharczyk *et al.*, 2010).

Table 5. Water quality for rearing neon tetras, *Paracheirodon innesi*, throughout the experiment

Parameters	Tank/aquarium				
	Broodstock rearing	Spawning	Larva rearing	Seed rearing	Candidate broodstock rearing
Temperature (°C)	24.9-26.8	26.2-26.3	25.0-27.6	23.9-27.3	24.8-26.9
pH	3.9-5.2	4.5-5.1	5.1-6.1	5.1-6.8	4.7-5.5
Dissolved oxygen (mg/L)	2.9-3.4	2.8-3.0	2.2-3.9	2.0-3.4	2.5-3.9
Total dissolved solids (mg/L)	67-85	31-34	385-519	305-1878	60-90
Conductivity (µS/cm)	135-173	64-68	769-1058	609-3717	125-200
Hardness (mg/L)	540-550	25	590-620	37-170	47-61
Alkalinity (mg/L)	1.98-14.80	2.97	9.90-10.90	6.9-27.7	3.0-14.8
Total Ammonia (mg/L)	0-5	0	1.5-3	1.5-5	0-5

Notably, although the spawning media followed low-alkalinity and low-hardness standards (Chapman *et al.*, 1998), the hardness (590-620 mg/L) and TDS (up to 1878 mg/L) recorded during rearing greatly exceeded the typical ideal ranges of 28-42.66 mg/L (Sanaye *et al.*, 2014). Despite these elevated levels, the conditions were considered acceptable because domesticated neon tetra strains in Indonesian aquaculture have adapted to mineral-rich groundwater over multiple generations (Budiardi & Wahjuningrum, 2008). Although extreme hardness can hinder egg permeability during spawning, domesticated ornamental fish often tolerate high osmotic conditions during rearing, especially when ammonia levels stay below 1.0 mg/L, and waste is regularly siphoned. Furthermore, the use of *Terminalia catappa* likely served as an important buffer, with humic substances helping reduce potential osmotic stress from high TDS levels (Ardi *et al.*, 2020).

CONCLUSIONS

The estimated heritability of neon tetra fish is 0.42, with a response to selection of 0.13 cm (4.9%). These moderate heritability levels suggest that selection programs can effectively improve genetic gain in future generations of neon tetras. For long-term sustainability, strategies such as strain hybridization and strict inbreeding control should be implemented to preserve genetic diversity.

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AUTHOR CONTRIBUTIONS

Siti Zuhriyyah Musthofa: Conceptualization; methodology; data curation; investigation; formal analysis; visualization; writing-original draft preparation; writing-review and editing. Alimuddin Alimuddin: Conceptualization; methodology; validation; supervision; writing-original draft preparation; writing-review and editing. Harton Arfah: Conceptualization; methodology; writing-review and editing. Dinar Tri Sulistyowati: Conceptualization; methodology; writing-review and editing. Odang Carman: Conceptualization; methodology; writing-review and editing. Eni Kusrini: Conceptualization; methodology; writing-review and editing.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest regarding the publication of this paper.

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