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Nile Tilapia Farming and Diversity in Sub-saharan Africa: A Review

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ABSTRACT

This paper examines Nile tilapia (*Oreochromis niloticus*) in Sub-saharan Africa, where the expansion of aquaculture farms has resulted in the escape of fish, including Nile tilapia, into natural water bodies. This has led to the mixing of escaped tilapia with native species. To successfully manage and conserve these mixed species, it is important to understand their morphogenetic features. This review analyzes different production systems and morphometric variations of Nile tilapia in Sub-Saharan Africa, providing insight into the underlying factors. This review was carried out by exploring published papers, reports and books to gather information on the subject. The results showed that Nile tilapia are cultured in various systems, depending on the economics, skills, infrastructure and environmental conditions of farmers. Sub-saharan Africa exhibits a significant morphometric diversity of Nile tilapia, which has been studied using traditional and geometric morphometric methods. Both *in situ* and *ex situ* conservation methods are recommended to preserve the diversity of Nile tilapia for future aquaculture breeding programs in the region.

Key words: Diversity preservation, Nile tilapia, Production system, Sub-saharan Africa.

Oreochromis niloticus (Nile tilapia*)* is one of the most cultured tropical fish species in the world. In 2018, its production reached 4.53 million tonnes, which accounted for 75 % of the total farmed tilapia production in the world (Miao and Wang, 2020). It is one of the most important Cichlid species based on its nutritional and economic role in many tropical and sub-tropical countries (Sosa *et al.,* 2005). It has a certain number of important characteristics that makes it a special species for aquaculture. One of those key characteristics is the relatively short generation time estimated at approximately 6 months in farm ponds and about 10 to 12 months in natural environment; relative to other species such as common carp (10 to 14 months in ponds and 36 to 60 months in the wild), Clarias (6 to 9 months in captivity and 12 to 24 months in the wild)and trout (12 to 14 months in captivity and 12 to 24 months in the wild), which ensures that the production cycle is completed within a single year (Kurbanov and Kamilov, 2017; FAO, 2023). The species is also both planktivorous and omnivorous, making it an excellent fit for low-cost aquaculture (Tesfahun and Temesgen, 2018). The Nile tilapia has ability of adaptation to various environmental conditions hence, leading to its widespread production (Fitzsimmons, 2000). It is widely distributed in Africa ranging from the entire Nilo-Sudanian region to the Northern part of the East African Rift-Valley (Bezault *et al.,* 2011).

In these areas, the massive establishment of aquaculture farms along water bodies (rivers and lakes) has led to escape of fish from the ponds into large water bodies, hence resulting in mixing of escapees with native species (Ntirenganya, 2019). The repercussions of such mixing have been previously reported by Firmat *et al.* (2013) to be competition, hybridization and introgressions between species. The most remarkable incident in the world of fisheries was the disappearance of *Oreochromis variabillis* from the main Lake Victoria caused by *Lates niloticus* in 1960s (Boulenger, 1906; Welcomme, 1966, Canonical *et al.,* 2005; Angienda *et al.,* 2011).

In Sub-Saharan Africa, conservation and management of the already admixed species might not be successful if the morphogenetic features of the concerned species are not well elucidated. Therefore, considering the various anthropogenic activities, various production systems and environmental conditions in Africa and their influence on phenotypic variation of species, the characterization of

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O. niloticus in the major production systems in Africa is highly needed for better management and utilization. The morphometric diversity of the currently raised strains of *O. niloticus* has been characterized only in selective environment with varying results (Appleyard and Ward, 2001). This paper reviews the morphometric variations of farmed Nile tilapia in Sub-Saharan Africa in order to provide a better understanding of underlying factors across the region. In addition, it documents actions needed to preserve and/or sustain utilization of the diversity of Nile tilapia in Sub-saharan Africa.

Geographic distribution of Nile tilapia

The culture of Nile tilapia can be traced to ancient Egyptian times (FAO, 2009). Introductions of the species are summarized in www.fishbase.org (Fishbase, 2014). FishBase (2014) reported the occurrence of Nile tilapia in 102 countries across the world (Fishbase, 2014, Fig 1).

Tropical and subtropical Africa are the native ranges of Nile tilapia. The species is found in the Nile basin including Lake Albert, Edward and Tana, Jebel Marra, Lake Kivu, Lake Tanganyika, Omo River system, Lake Baringo, Awash River, Suguta River, several Ethiopian lakesand Lake Turkana (Trewavas, 1983; FishBase, 2014; FishBase, 2023). In West Africa, it is naturally found in the Basins of the Senegal, Benue, Gambia, Volta, Niger and Chad (Picker and Griffiths, 2011; FishBase, 2023).

Nile tilapia production systems in Sub-Saharan Africa

In Sub-Saharan Africa (SSA), Nile tilapia is cultured in different systems, which include water-based and land-based systems (El-Sayed, 2006). The choice of the culture system mostly depends on the farmer's economy and skills, available infrastructureand environmental conditions (Donbæk *et al.,* 2019). The Nile tilapia production system can also be classified as extensive, semi-intensive and intensive system based on the input utilization (Omasaki *et al.,* 2016). These Nile tilapia production systems are below discussed with examples in the context of Sub-Saharan Africa (Table 1).

Extensive and semi-intensive fish production systems, commonly used by smallholder farmers in developing countries, involve culturing fish in ponds or small bodies of water with minimal inputs (Hernández-Mogica *et al.,* 2002). In Kenya, Nile tilapia production primarily occurs in earthen ponds, although Recirculating Aquaculture Systems (RAS) are also used (Omasaki *et al.,* 2017). RAS offers advantages such as reduced land and water requirements, but it requires a stable energy supply and careful biosecurity management. In Zambia, various systems such as ponds, raceways, hapas, tanksand cages are used while in the DR Congo, Nile tilapia farming is mostly extensive for household consumption, with a few semi-intensive and intensive systems in periurban areas (Fagbenro and Adebayo, 2005; MINPE, 2021). Intensive culture systems, including earthen ponds, tanksand Recirculating Aquaculture Systems (RAS), are spreading in Sub-Saharan African countries, with stocking densities ranging from 50,000 to 100,000 fish/ha and yields of 25 to 40 kilograms per cubic meter. Challenges faced by farmers include the lack of quality seed and feed (El-Sayed, 2013; El-Sayed, 2017).

Variation factors used to morphometrically characterize Nile tilapia in Sub-Saharan Africa

Morphometric characters have been widely used to differentiate the various populations of Nile tilapia across Sub-Saharan Africa. Different variation factors have been used to study the morphometric characteristics of Nile tilapia populations in Sub-Saharan Africa (Table 2).

With regard to the sex, Amoussou *et al.* (2017) found significant differences between male and female Nile tilapia, with males exhibiting higher body weight, total lengthand standard length ($p<0.05$). Environmental factors also influenced morphometric traits, as fish from Ouémé River and Couffo River had higher total and standard lengths compared to those from Lake Toho ($p<0.05$). With regards to the population type, Fakage *et al.* (2019) observed distinct morphometric traits between natural populations (Lake Kivu, Ruzizi River) and a cultured strain (Nyakabera strain) in DR Congo, with discriminant traits including Head Length, Body Height, Eye Length, Eye Diameterand Anal fin length. Vreven *et al.* (1998) noted morphological differences between Nile tilapia populations from different regions, with Nile populations closer to East African populations than West African populations. Makeche *et al.* (2020a, b) identified significant morphometric differences among Nile tilapia strains from Zambia (Yalelo Fishery, Fwanyanga Fishery), including total length, body weight, standard length, body height, head length, pre-anal distanceand pre-ventral distance (Table 2).

Nile tilapia strains

Studies conducted across the Sub-Saharan Africa revealed the existence of different strains of Nile tilapia in natural as well as artificial environments. A summary of their results is presented in Table 3.

Actions needed to preserve the diversity of Nile tilapia in Sub-Saharan Africa for appropriate aquaculture breeding programs across the region

Conserving diversity is a global challenge. For Nile tilapia, both in situ and ex situ conservation methods are feasible. Long-

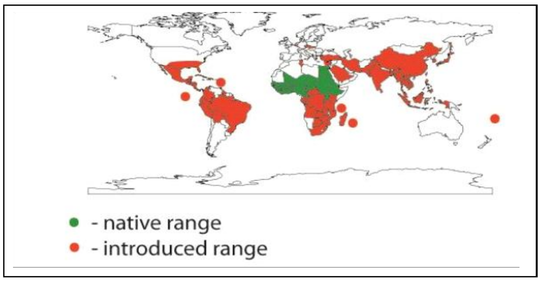

Fig 1: Native and introduced range of Nile tilapia (Picker and Griffiths, 2011).

Table 1: Nile tilapia farming characteristics in Sub-Saharan Africa (DR Congo, Kenya, Ghana and Zambia).

Farming characteristic	DR Congo	Kenya	Ghana	Zambia	Comments
Density	2-5 fry/m2	1-4 fry/m^2	63-188 fry/m^3	5–8 fry/m^2	The stocking densities are higher under intensive culture systems then intensive ones.
Species size harvested	85 - 282.9 g (under experimental conditions).	300 g (extensive and semi-intensive systems) 400 to 500 g in recirculating aquaculture system (RAS)	300 - 500 g in cages	187.8-73.6 g (under experimental conditions)	Fish cultured under intensive systems (cages and RAS) show higher sizes at harvest
Production cycle	6-12 months	9 months in extensive and semi-intensive systems4-5 months in RAS	6 months in Volta Lake (natural environment)	4-6 months (natural environment)	Short production cycle in intensive systems.
Feeding type	Natural feed produced in the water after fertiliz -ation Supplementation with agricultural by-products and imported feed	Natural feed (Shrimp meal diet, Wheat bran, local diets, pig diets) supplemented by imported pellets.	Natural feed (chicken manure, rice bran)	Farm-made feeds and commercial pellets.	
Facilities available	Ponds, cages, tanks	Earthen ponds, pens, tanks, cages and raceways	Earthen/Dugout Ponds, cages, few concrete tanks and raceways	Ponds, cages, circular and 'D-ended' concrete tanks KabompoRiver,	
Production environment	Natural environment (*e.g.* Lake Kivu, Tanganyika, Ruzizi River) and artificial one including ponds, tanks and cages	Natural environment (*e.g.* Lake Turkana, Lake Naivasha, Tana River, *etc.*) and artificial systems including ponds, tanks and cages	Natural environment (*e.g.* Crystal Lake, Volta Lake, Pra, Densu, Ankobra and Bia rivers) and in ponds, cages and tanks	Lake Kariba, Lake Tanganyika, Upper Zambezi, Kafue rivers and in artificial environments	Nile tilapia in SSA is produced in natural as well as artificial environment.
Fish and crop or animal integration	rice-fish, pork-fish, poultry-fish, rabbit-fish	Chicken-fish, cow-fish, r abbit-fish	Fish-rice	Fish-and-duck, fish-and-crops (mostly vegetables),fish-poultry and fish-and-swine	

Table 1: Continue...

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Type and level of Input utilization	Fertilization+++ Improved feed++	Fertilization++++ Improved feed++++	Fertilization+++ Improved feed+++	Fertilization++++ Improved feed+++++	Fertilization is practiced across SSA.
References	Bosanza *et al.*, 2017; Lokinda *et al.*, 2017; Nihoreye *et al.*, 2019; Yossa *et al.*, 2022	Liti *et al.*, 2006; Rasowo and Auma, 2006; Gozlan *et al.*, 2010; Nyonje *et al.*, 2011; Orina *et al.*, 2018	Abban, 2005; Ofori *et al.*, 2009; Mireku *et al.*, 2017	Hecht, 2007; Mudenda, 2009; El-Sayed, 2013; Hoevenaars and Ng'ambi, 2019; Yossa *et al.*, 2022	

+, ++, +++, ++++: level of utilization varying from occasionally used (+) to frequently used (++++). RAS: Recirculating Aquaculture Systems

term in situ conservation should be complemented with *ex situ* efforts.

In situ conservation

According to Pullin and Capilli (1988) the best strategy for tilapia conservation is to maintain their original habitats. Toward this the documentation of the status of the species genetic diversity is of great importance. For tilapia, documentation has just begun through databases such as FishBase that already comprises a tilapia strain registry. In Sub-Saharan Africa, Malawi and Ghana are examples of countries with responsible attitudes and important fish populations. Malawi ensures preservation of the Lake Malawi ecosystem and Ghana has created a nature reserve on an ecologically important sector of the Volta catchment (Pullin and Capilli, 1988).

Ex situ conservation

So far, only live fish and sperm banks are possible. Examples of institutions maintaining live fish and sperms banks include ICLARM. The later collects African strains for the purpose of establishing a national breeding programme in the Philippines. ICLARM's strategy consists on collecting *O. niloticus* subspecies from different river basins. Despite the fact that the *ex-situ* conservation method plays a critical role in the preservation of Nile tilapia diversity it should be recognized that the establishment and maintenance of collections are costly.

As part of strategies that are suggested for preservation of the diversity of Nile tilapia especially the conservation of indigenous populations, Lind *et al.* (2012) suggested zoned aquaculture systems based on large water body catchements. On the other hand, Mbiru *et al.* (2015) and Mapenzi and Mmochi (2016) proposed the use of all-male hybrid populations.

Researchers have proven that the attempt to improve population diversity through hybridization mostly results in a reduced fingerling production associated with potential reproductive incompatibilities between crossed species (Popma and Lovshin, 1995). In view of this, Moses *et al* (2020) suggest that decision related to the importation of GIFT as a main seed source in tilapia and Nile tilapia particularly, should be taken based on data originating from growth performance, population genetics and potential biodiversity threats for the wild native populations.

According to Leung *et al.* (2002), the control of invasive species through prevention is the cost-effective means of species biodiversity conservation. Towards this it is suggested that all land-based facilities should be constructed with infrastructure that can resist the effect of floods or tidal currents (Hinrichsen, 2007); physical barriers surrounding the facility are also of great importance to prevent invasive species (Novinger and Rahel, 2003). Additionally, as a way of reducing the risk of escapes, facilities should be constructed at appropriate gradient and water level frequently monitored to assess flood threat (Hinrichsen, 2007).

Table 2: Variation factors used to characterize Nile tilapia populations in Sub-Saharan Africa.

Country	Variation factors	Modalities modalities	Subtypes of (BH)	Body height (TL)	Total length length (SL)	Standard (W)	Weight	Comments	Reference
Benin	Sex	M		36.42±1.11	13.98±0.36	10.81±0.29	66.20±7.58	Values are expressed as per cent to SL except for W.	Amoussou *et al.*, 2017
		F		35.18±0.43	13.03±0.19	10.07±0.15	46.56±3.15		
Benin	Environment	River	Ouémé River	33.50±0.95	11.27±0.55	8.95±0.44	91.31±13.25	Values are expressed as per cent to SL except for W.	Amoussou *et al.*, 2017
			Couffo river	37.48±0.91	13.65±0.15	10.44±0.12	49.09±1.63		
	Lake	Lake Toho	34.98±0.49	15.57±0.25	11.97±0.2	31.70±1.96			
DR Congo	Population type	Wild population	From Ruzizi	41.3±1.8	-	-	-	TL is expressed in (Cm) and W in (g)	Fakage *et al.*, 2019
			From Lake Kivu	41.0±1.4	-	-	-		
		Cultured population	Nyakabera strain	42.0±1.6	-	-	-		
Ethiopia	Environment	Lakes	Chamo	0.392±0.02	278.15±47.89	225.63±41.73	412.24±218.21	TL is expressed in (Cm) and W in (g)	Endebu *et al.*, 2021
			Koka	0.36±0.02	239.0±26.35	191.74±22.26	259.17± 87.65		
			Ziway	0.370±0.02	184.43±24.61	149.44± 20.59	115.13± 47.14		
Ethiopia	Environment	Lakes	Koka	0.44±0.021	1.31±0.028	-	11.32±2.62	Significant factors differences in terms of weight. Other discriminating factors are not presented in this table.	Asmamaw and Tessema, 2021
			Ziway	0.44±0.026	1.32±0.058	-	9.76±3.721		
			Langano	0.41±0.02	1.36±0.036	-	6.42±1.59		Makeche *et al.*, 2020a
Zambia	Identified strains	Strain 1		-	24.6	-	289.0	Identified strains showed significant differences in terms of weights among other factors not shown in this table.	
		Strain 2		-	23.2	-	250.0		
		Strain 3		-	23.1	-	246.2		
		Strain 4		-	23.1	-	237.5		
		Strain 5		-	22.5	-	211.0		
		Strain 6		-	21.8	-	204.0		
		Strain 7		-	20.3	-	157.0		
		Strain 8		-	21.3	-	181.0		
Zambia	Identified	Strain 1		-	21.8	-	172.0	TL is expressed in (Cm) and W in (g)	Makeche *etal.*, 2020b
		Strain 2		-	19.6	-	140.0		
		Strain 3		-	18.1	-	106.0		

Table 3: Nile tilapia (*O. niloticus*) strains in Sub-Saharan Africa.

Country	Studied environment	Sample size	Number of variables used	Type of variables used	No. of strains identified	Discriminating traits	References
Zambia	Lake Kariba	409	30	Meristic and morphometric variables	4 (Based on meristic traits) and 3 (based on morphometric traits)	Number of anal fin spines and TL	Makeche *et al.,* 2022
Zambia	Yalelo Fishery	66	22	Morphometric traits	8	TL	Makeche *et al.,* 2020a
Zambia	Fwanyanga Fishery	81	23	Morphometric parameters	3	TL	Makeche *et al.,* 2020b
Zambia	Yalelo Fishery, Fwanyanga Fishery and Choombwe Fishery	64	30	Morphometric measurement and meristic counts	3	BH, TL, BW, SL, HL, PAD, PVD	Makeche *et al.,* 2020c
Benin	Ouémé River, Couffo River and Lake Toho	459	27	Morphometric and meristic variables	2	BH, ED, DAL, HL, PPL, DFBL, CPH, DFR, LLLS, OS	Amoussou *et al.,* 2017
Ethiopia	Koka, Ziway and Langano lakes	391	12	Morphometric variables	2 (Appendix A)	BD, PPL, PDL, ED, BW	Asmamaw and Tessema (2021)
Ethiopia	Chamo, Koka and Ziway lakes	450	34	Morphometric and meristic parameters	3 (Appendix B)	BW, TL and SL	Endebu *et al.,* 2021
Kenya	Loboi swamp drainage system, Baringo, Turkana, Crocodile and Victoria Lakes	237	14	Landmarks	2	Head, CP, AF and BD	Ndiwa *et al.,* 2016
DR Congo, Uganda, Kenya and Tanzania	Fish farms, Nile River, Albert, Edward, George, Turkana, Kyoga, Mulehe, Kayumbu and Victoria lakes	490	10	Landmarks	7	Anterior region of the fish, DFBL, Origin of the caudal fin, opercular spine and the dorsal insertion of pectoral fin	Tibihika *et al,* 2017
DR Congo	Lake Kivu, Ruzi River and Nyakabera Research Station farms	147	36	Morphometric and meristic variables	2	Morphometric: BH, LPB, LLDS and the LAS. Meristic traits: NSRDF, NSPIRDF, NGRAF, NGRLGA	Fakage *et al.,* 2019

Table 3: Continue...

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Uganda	Albert, Edward-George, Kyoga and Victoria Lake.	425	22	Morphometric traits	4	BL, peduncle length and the interorbital distances	Mwanja *et al.*, 2016
Uganda	Farms from Uganda's Southwestern Highland Agro-Ecological Zone	258	8	Morphometric traits	3	SL, TL, CFL, HL, BW, pelvic fin length and pectoral fin length	Kwikiriza *et al.*, 2023
Senegal, Mali, Ghana, Tchad, Egypt, Uganda	9 natural population and 3 cultured strains	220	33	Morphometric and meristic parameters	3	CPL, TPBL, width, JL, BD and pelvic fin length	Vreven *et al.*, 1998

Legend: TL: Total length; BH: Body height; BW: Body weight; SL: standard length; HL: Head length; PAD: Pre-anal distance; PVD: pre-ventral distance; ED: eye diameter; DAL: Dorso-anal length; PPEL: Prepectoral length; DFBL: Dorsal-fin base length; CPH: caudal peduncle height; DFR: dorsal-fin rays; LLLS: lower lateral line scales; PDS: pre-dorsal scales; OS: operculum scales; BD: Body Depth; PPL: Pre-pelvic length; PDL: Pre-dorsal length. Legend: CPL: Caudal peduncle; AF: Anal fin; LPB: length of the pharyngeal bone; LLDS: length of the longest dorsal spine; LAS: length of the 3rd anal spine; NSRDF: Number of soft rays on dorsal fin, NSPIRDF: number of spiny rays on dorsal fin; NGRAF: number of gill rays on anal fin; NGRLGA: number of gill rays on lower part of first gill arch; CPL: Caudal fine length; TPBL: toothed pharyngeal bone length; JL: jaw length.

CONCLUSION

The Nile tilapia is a widely farmed fish speciesand it is important to improve its production and preserve its diversity. In Sub-Saharan Africa, there are challenges to maintaining the species' biodiversity, including the mixing of escaped tilapia with native populations, leading to competition and hybridization. This review focused on the farming characteristics and morphometric diversity of the Nile tilapia raised in Sub-Saharan Africa. It was found that Nile tilapia is cultured in various systems, including water-based and land-based systems, classified as extensive, semi-intensiveand intensive. Earthen ponds are commonly used for aquaculture in the region. Different methods have been used to differentiate Nile tilapia populations including the traditional and geometric morphometric characterization. Both *in situ* (on-site) and *ex situ* (off-site) conservation methods are feasible for preserving Nile tilapia biodiversity in Sub-Saharan Africa, with a recommendation to maintain long-term *in situ* conservation complemented by *ex situ* conservation efforts.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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