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Effect of Stocking Density on Growth Performance of *C. gariepinus* and Breeding Values for Key Economic Traits from Three Eco-Regions in Nigeria: River Niger (N), River Benue (B) and River Hadejia (H)

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Abstract

The researched was practically investigated with the objective on effect of stocking density on growth performance and breeding values for key economic traits in crosses between broodstock from three eco-regions: River Niger (N), River Benue (B) and River hadejia (H). Growth parameters were determined using a weighing scale (weight) and a metre rule (length). Parameters determined after six months (2 stocking densities: 30fish.m^{-2} *and 60 fish.m*$^{-2}$*). Economic traits that were determined after 6 months of growth include: total length (TL), standard length (SL), body depth (BD) and head length (HL). Breeding values for final weight, final total length, final standard length, final body depth and final head length were determined based on narrow sense heritability estimate using the model of additive genetic variance. To estimate the variance components and breeding values of cross from broodstock of various ecoregions, the animal model in the R package breedR was used. Breeding values were then used to agglomerate offspring and determined which economic traits best explain the variation in the populations using principal component analysis in R. Under culture for 6 months, MFW differed among the crosses regardless of stocking density (p<0.05). The MFW ranged from 415.16g (♀H×H♂) to 733.78g (♀H×N♂). The narrow sense heritability (h*^{2}*) was higher for body depth in progenies reared at low stocking density (0.1515) compared to those reared at high stocking density (0.0697). The breeding values for final weight and body depth was significantly impacted by both stocking density and cross (p<0.05). In conclusion, selective breeding for economic traits yields breeding values in the first generation of selection. Heritability for body depth was highest at low stocking density compared to high stocking density.*

Keywords: Stocking Density, Growth Performance, Breeding Value, Key Economic Traits, Nigeria.

1.0 Introduction

In Nigeria and some part of the globe,catfish are mainly produced in private ponds but some state and federal agencies stock hatchery-reared fish in public waters (Smitherman et al., 1996). According to (Edwards et al., 1993), propagated fishes could be used to enhance fisheries by supplementing existing populations, filling "uninhabited niches," and/or adding additional desirable fishes to the fishery but the assumption that all of these purposes were desirable and consistent with sound environmental principles has been challenged. Apart from deliberate stocking of natural waters with hatchery bred or domesticated fish, there is also the possibility of escape of cultured fish into the wild. (Smitherman et al., 1996) were of the opinion that cultured catfish are sometimes lost during flooding from aquaculture facilities to natural waters, where genetic influences and competitive interactions might impact indigenous populations of American catfish but these influences and interactions have not been evaluated.Breeding and re-stocking programmes and hatchery produced fishes have been alleged to cause problems in the natural environment outside of culture. Some of the allegations according to Edwards et al. (1993)include dependence on stocking programs, populations decline despite stocking programs, failure to prevent habitat destruction, pollution, and dam construction thereby permitting continued habitat loss, high cost of hatchery construction and operation,modification of ("pollution") the genetic integrity of "wild" fishes, increased harvest of wild populations that are already stressed by over-harvest, risk of higher pathogen loads than "wild" fish, thereby spreading pathogens, "stealing" spawners from wild populations thus reducing both the numbers and the genetic diversity of natural spawners, and stocking large numbers of "hatchery fish" may "swamp" native populations and change a genetic constitution that has been developed specifically in response to long-term evolutionary pressures. Petersson and Järvi (2006), compared the anti-predator responses of hatchery-reared brown trout (*Salmo trutta*) juveniles having sea ranched or wild origins, or the reciprocal crosses between wild and sea-ranched fish using pike and a heron predator dummy. They discovered that juveniles of wild origin differed from those of sea-ranched origin in their response to predator attacks and wild fish also differed in this regard from the crosses between wild and sea-ranched fish. The responses differed mainly in terms of response to the heron dummy and response time to first attack (i.e. duration of initial inactivity when subject to first attack). However, the reciprocal crosses were not intermediate in their response patterns, but were closer to the sea-ranched than to the wild fish in this regard. Kujawa et al. (2011), reported the artificial spawning of common tench *Tincatinca* of wild and domestic origin in three reproductive seasons using ovopel and carp pituitary homogenate (CPH). Ovopel produced a better percentage of ovulation (average 72%) in both stocks than CPH (average 58%). The authors also reported that the percentage of ovulation was higher in the wild stock than in the cultured one. In the second reproductive season, they observed no differences (P>0.05) among populations or hormonal treatments for ovulation. Plante et al. (2003), compared the stress response in wild and captive winter flounder (*Pseudopleuronectesamericanus*) broodstock to verify if wild winter flounder suffer from chronic stress when kept several months in captivity. They reported that the condition index of winter flounder kept in captivity was higher (1.50) than those from the wild (1.33) even after one year of captivity. The intensity of the acute stress response following short-term exposure to air was similar between wild and captive fish showing that there was no significant interaction between the factors ‘stress’ and ‘origin' of the fish. Reduction in fitness of released or escaped cultured or domesticated fish has been an issue of concern to conservation geneticists. In line with this, several scientists have carried out research into the effects of releasing domesticated fish into the wild.Fujii and Noguchi (1993) studied the interactions between released and wild Japanese Flounder (*Paralichthysolivaceus*) on a nursery ground, off Igarashi-Hama on the northwestern coast of Japan. They reported that this fish naturally feeds on mysids and that growth rate of wild flounder varies depending on availability of mysids. They also discovered that released flounder were inferior to wild ones in incidence of feeding and feeding rate with food composition being slightly different between released and wild flounder, and that recaptured released flounder had ingested gammarids, which the wild flounder had not. Studies have shown that stocked trout, even if restocked at very young stages, are more vulnerable to angling than wild trout(Champigneulle & Cachera, 2003; Mezzera & Largiader, 2001).Mylonas and Zohar (1998), compared the plasma levels of gonadotropin (GtH) II, the major pituitary hormone controlling final gamete maturation in fish between wild and captive broodstocks of striped bass (*Moronesaxatilis*) to understand the failure of captive fish to undergo final oocyte maturation (FOM) and spermiation. They reported that Captive fish, both male and female, had lower plasma GtH II levels during the spawning season, and this seems to be the cause of the reproductive dysfunction in striped bass, and presumably in other fishes reared in captivity. Domesticated catfish grow faster than wild catfish when cultured in ponds with production differences being as great as 250 percent and domestication has resulted in an average growth increase of 3 to 6 percent per generation with no differences in survival of domestic and wild strains in the aquaculture environment(Smitherman & Dunham, 1993).

Aims and Objectives

Determined the effect of stocking density on growth performance of *C.gariepinus* and breeding values for key economic traits in crosses between broodstock from the three eco-regions.

2.0 Materials and Methods

The study Area

The study were carried out in Makurdi, Benue State. Makurdi is located on latitude 7° 43' 55.92" N and 8° 32' 20.76" E. Makurdi town has two main seasons: the wet season usually between April and October and the dry season usually between November and March. Wild broodstock of *Clarias gariepinus* were obtained from artisanal fishermen along the River Hadejia and Jama’are (H) basin and flood plains, River Niger at Lokoja (N) and River Benue (B) at Makurdi.

Water Quality Parameters

Water obtained from a borehole was used for the hatchery and rearing experiments. The physicochemical parameters of water in the incubation tanks as well as the ponds used for rearing were analyzed as per standard methods by APHA (2005).

Temperature: The temperature of water in each tank was taken using mercury in glass thermometer (0-100^0C) every sampling morning.

Hydrogen ion concentration (pH):

The pH of the water in the tanks was taken using an electronic pH meter - B. Bran Scientific pH-meter (Model pHS – 25).

Dissolved Oxygen (DO): This was measured using Hanna Multiparameter Water Quality Probe Model HI-98129.

Experiment: Effect of stocking density on growth performance and breeding values for key economic traits

Stocking density and growth monitoring

Progeny from each cross were selected randomly and stocked in hapas of 1m × 1m × 0.7m capacity immersed in earthen ponds. Two stocking densities: 30 fish/m^2 and 60 fish/$m^2$was used. The growth trial lasted for 6 months and expected data output. Sampling involved half the population in each case every month. Data was also acquired in those of 8 weeks trials.

Table 3.2. Parameters acquired from growth trials under low and high stocking density

Parameters (Traits)	
Weight	Length
Initial Body weight (MIW), Final Body weight (MFW),	Final Total length (TL), Final Standard length (SL), Final Body depth (BD), Final Head length (HL)

Breeding values for final weight, final total length, final standard length, final body depth and final head length were estimated based on narrow sense heritability estimate using the model of additive genetic variance:

Narrow Sense Heritability $h^2 = \frac{\sigma_a^2}{\sigma_a^2+\sigma_{gg}^2+\sigma^2}$

Where:

$\sigma_a^2 = Additive\ Genetic\ Variance\ of\ Trait$

$\sigma_{gg}^2 = Phenotypic\ Variance\ among\ genetic\ groups$

$$\sigma^2 = Overall\ Variance$$

Therefore, Estimated Breeding value was estimated using:

$$EBV = h^2 \times P$$

Where P = difference between individual phenotype and mean phenotype of the population

Data Analysis

Data on growth and survival (6 months) was analysed using two-way ANOVA. Means from ANOVA were separated using Tukey's HSD ($p<0.05$). To estimate the variance components of the diallel cross from broodstock of various eco-regions, the animal model in the R package breedR (Muñoz & Sanchez, 2022) was used. The linear model fitted to the data was based on specification of the genetic group as an unstructured random effect via:

$$phe_X = \mu + Z_{gg} + \varepsilon$$

Where:
phe_x = Phenotype value
μ = overall mean
Z_{gg} = breeding value
ε = random error term
Breeding values were then used to agglomerate offspring and determine which economic traits best explain the variation in the populations using principal component analysis in R.

3.0 Results

Grow-out Performance: Effect of stocking density on growth performance

Growth over time among progenies from the crosses reared for six months at low stocking density (30 fish.m^{-2}) shows that four crosses♀B×B♂, ♀N×N♂, ♀H×B♂ and ♀H×N♂ lagged behind in weight from January to June. There was a fairly consistent growth pattern for the other five crosses (Figure 4.9).Survival pattern over time (Figure 4.10) shows that mortality was high in the cross ♀H×H♂ across the duration of culture while crosses ♀N×H♂ and ♀N×N♂ maintained a fairly good survival over time.Among progeny from crosses that were reared under high stocking density (Figure 4.11), shows that four crosses: ♀B×B♂, ♀N×N♂, ♀H×H♂ and ♀H×B♂ lagged behind in growth over the six months of culture. The top performers maintained a close competition from February to June.Survival over six months for progeny reared under high stocking density (Figure 4.12) indicates that the crosses ♀H×H♂, ♀B×B♂, ♀H×B♂ and ♀N×B♂ exhibited lower survival across the culture period with survival rate of the cross ♀H×H♂ falling below 80%.

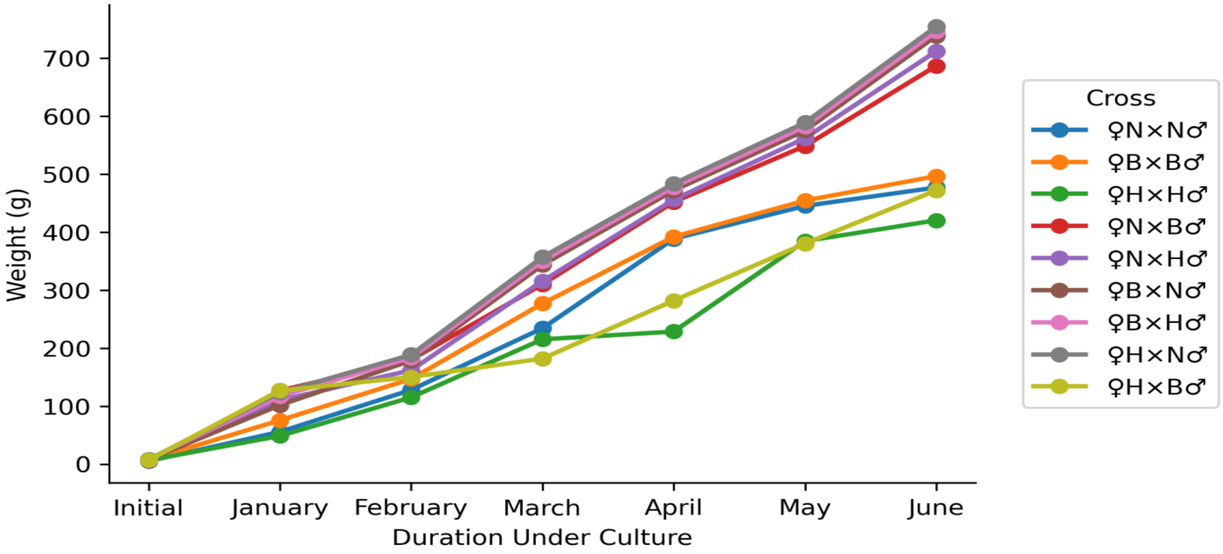

Figure 4.9. Progressive Weight of progeny under low stocking density (30/m^2) rearing for six months

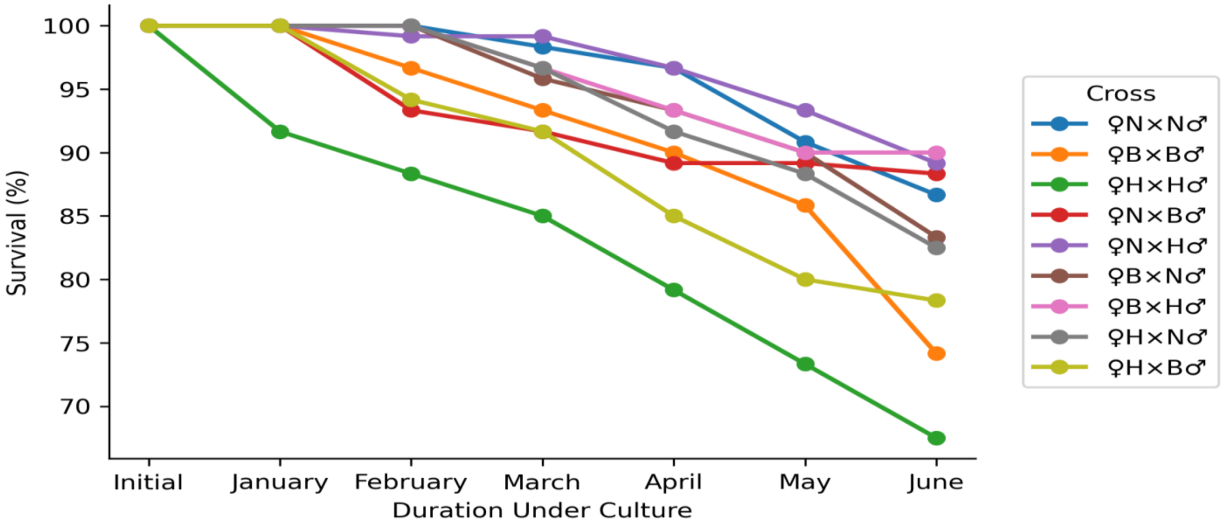

Figure 4.10. Progressive survival rate of progeny under low stocking density (30/m^2) rearing for six months

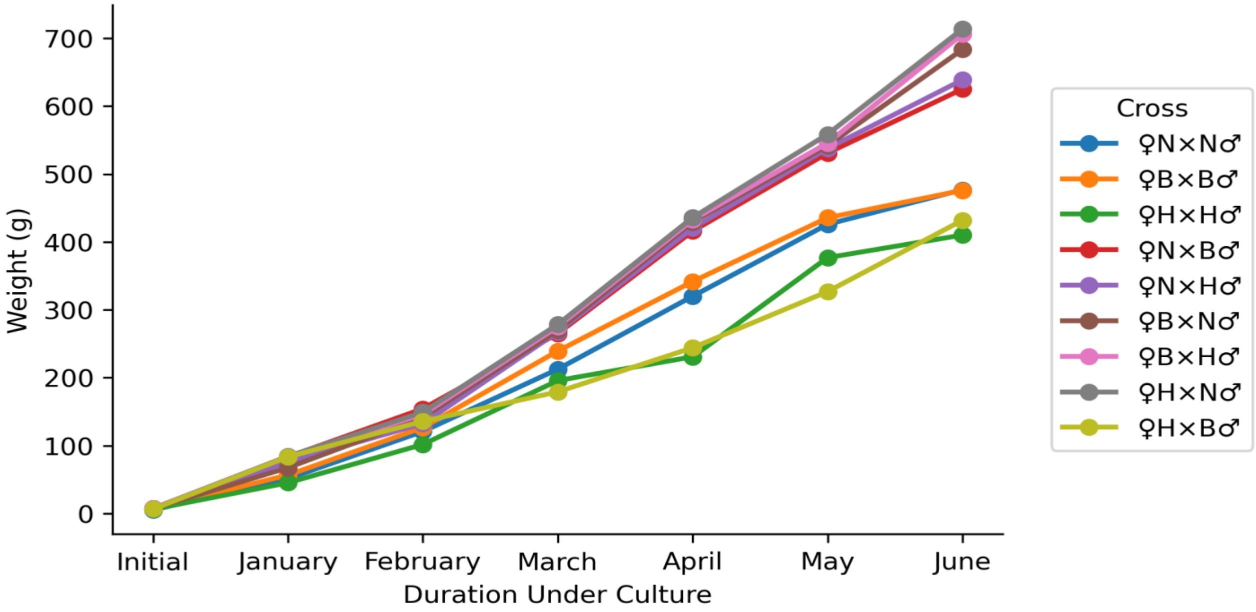

Figure 4.11. Progressive Weight of progeny under high stocking density (60/m^2) rearing for six months.

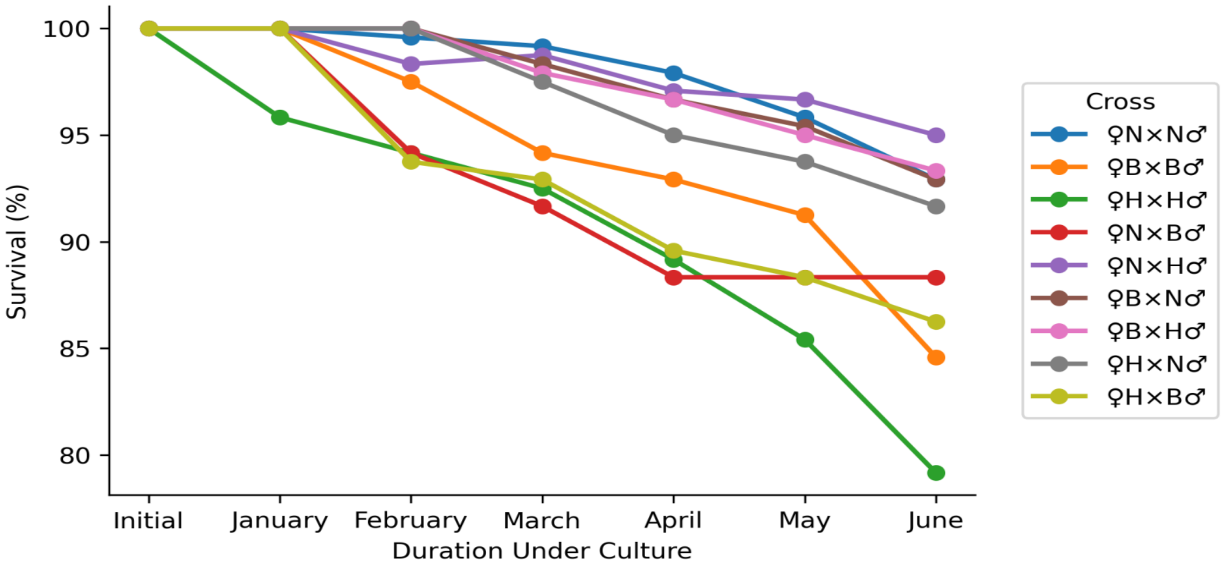

Figure 4.12. Progressive survival rate of progeny under high stocking density (60/m^2) rearing for six months

Growth parameters of progeny from the crosses reared under high and low stocking density (Table 4.12) indicates that stocking density significantly impacted ($p<0.05$) MFW with the highest value of 611.34g being recorded under low stocking density. This effect also extended to DWG with the same pattern where progeny under low stocking density regardless of cross produced a higher DWG (3.36g.day^{-1}). Progeny under low stocking density also had the highest SGR (2.48%.day^{-1}). The survival rate was also significantly different across the stocking densities ($p<0.05$) with the high stocking density producing the highest survival rate (89.35%).

Mean initial weight is significantly different ($p<0.05$) among crosses irrespective of stocking density. This was not tampered with since early growth already revealed the difference. However, selection for stocking density was done such that there was no significant difference between the densities. Mean final weight differed among the crosses regardless of stocking density ($p<0.05$). The MFW ranged from 415.16g (♀H×H♂) to 733.78g (♀H×N♂). Interaction of cross and stocking density was significant ($p<0.05$) in determining the MFW of the progenies. There was also a significant effect ($p<0.05$) of cross on DWG such that the cross ♀H×N♂ had the highest DWG of 4.03g.day^{-1} and the cross ♀H×H♂ gave the least DWG of 2.27g.day^{-1}. There was also a significant interaction ($p<0.05$) between stocking density and cross in shaping the DWG of the progenies. Specific growth rate was also significantly affected by cross with the highest SGR value of 2.56%.day^{-1} being recorded for the cross ♀N×B♂ while the least SGR (2.31%.day^{-1}) was recorded for the cross ♀H×H♂. There was no significant interaction ($p>0.05$) between cross and stocking density in shaping the SGR of the progenies.

Survival rates for progenies from the crosses irrespective of the stocking density was significantly different ($p<0.05$). The best survival rate (92.08%) was recorded for the cross ♀N×H♂ while the least survival rate of 73.33% was recorded for ♀H×H♂. There was a significant interaction ($p<0.05$) between stocking density and cross with regards to survival rates.

Table 4.12. Growth and survival of progeny from crosses of *C. gariepinus* broodstock obtained from three eco-regions reared for six months under high and low stocking density.

Density	MIW	MFW	DWG	SGR	Survival
High(60/m^{2})	6.93 ± 0.16	573.45 ± 19.90^{b}	3.15 ± 0.11^{b}	2.45 ± 0.02^{b}	89.35 ± 0.87^{a}
Low(30/m^{2})	6.92 ± 0.16	611.34 ± 22.40^{a}	3.36 ± 0.12^{a}	2.48 ± 0.02^{a}	82.22 ± 1.25^{b}
p-value	0.935	0.000	0.000	0.003	0.000
Cross					
♀N×N♂	5.21 ± 0.21^{d}	476.82 ± 2.82^{d}	2.62 ± 0.02^{d}	2.51 ± 0.02^{b}	89.79 ± 1.35^{ab}
♀B×B♂	7.45 ± 0.15^{ab}	486.15 ± 4.25^{d}	2.66 ± 0.02^{d}	2.32 ± 0.01^{c}	79.38 ± 2.04^{e}
♀H×H♂	6.49 ± 0.25^{c}	415.16 ± 2.97^{f}	2.27 ± 0.02^{f}	2.31 ± 0.02^{c}	73.33 ± 2.38^{f}
♀N×B♂	6.51 ± 0.17^{c}	655.82 ± 13.10^{c}	3.61 ± 0.07^{c}	2.56 ± 0.02^{a}	88.33 ± 0.94^{bc}
♀N×H♂	6.92 ± 0.32^{bc}	675.16 ± 15.00^{c}	3.71 ± 0.08^{c}	2.55 ± 0.03^{ab}	92.08 ± 1.17^{a}
♀B×N♂	7.65 ± 0.15^{a}	710.90 ± 14.80^{b}	3.91 ± 0.08^{b}	2.52 ± 0.01^{ab}	88.12 ± 1.85^{bc}
♀B×H♂	7.93 ± 0.19^{a}	725.95 ± 10.60^{ab}	3.99 ± 0.06^{ab}	2.51 ± 0.01^{b}	91.67 ± 0.63^{a}
♀H×N♂	7.49 ± 0.20^{ab}	733.78 ± 9.93^{a}	4.03 ± 0.05^{a}	2.55 ± 0.01^{ab}	87.08 ± 1.80^{c}
♀H×B♂	6.65 ± 0.14^{c}	451.83 ± 8.05^{e}	2.47 ± 0.04^{e}	2.34 ± 0.02^{c}	82.29 ± 1.60^{d}
p-value	0.000	0.000	0.000	0.000	0.000
Interaction Density*Cross					
p-value	0.370	0.002	0.001	0.116	0.000

Means in the same column of treatments followed by different superscripts differ significantly ($p<0.05$)

Water quality as monitored in individual hapas used to rear the progeny (Table 4.13) shows that dissolved oxygen was optimal ($>5.0mg.l^{-1}$) in all hapasand pH was near neutral (7.00 to 7.57). Temperature was between 29.04°C and 30.02°C.

Table 4.13. Water quality in hapas used to rear progenies from crosses of broodstock from three eco-regions at high (60/m^{2}) and low (30/m^{2}) stocking density.

Cross	DO (mg/l)	Temp (°C)	pH
High Stocking Density			
♀N×N♂	7.20±0.03	29.35±0.12	7.13±0.04
♀B×B♂	7.20±0.01	29.54±0.10	7.16±0.07
♀H×H♂	7.22±0.02	29.54±0.10	7.19±0.07
♀N×B♂	7.34±0.09	29.79±0.05	7.21±0.03
♀N×H♂	7.48±0.07	29.93±0.11	7.43±0.04
♀B×N♂	7.41±0.07	30.02±0.04	7.44±0.03
♀B×H♂	7.47±0.04	29.61±0.10	7.55±0.04
♀H×N♂	7.53±0.05	29.75±0.09	7.57±0.03
♀H×B♂	7.35±0.03	29.19±0.11	7.36±0.03
Low Stocking Density			
♀N×N♂	7.13±0.04	29.15±0.11	7.00±0.07
♀B×B♂	7.10±0.04	29.04±0.11	7.29±0.08
♀H×H♂	7.17±0.04	29.06±0.12	7.09±0.07
♀N×B♂	7.43±0.04	29.50±0.10	7.40±0.02
♀N×H♂	7.46±0.03	29.58±0.10	7.43±0.03
♀B×N♂	7.41±0.03	29.44±0.11	7.41±0.03
♀B×H♂	7.33±0.02	29.50±0.10	7.32±0.02
♀H×N♂	7.45±0.03	29.46±0.10	7.44±0.02
♀H×B♂	7.58±0.02	29.50±0.10	7.55±0.02

Effect of stocking density on growth performance and breeding values for key economic traits Heritability for economic traits: The narrow sense heritability (h^2) which is the proportion of trait variance that is due to additive genetic factors (Table 4.14) was higher for body depth in progenies reared at low stocking density (0.1515) compared to those reared at high stocking density (0.0697). Heritability was higher in the other traits for progeny reared under high stocking density compared to low stocking density. There was however the occurrence of a rare phenomenon of negative heritability for standard length in progeny reared under low stocking density. The biological basis as well as mathematical interpretations are beyond the scope of this current research.

Table 4.14. Heritability estimates for traits among progeny from crosses of *C. gariepinus* broodstock sourced from three eco-regions

Trait	High Stocking Density	Low Stocking Density
Final Weight	0.02188	0.005028
Final Head Length	0.05931	0.012820
Final Body Depth	0.06970	0.151500
Final Total length	0.01761	0.011830
Final Standard Length	0.06070	-0.0004558*

*Negative heritability is a mathematical possibility but this has deleterious impact on biological projections hence it will be used with caution.

Breeding Values for economic traits

The median breeding value for standard length for progeny reared under high stocking density (Figure 4.13) was highest (0.2891) in the cross ♀H×B♂ with the least value of -1.3318 being recorded for the cross♀N×H♂ and the maximum breeding value of 1.9981 being recorded for progeny from the cross♀N×B♂. At low stocking density (Figure 4.14), the highest median breeding value for standard length was recorded also in the cross♀H×B♂ (0.1757) while the least value of -0.9682 was obtained for the cross♀N×H♂. The highest or maximum breeding value of 0.8594 was recorded in the cross♀H×B♂.

Distribution of breeding values for total length in progeny reared at high stocking density (Figure 4.15) shows that the highest median breeding value (0.2887) was also recorded for the cross♀H×B♂ while the least breeding value (-1.33) was obtained for the cross♀N×H♂. The highest breeding value (1.9965) for total length was recorded for the cross♀N×B♂. At low stocking density (Figure 4.16), the highest median breeding value for TL (0.1786) was recorded in the cross♀H×B♂ and this also doubled as the 75th percentile value for breeding value of TL

for the cross. The least breeding value for TL in progeny reared at low stocking density was observed in the cross ♀N×H♂ (-0.9833) while the highest breeding value for TL at low stocking density (0.8729) was recorded for the cross♀H×B♂.

The distribution of breeding values for head length among progeny reared at high stocking density (Figure 4.17) was such that the lowest 25th percentile (-0.8037) was recorded in the cross ♀H×B♂ while the lowest median (-0.1668) was observed in the cross♀B×B♂. The least value among the 75th percentiles was recorded for the cross♀N×H♂ (0.0349). At low stocking density (Figure 4.18), the least 25th percentile (-0.1863) was recorded for the cross♀B×B♂. The least median value (-0.1066) was recorded for the cross♀H×N♂. The least 75th percentile of breeding values for head length at low stocking density (0.00218) was recorded for the cross♀H×H♂.

Breeding values for body depth as distributed among progeny reared at high stocking density (Figure 4.19) shows that the highest median breeding value (0.0334) occurred in the cross♀H×H♂ with the highest 25th percentile (-0.0023) being recorded in the cross♀H×N♂. The highest breeding value (0.2826) was recorded for the cross♀H×H♂. Breeding values for body depth in progeny reared at low stocking density (Figure 4.20) was highest (0.2342) in the cross ♀H×H♂with the highest median breeding value of 0.03325 being recorded for the cross♀N×B♂.

Breeding value distribution for the trait of final weight at high stocking density (Figure 4.21) was highest in the cross♀B×N♂ (60.81) with the highest median value of 2.28 also occurring in the same cross. The highest median breeding value for weight in progeny reared under low stocking density (Figure 4.22) was recorded for the cross♀H×N♂ (1.167) while the highest breeding value for this trait at low stocking density was 16.97 in the cross ♀N×B♂.

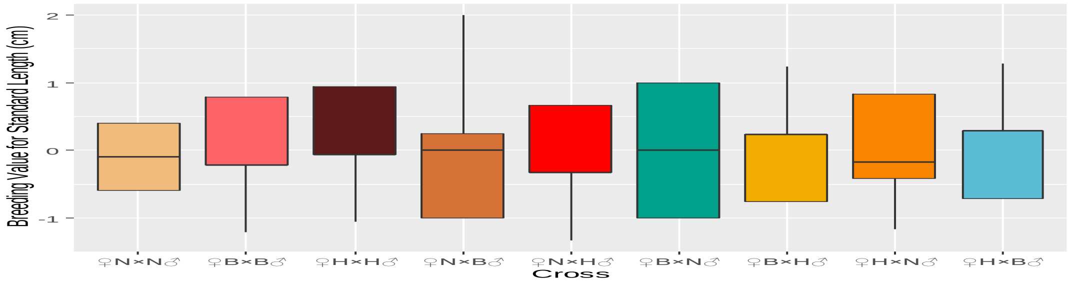

Figure 4.13. Distribution of breeding values for standard length in progeny of crosses between broodstock of *C. gariepinus* from three eco-regions reared at high stocking density

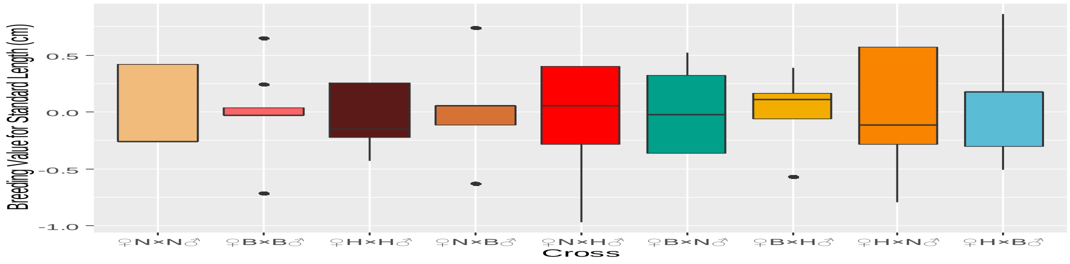

Figure 4.14. Distribution of breeding values for standard length in progeny of crosses between broodstock of *C. gariepinus* from three eco-regions reared at low stocking density

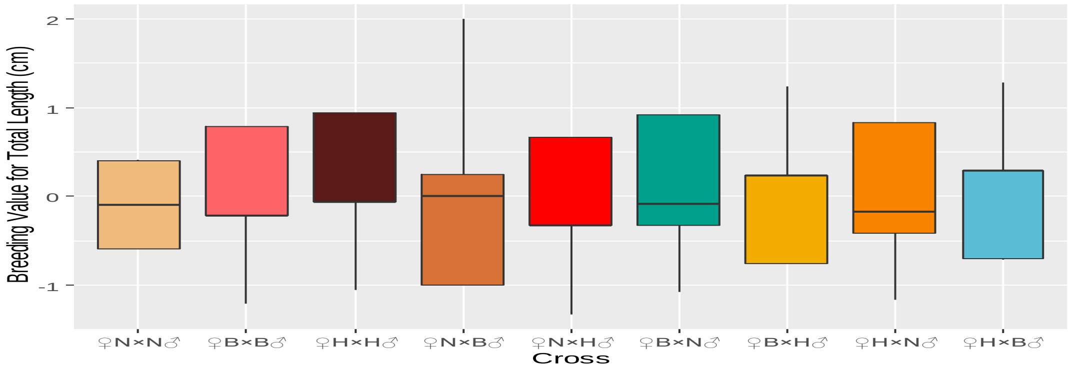

Figure 4.15. Distribution of breeding values for total length in progeny of crosses between broodstock of *C. gariepinus* from three eco-regions reared at high stocking density

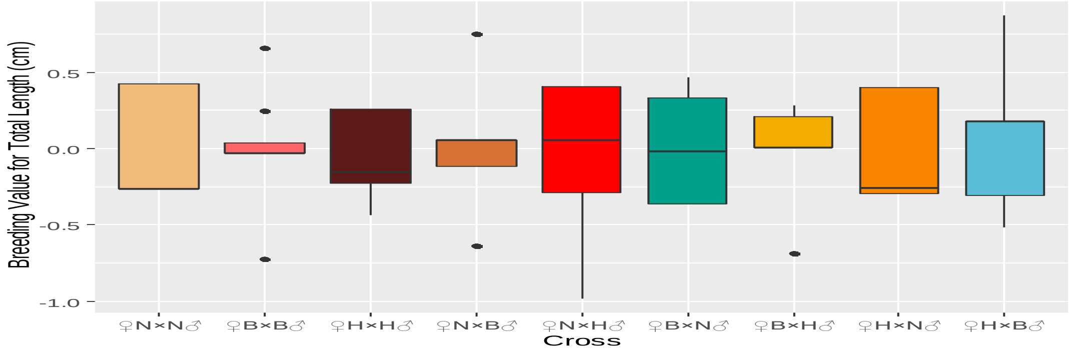

Figure 4.16. Distribution of breeding values for total length in progeny of crosses between broodstock of *C. gariepinus* from three eco-regions reared at low stocking density

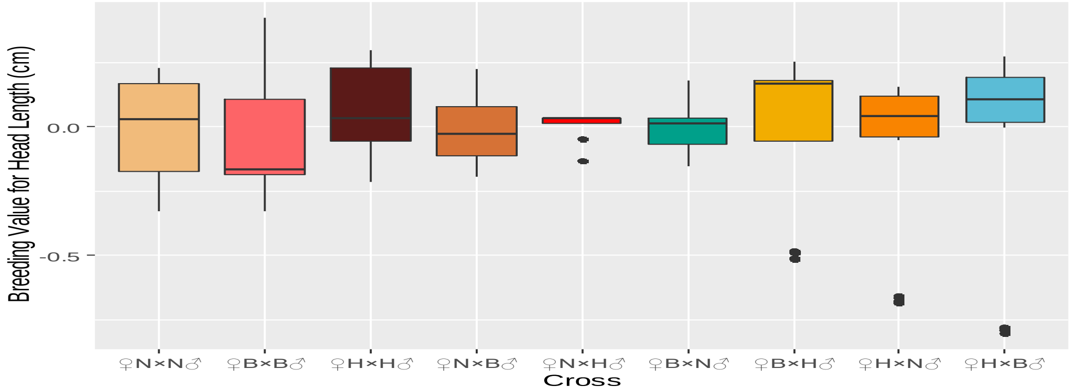

Figure 4.17. Distribution of breeding values for head length in progeny of crosses between broodstock of *C. gariepinus* from three eco-regions reared at high stocking density

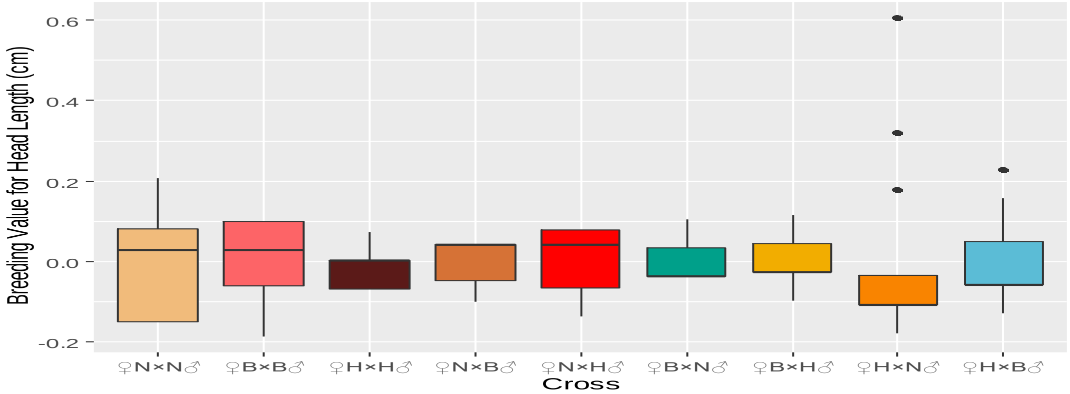

Figure 4.18. Distribution of breeding values for head length in progeny of crosses between broodstock of *C. gariepinus* from three eco-regions reared at low stocking density

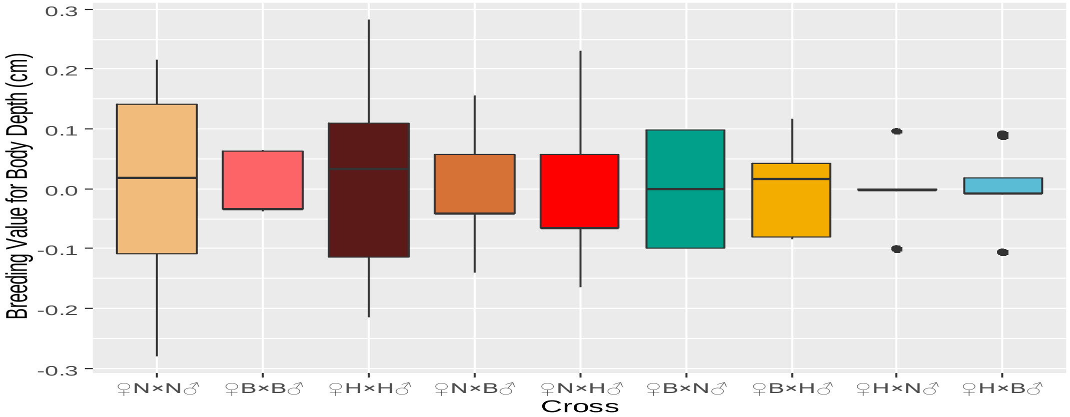

Figure 4.19. Distribution of breeding values for body depth in progeny of crosses between broodstock of *C. gariepinus* from three eco-regions reared at high stocking density

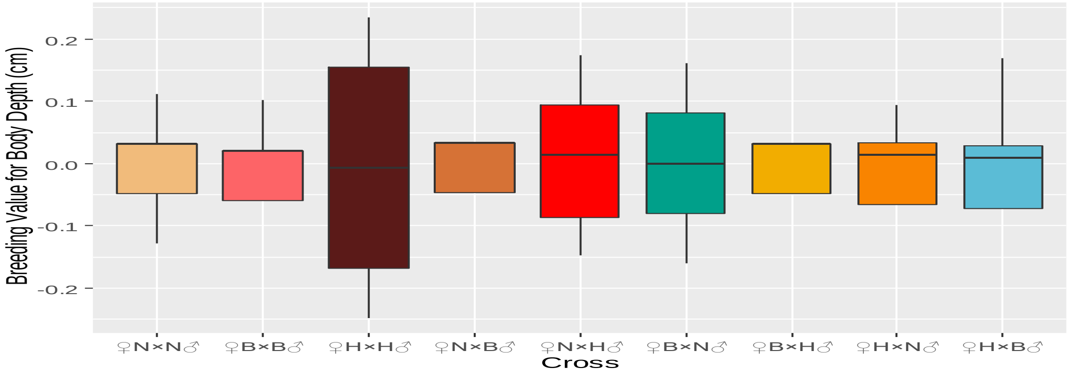

Figure 4.20. Distribution of breeding values for body depth in progeny of crosses between broodstock of *C. gariepinus* from three eco-regions reared at low stocking density

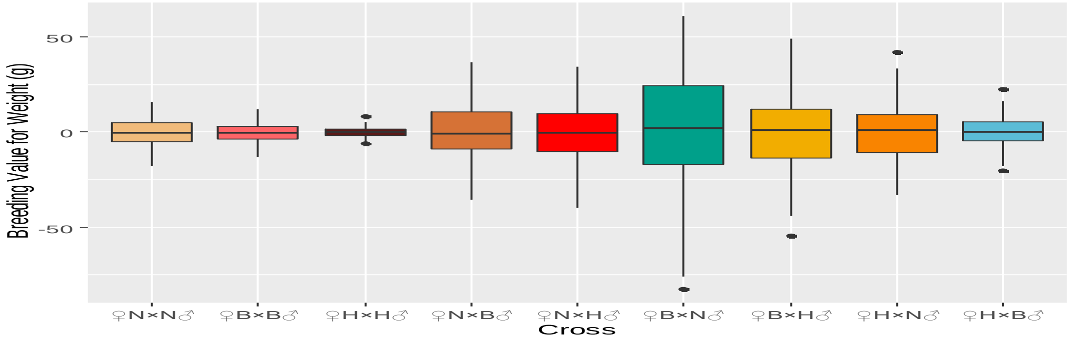

Figure 4.21. Distribution of breeding values for body weight in progeny of crosses between broodstock of *C. gariepinus* from three eco-regions reared at high stocking density

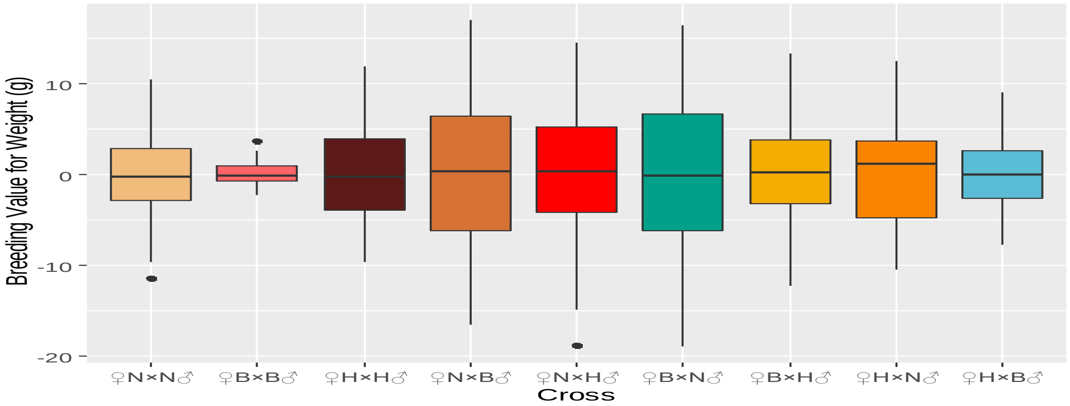

Figure 4.22. Distribution of breeding values for body weight in progeny of crosses between broodstock of *C. gariepinus* from three eco-regions reared at low stocking density.

Validating breeding values and classification of progeny

Among the pure line crosses at high stocking density, the cross ♀H×H♂ was well classified by the breeding values (Figure 4.23) than the other pure crosses. The dimensionality of breeding values was reduced to two, with the first-dimension accounting for 61.8% variation while the second dimension accounted for 20.8% of the variation in the breeding values. Four traits: body depth, head length, standard length and total length contributed more to the first dimension while weight contributed substantially to the second dimension (Table 4.15).At low stocking density (Figure 4.24), the progeny from the pure line cross ♀B×B♂ was well grouped compared to the other pure line crosses. The first dimension which comprised mostly of body depth, head length, standard length and total length (Table 4.15) accounted for 56.3% of the variation in breeding values while weight contributed more to the second dimension and accounted for 20.3% of the variation.

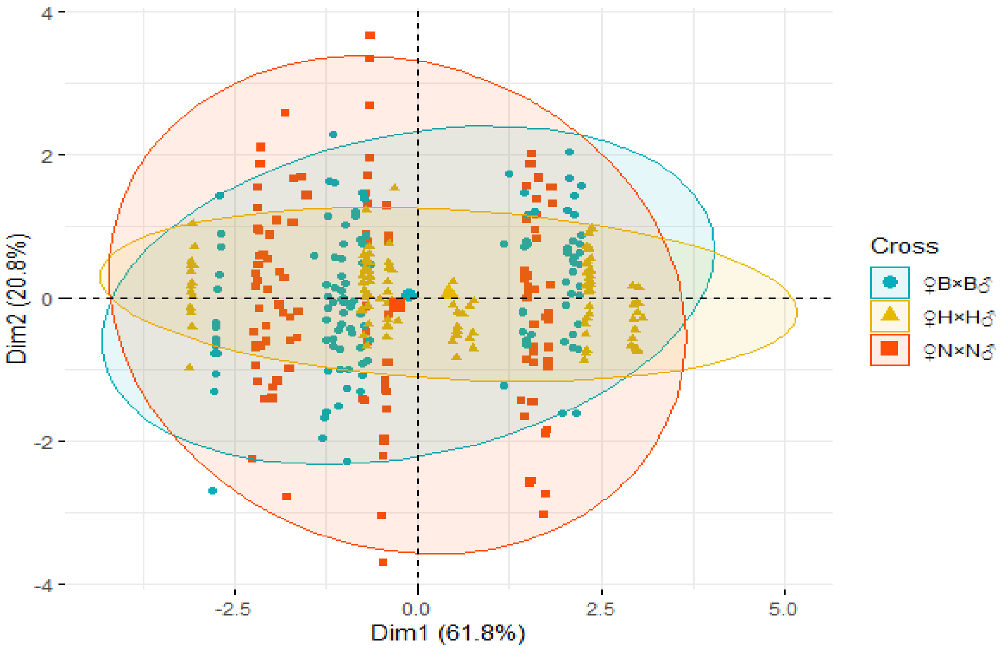

Figure 4.23. PCA biplot of breeding values for five economic traits in offspring of pure line crosses of *C. gariepinus* from three eco-regions reared at high stocking density

Table 4.15. Component loadings for principal components explaining the structure of the population of progenies of pure line crosses of *C. gariepinus* broodstock from three eco-regions raised at high and low stocking density over six months

	Percentage Contributions: High Stocking Density				
Trait	**Dim.1**	**Dim.2**	**Dim.3**	**Dim.4**	**Dim.5**
Body Depth	16.90	6.75	57.62	18.72	0.00
Head Length	26.01	0.42	3.22	70.34	0.00
Standard Length	28.51	1.23	14.80	5.48	49.97
Total Length	28.52	1.23	14.76	5.45	50.03
Weight	0.05	90.36	9.59	0.00	0.00
	Percentage Contributions: Low Stocking Density				
Body Depth	7.64	6.25	85.33	0.77	0.00
Head Length	27.03	0.69	0.95	71.34	0.00
Standard Length	32.60	1.67	2.89	12.84	50.00
Total Length	32.60	1.67	2.89	12.84	50.00
Weight	0.14	89.73	7.93	2.20	0.00

Purelines: ♀N×N♂; ♀B×B♂; ♀H×H♂

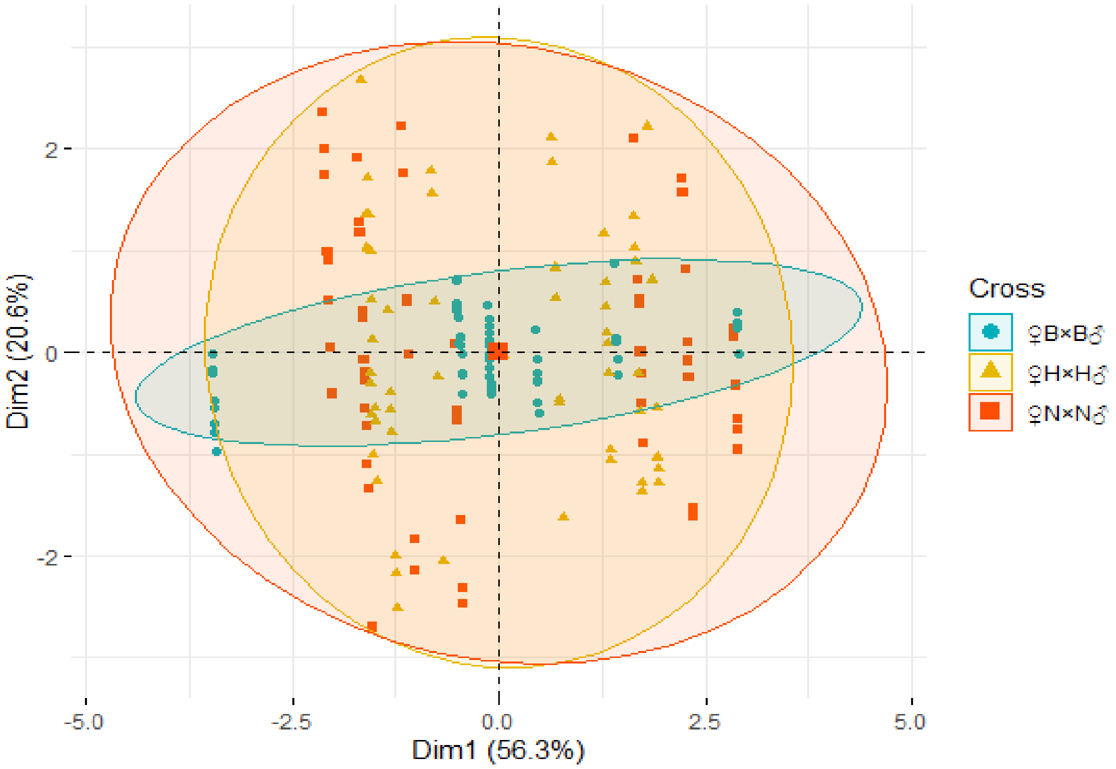

Figure 4.24. PCA biplot of breeding values for five economic traits in offspring of pure line crosses of *C. gariepinus* from three eco-regions reared at low stocking density

Progenies from two crosses between broodstock from three eco-regions: ♀H×B♂ and ♀N×H♂ were well described by the breeding values as reduced into two dimensions (Figure 4.25) using data from progeny reared at high stocking density. The first dimension, accounts for 52.3% of the variation with contributions coming strongly from body depth, head length, standard length and total length while the second dimension, accounts for 19.9% of the variation with the strongest contribution from weight alone (Table 4.16).At low stocking density, the breeding values tightly grouped the progeny from the cross ♀H×B♂ with loose grouping occurring in the other crosses (Figure 4.26). The dimension reduction to classify the progeny under low stocking density using breeding values shows that the dimension 1 accounted for 53.6% of the variation among the progeny while dimension two (contributed mostly by weight) accounted for 20.8% of the variation. The pattern of breeding value contributions to the dimensions was also similar for the crosses under low stocking density (Table 4.16).

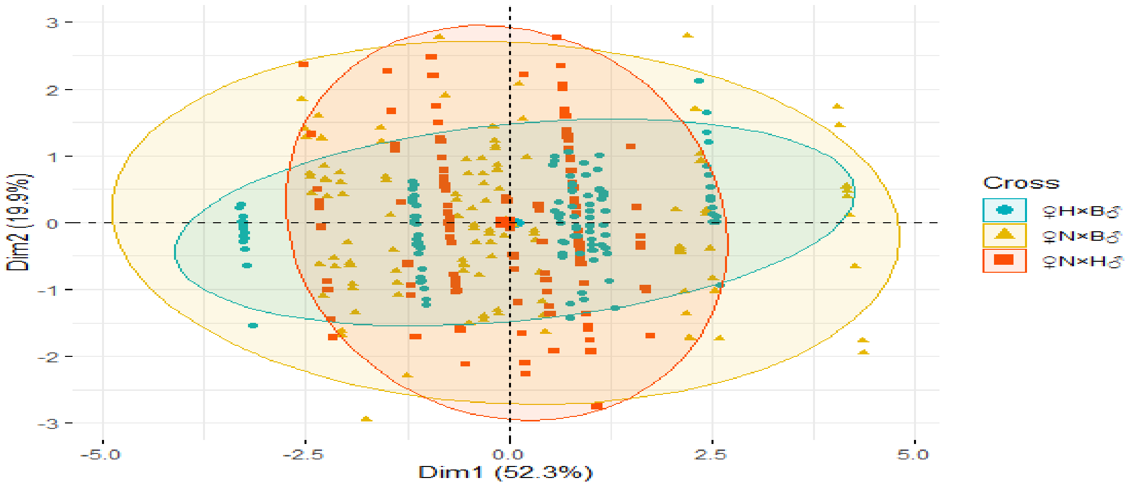

Figure 4.25. PCA biplot of breeding values for five economic traits in offspring of crosses of *C. gariepinus* from three eco-regions reared at high stocking density

Table 4.16. Component loadings for principal components explaining the structure of the population of progenies of crosses of *C. gariepinus* broodstock from three eco-regions raised at high and low stocking density over six months

	Percentage Contributions: High Stocking Density				
Trait	Dim.1	Dim.2	Dim.3	Dim.4	Dim.5
Body Depth	14.09	1.78	67.00	17.13	0.00
Head Length	18.02	0.52	6.50	74.95	0.00
Standard Length	33.57	0.81	12.04	3.59	50.00
Total Length	33.57	0.81	12.03	3.59	50.00
Weight	0.75	96.09	2.44	0.73	0.00
Percentage Contributions: Low Stocking Density					
Body Depth	16.25	0.96	80.13	2.66	0.00
Head Length	17.36	7.68	0.00	74.97	0.00
Standard Length	33.20	0.43	9.81	6.56	50.00
Total Length	33.20	0.43	9.81	6.56	50.00
Weight	0.00	90.50	0.24	9.25	0.00

Crosses: ♀H×B♂; ♀N×B♂; ♀N×H♂

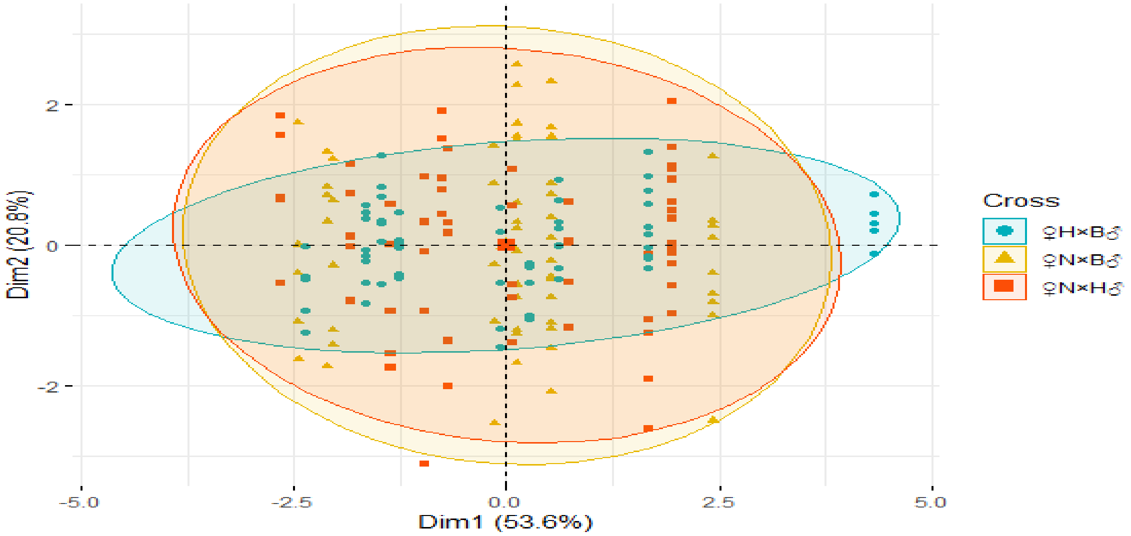

Figure 4.26. PCA biplot of breeding values for five economic traits in offspring of crosses of *C. gariepinus* from three eco-regions reared at low stocking density

Agglomeration of progeny from reciprocal crosses at high stocking density (Figure 4.27) shows that the breeding values tightly knitted progeny from the cross ♀H×N♂ compared to the other reciprocal crosses. Dimension 1 accounted for 52.2% variation in the breeding values with contributions coming strongly from body depth, head length, standard length and total length (Table 4.17). Dimension 2 accounts for 20.1% of the variation and this is mostly accounted for by weight.The collection of progeny reared at low stocking density, into groups based on their breeding values (Figure 4.28), the cross ♀B×H♂ was tightly grouped compared to the other reciprocal crosses. The first dimension of the principal component plot accounts for 51.8% of the variation with the same group of traits as in the previous groups contributing more to this dimension (Table 4.17).

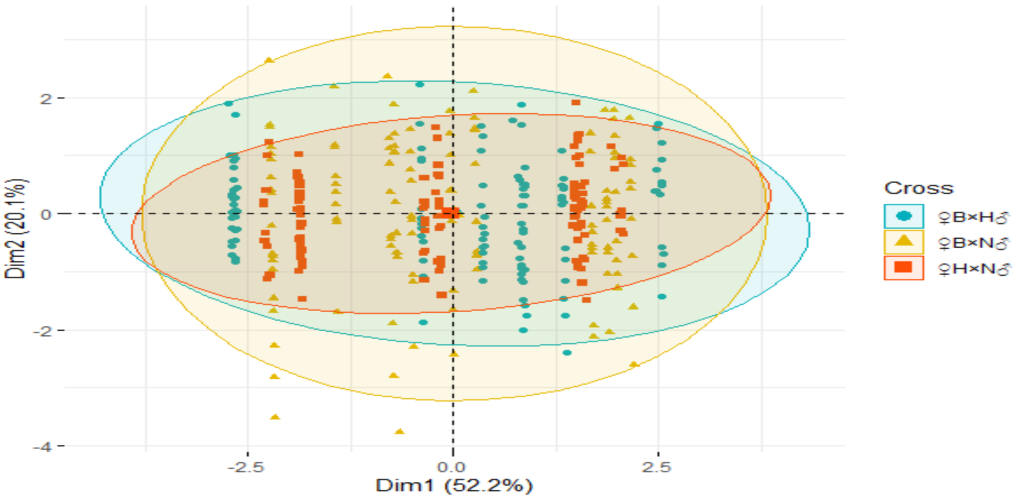

Figure 4.27. PCA plot of breeding values for five economic traits in offspring of reciprocal crosses of *C. gariepinus* from three eco-regions reared at high stocking density

Table 4.17. Component loadings for principal components explaining the structure of the population of progenies of reciprocal crosses of *C. gariepinus* broodstock from three eco-regions raised at high and low stocking density over six months

	Percentage Contributions: High Stocking Density				
Trait	**Dim.1**	**Dim.2**	**Dim.3**	**Dim.4**	**Dim.5**
Body Depth	11.37	0.22	64.07	24.33	0.00
Head Length	23.71	0.30	9.12	66.84	0.03
Standard Length	32.22	0.04	13.84	4.62	49.28
Total Length	32.69	0.04	12.96	3.62	50.69
Weight	0.02	99.39	0.00	0.59	0.00
	Percentage Contributions: Low Stocking Density				
Body Depth	18.78	4.07	31.33	45.06	0.75
Head Length	15.42	0.81	67.62	15.88	0.27
Standard Length	33.79	0.06	0.47	10.88	54.81
Total Length	31.57	0.63	0.46	23.19	44.16
Weight	0.44	94.44	0.11	4.99	0.02

Reciprocal Crosses: ♀B×N♂; ♀B×H♂; ♀H×N♂

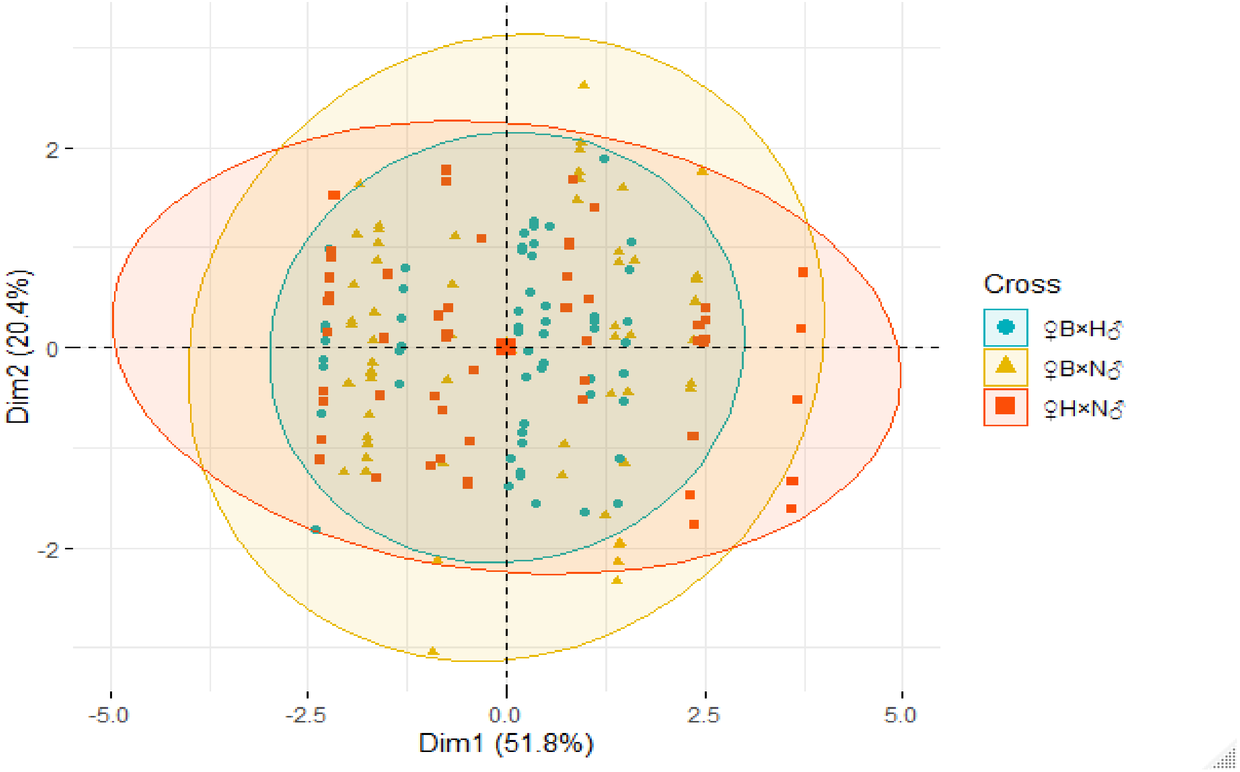

Figure 4.28. PCA plot of breeding values for five economic traits in offspring of reciprocal crosses of *C. gariepinus* from three eco-regions reared at low stocking density

4.0 Discussion

Grow-out Performance: Effect of stocking density on growth performance

Growth in fish depends on food intake and a host of intrinsic factors (Eyo, 2003). Regardless of cross, the low stocking density of 30 catfishes.m^{-2} had the best MFW of 611.34g while the high stocking density of 60 catfishes.m^{-2} had MFW of 573.45g. This finding was similar to that of Anibeze et al. (2000) who observed an inverse relationship between stocking density and daily average increase in weight of *C. gariepinus*.Furthermore, in an earlier study, Oké and Goosen (2019) observed that the mean final weight of *C. gariepinus* reared at 7 catfish.m^{-2} was greater than that at 10 catfish.m^{-2} Oguguah et al. (2011), Wei et al. (2011) and Shoko et al. (2016), also observed that increasing stocking rates resulted in significant reduction of in weight. Sahoo et al. (2004), observed that increase in stocking density resulted in increased growth and survival of *C. batrachus* larvae and fry during hatchery rearing. There was a significant difference ($p<0.05$) in specific growth rate (SGR) of offspring grown for 180 days under two stocking stocking densities with differences occurring between the crosses as well. The effect of stocking density on specific growth rate (SGR) regardless of cross was highest at stocking density of 30 catfish.m^{-2} (2.48%.day^{-1}) and among the crosses, the highest SGR recorded was for the cross ♀N×B♂ (2.56%.day^{-1}). Bombeo et al. (2002) observed that fish reared at lower densities had significantly higher SGR than fish reared at higher densities. This agrees with this work where there was better SGR under low stocking density than high stocking density.Odedeyi (2007) compared specific growth rate and average daily growth and opined that specific growth rate would be a better parameter to measure fish growth since it measures growth performance over a long period of time. In the present study, specific growth rates were higher in the crossbreeds than the pure breeds except in the cross ♀H×B♂ where SGR approximated the pure line crosses. The trend of SGR within the crosses was ♀N×B♂>♀N×H♂=♀H×N♂>♀B×N♂>♀B×H♂>♀H×B♂. The reciprocal crosses ♀N×H♂ and ♀H×N♂ share the same mean SGR of 2.55%.day^{-1} indicating that the genes for growth add equally from both parents regardless of the combination. However, an earlier report by Ataguba et al. (2009) indicated that the intergeneric hybrid between *C. gariepinus* and *Heterobranchus longifilis* gave less SGR than the pure line crosses. Conversely, Adewolu et al. (2008) showed that the hybrids produced better growth rates. The reason behind these differences will lie in the combination of genetic factors that originate from the source of broodstock and mating combinations as affected by environment (Piferrer et al., 2012).

Breeding values and heritability for key economic traits

In the present study, have reported for the first time in Nigeria, the results of a selection program to improve growth of *C. gariepinus*, which is a commercially important freshwater species cultured worldwide. Notably, this was among very few selection programs in catfishes in which selection was based on EBV rather than phenotypic traits alone (e.g. channel catfish, *Ictalurus punctatus*, Bosworth et al. (2020); striped catfish, *Pangasianodon hypophthalmus*, Vu et al. (2019)).Selection intensity is one of the major factors determining selection response. In the present study individual EBV was estimated and the selection was made by individual EBV. This is ideal for traits that can be directly linked to each individual but family-based selection is ideal where traits cannot be directly measured in individuals, e.g. disease resistance (Argue et al., 2002) and carcass trait (Thodesen et al., 2011), and has resulted in substantial response. The way our use of low selection intensity (selecting from the least positive EBV to the highest EBV) was in line with Gjedrem and Akvaforsk (2005), who suggested that in the first generation, selection should be performed with mild selection intensity to reduce loss of genetic diversity.The present study reported low heritability for growth traits (low = 0.05–0.15, Guan et al. (2016)), which was much lower than heritability for some of the traits reported earlier: h^2 = 0.25–0.35 (Srimai et al., 2020). This indicated a decline of additive genetic variance for growth due to selection, despite the appropriate mating design used in this selection program. Dupont-Nivet et al. (2006), based on simulation, showed that the partial factorial design had similar advantages to the full factorial design in reserving genetic variation while achieving high genetic response, and it was superior to single pair mating.It is also possible that the heritability might have been under-estimated due to the exclusion of data of individuals that succumbed to mortality. This might result in underestimation of the additive genetic variance and, to lesser extent, the phenotypic variance. Nevertheless, our result was in line with the “Bulmer effect” (Bulmer, 1971), which states that genetic variance will be reduced remarkably in the first generation of selection, but the effects will be smaller in the successive generations (Lloyd et al., 2016). Therefore, monitoring of heritability and genetic correlations has been suggested throughout successive generations of selection (Gjedrem & Akvaforsk, 2005).

Conclusion

Selective breeding for economic traits yields low estimated breeding values in the first generation of selection. Broodstock selected from the various eco-regions were fit given the condition factors, high fecundity, milt quality and sperm quantity. The weight of the left testes lobe is greater than that of the right testes lobe and thus creates a difference in the milt quantity. Growth at first feeding stage is affected by the parental crossing with most crossbreeds performing better than the pure line crosses. Grow-out is affected by stocking density with greater individual weight among fish reared at low stocking density than those reared at high stocking density. Hatching rates and survival of progeny to first feeding is affected by weight of broodstock used for artificial propagation. Heritability for body depth was highest at low stocking density compared to high stocking density.

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