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RESEARCH ARTICLE

Determination of body shape and meristic characters variations in wild and cultured populations of cichlid fish, *Oreochromis niloticus*, from the Republic of Benin, West of Africa

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Abstract. This study was designed to assess morphological changes between cultured and wild tilapia, *Oreochromis niloticus* (L.). Wild fish samples were obtained from fishermen operating in the waters of the vicinity of the province Parakou, Benin in November 2014, while the cultured samples were obtained from a fish farm in the municipality of Sô-Ava in the Atlantic region of the southern part of the Republic of Benin. Significant differences were observed in all nine morphometric traits measured. Discriminant analysis of morphometric parameters showed high divergence between the populations. The meristic count, however, overlapped broadly showing no divergence between the populations. The morphometric differences between the cultured and wild tilapia, *O. niloticus*, could have been linked to genetic differences or environmental factors or a combination of these.

Keywords: Morphometric, meristic, escapees, body shape variation, Benin, Africa

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Introduction

The rapid growth of tilapia (*O. niloticus*) ability to grow under sub-optimal nutritional conditions, and high fecundity all render them well suited for aquaculture. Tilapia is the second most cultivated fish in the world, only surpassed by carp, with almost 100 countries as producers (FAO 2002). The worldwide use of Nile tilapia in aquaculture represents a somewhat unique scenario. Tilapias are being cultured in >100 countries and it is cultured in 23 African countries (Hassanien et al. 2011).

The cichlid species known as tilapia is common in Africa, and it belongs to the genus *Oreochromis* that consisting of the three species of the Nile tilapia (*O. niloticus*), the blue tilapia, *Oreochromis aureus* (Steindachner), and Mozambique tilapia, *Oreochromis mossambicus* (Peters), all of which are endemic to Africa. These species are rich sources of

protein and nutritionally essential elements like potassium, phosphorus, vitamin B-12, and a low fat content, all of which is required for human body growth (Ikpeme et al. 2017).

Poor management and overfishing of wild tilapia by local fishers who aim to meet market needs pose an increasing threat as it could lead to the genetic erosion of this species. Therefore, we propose that it is necessary to strengthen efforts in tilapia research to facilitate its domestication. The first step is to determine methods to assess and manage the genetic blueprint of tilapia. Management of aquaculture genetic, including that of tilapia, should include a number of measures such as keeping suitable records of the genetic resources and the various ecosystems in which they are found, categorizing and ordering these resources to assess genetic variation and conservation potential, determining direct and indirect economic potential of the resources, and utilizing them in sustainable genetic improvement schemes (Hassanien et al. 2011).

With a growing body of research on wild and cultured fish morphology, it is apparent that cultured fish vary from wild fish in vital fitness-related characters. These differences develop, in part, from phenotypically plastic reactions of the fish to the fundamentally different environments of culture facilities relative to the wild (Swain et al. 1991, Fleming et al. 1994, 1997, Olla et al. 1994). In contrast to the wild, culture facilities offer predator-free, high-density, rapid growth environments that can influence the morphological, behavioral, and life-historical development of fishes. In addition to genetic factors as bases for dissimilarities between cultured and wild fish, three other possibilities can account for these differences: first, the non-indigenous origin of the cultured fish (Youngson et al. 1991); second, the availability of small genetically-effective population sizes that can result in random genetic changes (Ryman and Stahl 1980, Allendorf and Phelps 1988); third, human intervention during breeding can produce intentional and unintentional selections (Fleming 1995). In some species, developmental changes can also be strongly linked to ontogenetic deviations in supply use (Ward- Campbell and Beamish 2005). Such dissimilar developmental alterations can occur between wild and farmed fish assuming that large variations in feeding regimens and environments are in play. Both morphometric and meristic characters react to fluctuations in environmental influences, and their responses are diverse in some circumstances and can differ from species to species.

Variances in the morphology of individuals inhabiting both wild and hatchery environments have been reported in many fish species (Vay et al. 2007), and for *O. niloticus*, in particular, they are from different parts of Africa by Hassanien et al. (2011), Ikpeme et al. (2017), Vreven et al. (1998), Mwanja and Mwanja (2009), and El-Zaeem et al. (2012). No reports about the morphological population structure of *O. niloticus* in the river systems of the Republic of Benin compared with hatchery stocks are available in the literature.

Since morphometric and meristic information is vital for the proper management of the fisheries and for the optimum utilization of resources, the aim of the current study was to assess the morphological and meristic traits of *O. niloticus* caught in different habitats (cultured and wild) of the Republic of Benin. This will help in planning further breeding and conservation strategies for this fish and in improving productivity.

Materials and Methods

Sample collection and preparation

One-hundred and sixty-seven samples of cultured (66 individuals) and wild (100 individuals) *O. niloticus* were obtained from two different locations. The cultured samples were obtained from the farms of the Tonon Cossi Gilbert Foundation, which is located in the northeast of Ouédo in the municipality of Abomey-Calavi about 15 km from the large Calavi-Kpota crossroads. It covers an area of ten (10) hectares and is specialized in fish farming and conducts activities such as fry production, semi-intensive and

intensive fattening, and marketing clarias and tilapia fishes. In the propagation of tilapia, hormonal feed was used, which contained 1.5 g of the hormone 17α-2-methyl-testosterone in 20 kg of food. After treatment, the food obtained was dried for four days and used for 30 days for the tilapia in order to make their population single sex to facilitate their growth. Tilapia individuals were reared in floating cages made with iron bars and well-sealed plastic barrels fitted with wires that allow them to be attached to the iron bars. Approximately 3,000 fry were seeded into these floating cages and were fed until they reached market size. Mortality during rearing until the final fishing was about 20 to 25%. Eggs collected from the floating cages were placed in incubators where they were kept for five days to hatch into larvae. These larvae were set apart and were transferred three to five days after harvest while the larvae resorbed their yolk reserves. Larval food was usually changed after 30 days and then after 15 days. In each change the granule size of the food was increased from approximately 0.2 to 0.5 mm in diameter. The nursery area was equipped with aeration devices. There were nursery ponds, fattening ponds, and broodstock ponds. Wild specimens of *O. niloticus* were obtained from fishers operating in waters in the vicinity of the province Parakou, Benin in November 2014. Parakou, which has special status, is the third city most important city, following Cotonou and Porto-Novo, in the Republic of Benin. The hydrographic network is very sparse. It is essentially made up of many small temporary rivers forming a network that feeds the Okpara a tributary of the Ouémé River. These rivers are endlessly subdivided and remain dry from January to May. The study area is imperilled by its subequatorial climate that is characterized by two rainy seasons (a heavy one from April to July and a light one from October to November), which mark the flood periods of continental waters. However, this area also characterized by two dry seasons (one from December to March and the second from August to September) (Adanlokonon et al. 2019) featuring periods of low water levels in the lagoon. Annual variation in water temperature, pH, conductivity, TDS, and dissolved oxygen were, respectively, 29.60 ± 0.80°C; 7.95 ± 2.14; 639.60 ± 425.81 μS cm^{-1}; 457.48± 548.99 mg L^{-1}, and 0.22 ± 0.04 mg L^{-1} (Adanlokonon et al. 2019).

Measurement morphometric and counting meristic characters

Identification, morphometric measurements, and meristic counts of *O. niloticus* were performed in the Département d'Aménagement et Gestion de Ressources Naturelles, Faculté d'Agronomie, University of Parakou, Republic of Benin. All morphometric measurements were taken on the left side of the fish to ensure uniformity using a Vernier Caliper adjusted to the nearest 0.01 mm. A total of ten morphometric and five meristic characters were measured and counted, as follows: total length, standard length, head length, eye diameter, body depth, predorsal fin length, postdorsal fin length, prepectoral fin length, preanal fin length, postanal fin length, number of dorsal fin spines, number of pectoral fin rays, number of anal fin rays, number of pelvic rays, and number of scales on the lateral line. The fin rays fins were counted using hand lenses.

Morphological analysis

The meristic variables were reviewed with boxplot diagrams and One-Way ANOVA to determine statistically significant differences between wild and cultured specimens. The morphometric characters were organized in nine columns for each morphological variable and 166 rows, or specimens. Total length was not used since it was highly correlated with standard length, therefore the later was utilized. The data were transformed according to the normalization of individuals of each group with the method described by Lleonart et al. (2000) to remove size effects. The resulting matrix was submitted to canonical discriminant analysis to compute generalized Mahalanobis distances to discriminate functions and to assess the efficacy in their classification. Cross-validated discriminant analysis was used to assess and compare the efficacy of fish shape in the classifications of wild and cultured

Table 1
Mean, standard deviation, and range (minimum–maximum) of the morphological characters of wild and cultured specimens of *O. niloticus*.

	Wild		Cultured	
Characteristics	Mean ± Std	Min-Max	Mean ± Std	Min-Max
Morphometric				
Total length	104.55±26.60	75-205	147.38±19.81	111-220
Standard length	82.53±21.41	58-166	120.77±16.01	95-180
Head length	26.67±6.90	18-55	41.29±5.79	30-60
Eye diameter	7.16±1.57	4-12	9.11±0.83	8-10
Body depth	30.45±8.61	19-62	39.42±7.57	28-70
Predorsal fin length	29.35±7.18	21-55	42.35±5.37	34-60
Postdorsal fin length	72.69±18.65	50-145	103.98±14.16	78-160
Prepectoral fin length	28.22±7.21	19-57	45.14±6.25	34-63
Preanal fin length	60.04±15.44	42-116	86.53±11.43	65-130
Postanal fin length	71.76±19.10	39-145	105.29±13.59	80-150
Meristic				
Number of dorsal fin spines	16.55±0.67	15-18	16.44±0.50	16-17
Number of pectoral fin rays	12.69±0.50	10-14	12.67±0.23	12-13
Number of anal fin rays	12.45±0.52	11-13	12.56±0.87	7-14

environments. One-Way ANOVA was run to determine whether morphometric variables were statistically significantly different between the wild and cultured specimens. All statistical tests were performed with SPSS version 23.

Results

Mean standard deviation and range (minimum–maximum) of the morphological and meristic characters of wild and cultured specimens of *O. niloticus* are shown in Table 1. Wide discrepancy among the morphological characters can be seen, and all variables were significantly different ($P < 0.001$). Since size was significantly different, the use of filtered data was justified. Discriminant analysis performed with the filtered data and the nine variables showed 72.3% of the classification with Wilks' lambda = 0.195; $P < 0.001$ (Table 2). The graphic result of this analysis is a histogram of canonical scores (Fig. 1). The wild group was identified with one mode and a mean = 0.49, while the cultured group also exhibited one mode and a mean = -0.75. Classification between environments was 73.0% and 71.2% for wild and cultured specimens, respectively (Table 2). However, significant differences among meristic variables were not noted. The number of pelvic rays and the number of scales on the lateral line were constant in both wild and cultured populations of *O. niloticus* with values of 6 and 31, respectively. The other three variables were not significantly different: the number of dorsal fin spines ($P = 0.255$); the number of

Table 2
Classification results (%) for total cross-validated predicted specimen membership using the morphological characters of *O. niloticus* from wild and cultured treatments. Discriminant analysis used filtered data. 72.3% of cross-validated grouped cases correctly classified

	Predicted Group Membership		
Ambient	Wild	Cultured	Total
Wild	73.0	27.0	100.0
Cultured	28.8	71.2	100.0

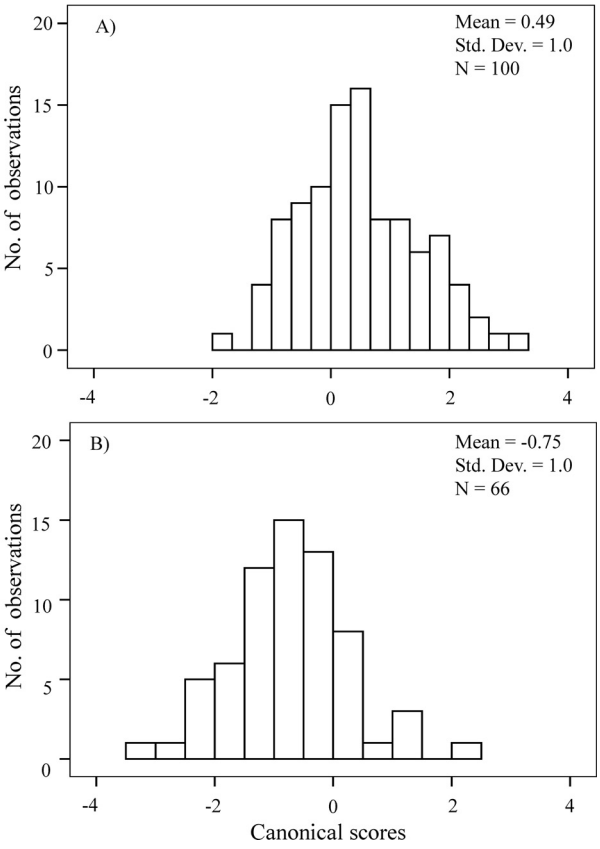

Figure 1. Discrimination analysis with the filtered method using morphometric variables: A) canonical scores from the wild specimens. B) Canonical scores from the cultured specimens.

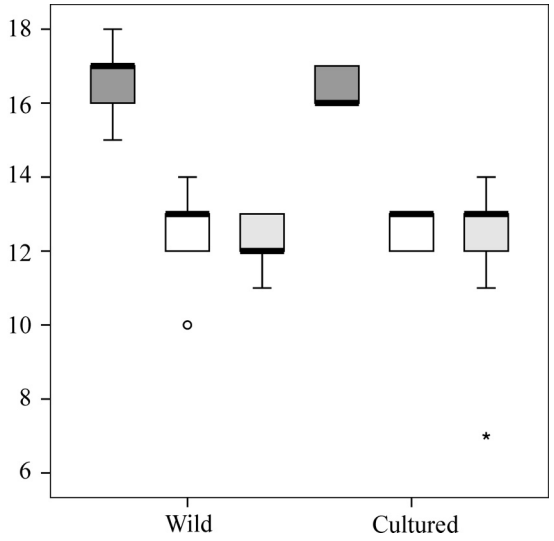

Figure 2. Boxplot depicting the number of dorsal fin spines (grey obscure), the number of pectoral fin rays (white), and the number of anal fin rays (grey light) for wild and cultured specimens of *O. niloticus*. Black line is the median and circle and asterisk are atypical and outlier values, respectively.

pectoral fin rays (P = 0.814), the number of anal fin rays (P = 0.328), and Fig. 2 shows very similar values for these three meristic variables.

Discussion

In general, the body shape of an organism is influenced by both genetic and environmental factors; fishes are recognized as displaying a high degree of environmentally induced morphological variation. Dissimilarities in environmental conditions can be revealed in the phenetic characters of fish populations. Several studies have revealed that body shape in fishes can be altered by culture conditions, such as the quantity of food (Currens et al. 1989), the type of food, or the feeding mode (Wainwright et al. 1991, Robinson and Wilson 1996). Diet has been noted to disturb body morphology in some fish species such as crucian carp (*Carassius carassius*) or to induce defenses in the presence of predators, while good food conditions have been observed to lead to a deep body shape in this species (Brönmark and Pettersson 1994).

In the present study, individuals from the wild *O. niloticus* population were caught directly in the field, while those of the cultured stock spent their whole life under laboratory conditions, which were notably dissimilar from the natural environment. Therefore, morphological differences between wild populations and cultured stocks might arise from genetic differences, environmental factors, or both. However, differences between wild and cultured populations are mainly reflected in environmental differences. Some investigations have verified the major role of the environment in morphological variability in populations of genetically homogenous fish (Ryman et al. 1984, Kinsey et al. 1994).

Numerous physical (*e.g.*, body color, size, and shape, and behavioral traits), immunological (major histocompatibility complex differences), biochemical (isoenzymes), and molecular (simple sequence-length polymorphism) (Sharp et al. 2002)

characters have been exploited to differentiate diverse cultured stocks. But, in contrast with other methods, morphological analysis can provide large amounts of data in a short time without high levels of skill or costs. In the present study, canonical discriminant analysis fully discriminated wild populations from cultured stock with significant differences in morphometric measures observed that identified these methods as useful tools for discriminating between populations of *O. niloticus*. In addition, the nine characters used in the analysis related to body depth and head size played important roles in morphological differentiation. Therefore, morphometric measurements combined with multivariate analysis were an effective method for discriminating among the cultured strains of *O. niloticus* in this study. In this study, all nine body proportions were larger in the cultured population than the wild stock. These changes between the populations were possibly linked to dissimilar habitat characteristics, such as water temperature, water turbidity, food availability, and water depth and flow. For example, the large eye diameter in the individuals of the cultured population could have stemmed from differences in turbidity between the rearing facilities and the wild habitats (Matthews and Robison 1988). This could be adopted as vertical habitat preference which was specified by Aleev (1969) to be associated with the position of eyes in the head. These morphological variations could stem from the selective breeding programs applied in aquaculture, genetic drift following founding generations, or the different origin of fish used as broodstocks (Karaiskou et al. 2009).

Vidalis et al. (1994) claimed that meristic characters showed an encoded narrow range of inconsistency, because divergence from that range could be harmful for individuals. The results of the present study suggested that there was no variability in meristic characters. The statistical analysis indicated that the ranges of all meristic counts overlapped so broadly between the cultured and wild populations that they could not be discriminated from each other. Moreover, modes of meristic values among populations were equal or close to each other, which indicated there were only tiny infraspecific variations.

As far as the comparison between wild and reared *O. niloticus* meristic counts were concerned, our study underscored a few changes between them. In the wild population, the range of variation in meristic traits such the number of dorsal, pectoral, and anal fin rays was higher than that in the cultured population. Similar results were observed by Matsuoka (1987) and Boglione et al. (2003). The presence of differences in meristic traits was anticipated to have had both environmental and genetic effects (Robinson and Wilson 1996, Foote et al. 1999), albeit, in some cases, some authors (Davidson et al. 1985, Hedgecock et al. 1989, Shepherd 1991, Kinsey et al. 1994) attributed the modifications merely to environmental effects, defining a phenotypic plasticity (Lindsey 1981, Stearns 1989, West-Eberhard 1989, Swain and Foote 1999).

The morphology of the farmed individuals of *O. niloticus* diverged from its ancestral form as represented by the wild population, with the body becoming more sturdy with smaller rayed fins. This alteration in body toughness contradicts the results obtained by other studies on sea-ranched salmon, where the opposite trend relative to wild fish was observed and was thought to be principally environmental in origin (Taylor 1986, Swain et al. 1991, Fleming et al. 1994). The different rearing regimes could be responsible for this. Unlike the wild population of *O. niloticus*, the cultured fish are reared throughout their lives and never exposed to natural selection for swimming performance. Furthermore, they were exposed to fixed artificial selection for rapid growth based on body weight (Gjedrem et al. 1988), which maybe generated a correlated positive response in body depth (Gjerde and Schaeffer 1989). The changes in fin morphology of the farmed tilapia did parallel observations from other studies (Taylor 1986, Swain et al. 1991, Fleming et al. 1994). Undisturbed selection for swimming exercise combined with artificial selection produced by high levels of fin nipping (Abbott and Dill 1985) and erosion

(Bosakowski and Wagner 1994) were likely to be responsible.

Increased appetite might have a direct effect on changing the morphology of the cultured population of *O. niloticus*. The potential predation in the cultured environment is nil (Johnsson et al. 1996, Einum and Fleming 1997), and such a relaxation of selection against predator-vulnerable phenotypes in culture facilities could concentrate on competition for food. The cause of these fluctuations in anti-predation behavior could be increased growth hormone production and thus appetite (Johnsson et al. 1996).

In the hatchery individuals, growth performance was higher than that in the wild stock (Metcalfe et al. 1988), which was affected by the state (lipid or weight) and/or rate of change of the state (growth rate) at this time (Thorpe 1986, Økland et al. 1993). Such a rapid growth phenomenon would be reflected and depicted genetically in the cultured individuals (Thorpe 1986). Our results indicated that the cultured individuals of *O. niloticus* exhibited changes in fitness other than those of the wild population due to domestication and to intentional and unintentional selection. As much of this change appeared to be an adaptive response to the culture environment, it can be of importance for programs endeavoring to develop aquaculture production (Doyle et al. 1991). This change, however, is a hazard to wild populations when these fish escape, and compete and breed with wild *O. niloticus*. The invasion of escaped farmed individuals into rivers not only increases competition for resources, but it also results in the infusion of different genetic traits into wild populations. Many of these characters are likely unsuitable for local environments both because of the non-indigenous origins of the farmed stock (Einum and Fleming 1997) and because of the changes that have occurred due to culturing. Whereas natural selection may be able to eliminate wild populations of such undesirable qualities, its actions are severely delayed by the year-after-year introgression of farmed stock.

The results obtained in the present study separating the cultured and wild populations of *O. niloticus* on the basis of morphometric traits are reflected in the findings of Barriga-Sosa et al. (2004) and Narváez et al. (2005), who reported morphological differences among wild and reared populations of *O. niloticus*. They attributed such differences to food, environmental conditions, and the type of habitat (wild and cultured). However, in the present study, all meristic characters showed no significant differences between populations, which correspond with the research of Solomon et al. (2015) on *Clarias gariepinus* (Burchell).

Fishes generally demonstrate greater variance in morphological traits both within the same and different species and among populations than do any other vertebrates. This largely reflects differences in feeding environments, prey types, food availability, and other features (Allendorf 1988, Thompson 1991, Wimberger 1992).

Further research on the functional significance of the morphological differences found here in *O. niloticus* may aid to clarify the influence of morphological disparity on hatchery individuals' survivorship in the wild. The use of a joint approach, such as morphometry, genetic, and other biological indicators (e.g. growth pattern of scales and otoliths, fatty acids and trace elements), should be considered for more detailed assessments of escapes within natural populations, fisheries landing, or for evaluation of stocking programs. This will not only contribute significantly to the biological and ecological knowledge of the species, but it will also help in the development of policies for natural stock conservation and improving aquaculture sustainability.

Author contributions. L.A.J. idea of the paper, experiment design, manuscript preparation; M.K. and P.G. collecting fish and data; All authors data analysis, drawing figures 1 & 2, writing part of the materials and methods and results.

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