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Differences in sexual size dimorphism among farmed tilapia species and strains undergoing genetic improvement for body weight

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ABSTRACT

Many tilapia (*Oreochromis* spp.) farmers produce all-male populations because of the superior growth rate of males compared to females. To investigate differences in body weight at harvest of males and females among different tilapia strains, we analyzed data from 62,787 individuals collected from pedigreed breeding programs of *O. niloticus* (GIFT from Malaysia, the Abbassa line from Egypt, and the Akosombo line from Ghana), *O. shiranus* (the Bunda College-Domasi selection line), *O. aureus* (a selection line under development in Abbassa, Egypt, and a selection line from Israel) and a synthetic selection line of Red tilapia under development in Jitra, Malaysia, derived from stock from Malaysia, Taiwan and Thailand (*O.* sp.). Mixed models were separately fitted to the data from each selection line. There was a significant sex effect in all strains ($P < 0.001$). A significant ($P < 0.001$) sex by generation interaction was observed in all strains (scale effect, not reversal of rankings), except Red tilapia and *O. shiranus*. Least squares means showed a large range in the magnitude of body weight differences between sexes across the seven strains. The largest percentage difference between females and males was in *O. aureus* from Egypt (female body weight was 52.2% that of males at harvest), whereas the smallest difference was observed in the GIFT strain of *O. niloticus* (female body weight 84.7% that of males). Female to male body weight percentages for Red tilapia, *O. shiranus*, Egypt *O. niloticus*, Israeli *O. aureus* and Ghana *O. niloticus* were 81.3, 81.0, 69.1, 61.7 and 61.0, respectively. We discuss the results in relation to the potential productivity improvements due to superior growth rates of all-male culture compared to mixed-sex culture in tilapia populations differing in the female to male body weight ratio.

1. Introduction

Growth rate is a focal production trait in commercial aquaculture. Differences in individual growth due to sex have important consequences for production, such as large variation in harvest weight or unsalable small fish. In tilapia (*Oreochromis* spp.), one of the most important aquaculture species, males are on average larger than females (Lorenzen, 2000; Turner and Robinson, 2000). Because of the superior growth rate of males and availability of sex-reversal techniques, large sectors of the tilapia aquaculture industry produce all-male populations to improve productivity and control reproduction (Beardmore et al., 2001). The growth rate advantages of mono-sex over mixed sex populations of tilapia are dependent on the magnitude of sexual size dimorphism (SSD). With the additional expenses or facilities involved in producing all-male fish, mixed-sex populations having low SSD could be more profitable than mono-sex populations. It has been demonstrated that mono-sex tilapia culture is not always superior to mixed-sex culture (Kamaruzzaman et al., 2009; Little and Edwards, 2004). To

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Table 1
Summary of tilapia strains and their origin.

Species	Strain name	Generations of selection	Nucleus location	Reference(s)
Oreochromis aureus	Abbassa	4	Egypt: 30°32′27.22″ N 31°44′13.50″ E	WorldFish Unpublished data
O. aureus	Dor	4	Israel: 32°36′29.19″ N; 34°55′48.27″ E	Zak et al. (2014)
O. niloticus	Abbassa	8	Egypt: 30°32′27.22″ N 31°44′13.50″ E	Ibrahim et al. (2013); Rezk et al. (2009)
O. niloticus	Akosombo	6	Ghana: 6°16′57.04″ N 0°03′30.54″ E	CSIR-Water Research Institute, Ghana, Unpublished data
O. niloticus	GIFT	9[a]	Malaysia: 6°15′27.55″ N 100°25′54.01″ E	Bentsen et al. (1998); Eknath et al. (2007); Ponzoni et al. (2005)
O. sp.[b]	Red tilapia	2	Malaysia: 6°15′27.55″ N 100°25′54.01″ E	Hamzah et al. (2008); Nguyen et al. (2011), WorldFish Unpublished data
O. shiranus	Bunda-Domasi	3	Malawi: 15°18′31.33″ S 35°23′37.72″ E	Maluwa and Gjerde (2006); Maluwa and Gjerde (2007)

[a] At current location in Malaysia, see Ponzoni et al. (2011) for details of strain history after transfer from Philippines.
[b] A hybrid strain derived from *O. niloticus*, *O. mossambicus* and *O. aureus*.

predict the likely benefits of all-male populations it is important to determine if SSD for body weight differs among tilapia species or strains and by how much. Reported estimates of tilapia body weight indicate variation in the magnitude of SSD among strains or species (Palada-de Vera and Eknath, 1993; Rezk et al., 2002). Among these only a few utilize large datasets (e.g., Bentsen et al., 1998; Bentsen et al., 2012; Nguyen et al., 2007; Ponzoni et al., 2005). Furthermore, comparative studies are rare. Recent implementation of structured breeding programs in Asia and Africa has generated large datasets where individual tilapia growth rates are recorded. In this study multigenerational pedigreed data sets from seven tilapia breeding programs were analyzed to investigate the magnitude of SSD for body weight in a range of tilapias, and how this may influence the potential benefits of mono-sex culture.

2. Materials and method

Data were assembled from seven tilapia strains of three different species (Nile tilapia, *Oreochromis niloticus*; Blue tilapia, *O. aureus*; and Shiré tilapia, *O. shiranus*) and one hybrid strain (Red tilapia, *Oreochromis* spp.), developed and maintained at aquaculture field stations in Ghana, Malawi, Israel and Malaysia (Table 1). In all these strains genetic improvement programs to increase body weight are being implemented. No differential treatments were applied to the fish during the implementation of the breeding programs. All fish were reared and managed using standard industry practices (regular water exchange; acceptable stocking densities; use of anesthesia and antiseptics during tagging) to ensure appropriate care of animals.

2.1. Overview of selective breeding procedure and description of tilapia strains

2.1.1. General

The following general description of the breeding programs applies to all the strains studied, except the Israeli *O. aureus* selection program, which was conducted using a slightly different approach (see below). Genetic improvement programs for all other tilapia strains followed the general approach and recommendations for selective breeding of tilapias outlined in Thodesen and Ponzoni (2004). A "combined selection" approach utilizing information on individual fish and information coming from relatives was used to determine the genetic merit of potential brood stock. Animal model estimated breeding values (EBVs) of selection candidates were determined using Best Linear Unbiased Prediction (BLUP). Those with the greatest EBV for body weight at harvest were selected to be the parents of the next generation. To control inbreeding, mating of full- and half-sib relatives was avoided, and the number of individuals selected from each family was restricted in the manner described by Ponzoni et al. (2010). Selected brood stock were mated in mesh hapas suspended within earthen ponds, with a mating ratio of one male to two females in each hapa. Following successful mating, fertilized eggs were collected from females and full-sib families were reared separately in incubators, and subsequently in nursing hapas, until juveniles were large enough for individual tagging (approximately 3 to 5 g). Between 50 and 100 randomly selected juveniles from each full-sib family were tagged with Passive Integrated Transponder (PIT) tags (unless otherwise stated) each having a unique code. After tagging, fish were placed into communal (i.e., mixed families) grow-out ponds for a period of 4–6 months. Fish were fed a commercially available formulated feed throughout the nursing and grow-out periods at an amount equivalent to 3 to 5% of their body weight per day, unless stated otherwise below. The body weight of each fish was measured at the end of communal rearing period. Additional details about each strain are given below and in Table 1.

2.1.2. Blue tilapia (O. aureus), Abbassa strain

This strain is the subject of an ongoing genetic improvement program at the WorldFish Center Aquaculture Research Station at Abbassa, Egypt. A pedigreed base population was created in 2006 from a previous genetic improvement program based on mass-selection. The mass-selected line was derived from a combination of several cultured and wild populations. During winter months (December to March) average minimum water temperatures can drop to 10 to 15 °C (Rezk et al., 2009), which necessitates an "over-wintering" rearing stage using heated water to avoid excessive mortalities. During over-wintering, tilapia are transferred to earthen ponds or to cement tanks covered by greenhouse Like structures in order retain heat. The dataset used for this strain is from generations 2–4 of the selection line. Two 0.1 ha replicate ponds were used for communal rearing in generations 2 and 3, whereas four ponds were used in generation 4 because a greater number of families was produced that year.

2.1.3. Blue tilapia (O. aureus), Israeli strain

A detailed description of this selection program is outlined by Zak et al. (2014). The strain was derived from three populations