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Carcass yield of *Oreochromis niloticus* deformed by inbreeding process evaluated by morphometry

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Abstract

Genetic improvement is the main responsible for the increase in tilapia production in the last decades. However, the tools used in broodstock selection have increased the mating of related animals, and as a consequence, animals with morphometric anomalies have appeared. In view of the above, this work was carried out with the objective of evaluating the effect of body deformities on the meat yield of tilapia. A total of 106 animals from assisted reproduction of the UFLA tilapia breeding program were used, among which 53 had visible deformities. The animals were weighed, measured, and photographed with a digital camera and had their body areas measured using computer software. Afterward, the animals were slaughtered and the fillet from the left side was removed to measure weights and yields. On the right side, cuts were made to measure the meat volume in the carcass. The residues were weighed separately to analyze processing losses. Using the software R-studio the normality test was applied to all data and afterwards, the tests of means and correlations between morphometries and yields were performed. No morphometric differences were identified between the groups, but deformed animals showed smaller caudal areas and caudal peduncles and high correlations with fillet weight. However, normal fish showed higher fillet yield and lower residue production. It is concluded that the anomalies imply lower filet yield and a higher amount of processing residues.

Keywords: Endogamy. Phenotype. Tilapia.

Introduction

The production of fish in Brazil is in evident growth, surpassing the production of 800 thousand tons in the year 2021 (PEIXE BR, 2021). The development of the chain is due to the technological package employed to the chain, however, among the lines of study, the one that most supported the gains was the genetic improvement applied to species considered wild (PORTO et al., 2015; RYE, 2012).

Genetic improvement of fish is very recent and difficult to carry out when compared to terrestrial animals. The genealogical control of fish is expensive, requiring space, separate tanks, and identification through chips, since there is the need for individual monitoring during the evaluation of the animal (TURRA et al., 2010).

Given these difficulties, most breeding programs began applying mass breeding, facilitating the loss of genealogical control and consequently increasing the frequency of mating of related animals, increasing the number of inbred animals (TURRA et al., 2010; FERNÖ et al., 2006).

Inbreeding increases the predisposition of populations to deleterious alleles, decreasing genetic variability and bringing damage to the production process. The expression of deleterious genes leads to lower growth, lower adaptability to the breeding environment, reproductive problems, and, consequently, the exposure of the population to the risk of extinction (EISSA et al., 2021; JAGIETTO et al., 2017; AFONSO et al., 2000).

Even though the genetic process that entails the anomalies is not well known, many works describe the damage to the morphology of the animals. Among the problems found in an inbred population, body deformities are among the most common. Deformities can be found in the mouth, spine, fins, and tail of the animal, reducing the swimming ability and making it difficult for these animals to remain in the normal breeding stock (KERNISKE et al., 2021; BOGLIONE et al., 2013; BABCOCK, et al., 2014).

The animal with deformity entails several problems: unevenness of the batch, difficulty in processing requiring adaptation of the filleting process, and produces unexpected body yields, making it impossible to estimate the final production of the batch processing. In view of the above, this work was carried out with the objective of evaluating the effect of body deformities on the meat yields of Tilapia.

Material and methods

The experiment was carried out in the fish culture sector of the Federal University of Lavras (UFLA) and included animals from the tilapia breeding program developed at the institution. Fifty-three animals without deformities and 53 deformed animals found in the breeding of the aquaculture year 2020/2021 (Figure 1) were used. All experimental procedures used were approved by the Ethics Committee on Animal Use (CEUA/UMC) under protocol number: (003/2021).

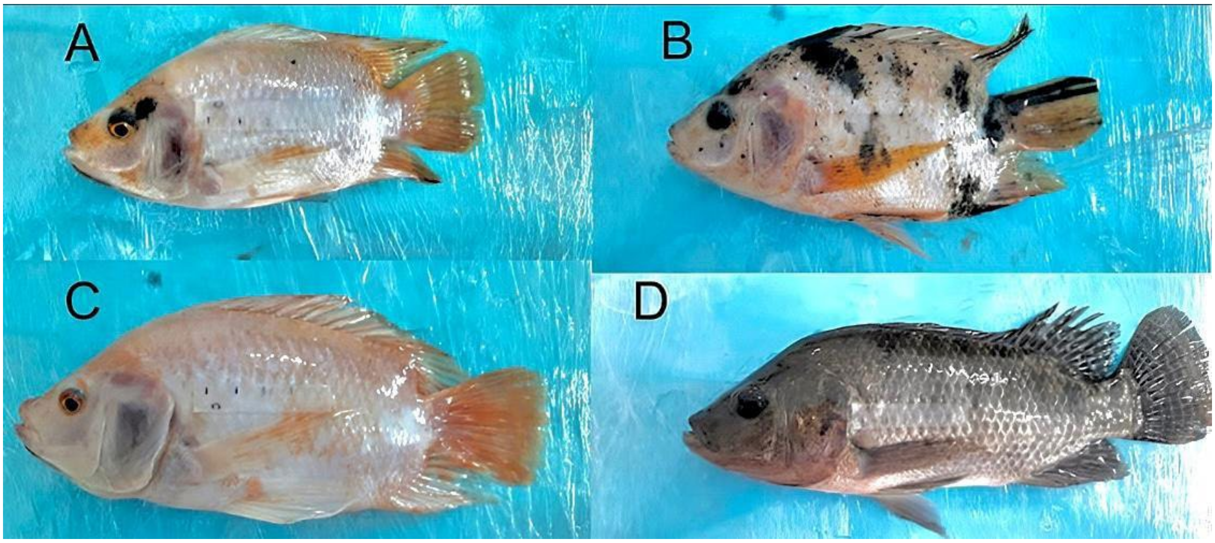
Restraint, morphometry, and photography of the animals

The animals were immersed in benzocaine solution (300 mg L^{-1}) until they lost swimming capacity. Afterward, the weight and morphometric measurements (CT) total length, (CP) standard length, (H) height, (W) width, (CC) head length and (AC) head height, were measured. The circumferences of the animals were collected in the direction of the fifth dorsal spine, eleventh dorsal spine, and posterior to the dorsal fin, and the ellipticity was measured by the method described by Trong et al. (2013).

Body area measurement

Body measurement was performed by individual photography with the aid of a Sony

Figure 1. Animals with abnormalities in body morphology.



Legend: Animals with absence of caudal peduncle, heart shape, kyphosis, and lordosis (A, B, and C) and animals with morphology considered normal (D). **Source:** authors.

Cyber-shot DSC-W690 Digital Camera featuring 16.1 Mp. A ruler with a known measurement was placed on the left side of the animal to standardize the pixels in centimeters and allow the images to be worked on later with ImageJ® software.

The areas measured (cm^2) were: the head area, caudal peduncle area, caudal fin, fillet, and abdomen (Figure 2). The abdominal and fillet areas were divided from the height of the pectoral fin to the central position of the urogenital fin of the animals. In animals whose anomaly results in the absence of a caudal fin the value considered was the beginning of the caudal peduncle.

Slaughtering and processing the animals

The animals were taken to the Fish Technology Laboratory, where, still sedated, they were slaughtered by medullar sectioning. The animals were eviscerated and their left side fillet was removed and divided into two parts: fillet from the lumbar and belly (Figure 3). The separation was performed on the lateral line of the fish to obtain these cuts.

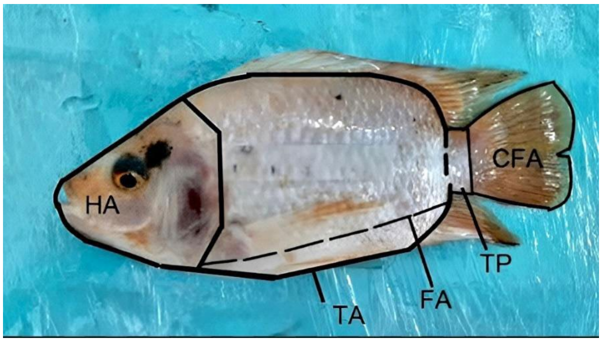
The fillets were weighed separately to obtain the yield of the cut. On the right side of the animal, the cut was made from the fifth dorsal spine, the eleventh dorsal spine, and posterior to the dorsal fin. All slices were photographed next to a ruler to have the flesh area measured later by ImageJ® (Figure 3. A).

In addition to the measured area, the lengths of the steaks were also measured to determine the volume of meat in the fillet. The other cuts defined as waste were weighed separately, obtaining the weight of the head and carcass of the animals.

Statistical analyses

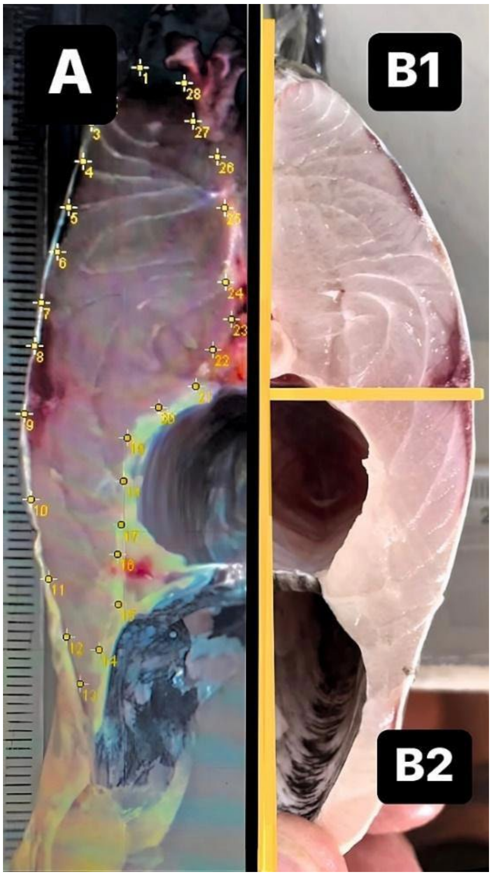
The normality of all data was tested using the Shapiro-Wilk test, $p<0.05$. To observe the existence of differences between body areas, belly and loin fillet yields, meat volume, meat area, and morphometrics of animals with

Figure 2. Body areas measured on the image.



Legend: Head area (HA); fillet area (FA); trunk area (TA); caudal peduncle area (TP) and caudal fin area (CFA).

Figure 3. Cuts for obtaining the carcass characteristics.



Legend: A= Meat area measured in the software for meat volume calculation; B1= Meat area present in the lumbar file; B2= Meat area present in the belly file.

abnormalities and normal, a t-test was performed with $p<0.05$.

The body areas, fillet meat area, cut volume, and morphometric measurements were correlated to the weights and fillet yields by Pearson correlation $p<0.05$. All data were worked in Software R (R CORE TEAM, 2021).

Results

No differences in morphometry and weight were observed in the animal (Table 1) and the meat volume in the fillet was statistically equal (Table 2). The meat volume of the third layer of the crooked animals had a high and positive correlation with the fillet yield, however, in the normal animals there was no association between the volume of meat in the fillet and the yield of the cut (Table 3).

The caudal peduncle and caudal fin area of deformed animals were statistically lower when compared to normal animals (Table 4). The body areas of the normal animals did not correlate significantly with fillet weight and yield, fillet loin, and belly fillet, however, head area correlated significantly with cut weight and total fillet yield (Table 5).

The diameters of the animals did not differ statistically and had high correlations with fillet weight, belly fillet weight, and fillet loin weight, as well as width and height measurements. However, a moderate correlation was observed between the diameter of crooked fish measured posterior to the dorsal fin and the total fillet yield (Table 6).

Table 1. Average weight, total length (TL), standard length (SL), width (W), height (H), head length (HL), and head height (HH).

	WEIGHT (g)	TL (cm)	SL (cm)	W (cm)	H (cm)	HL (cm)	HH (cm)
DEFORMED	236,27	21,67	17,47	3,43	7,18	6,48	5,08
NORMAL	234,91	23,21	19,15	3,34	7,21	6,28	4,90

Legend: Averages in the same column followed by different letters, differed by Tukey test (P<0.0 5).

Table 2. Average meat volume (cm^3) in the first layer (VL1), second layer (VL2), third layer (VL3), and in the total meat volume of the layers (TV).

	VL1	VL2	VL3	TV
DEFORMED	10,51	18,77	0,82	60,12
NORMAL	9,92	18,06	1,16	58,28

Legend: Averages in the same column followed by different letters, differed by Tukey test (P<0.0 5).

Table 3. Correlation between meat volume (cm^3) in the layer and fillet yield.

	VF1	VF1 N	VF2	VF2 N	VF3	VF3 N	TV	TVN
FY	0,60	0,40	0,40	0,22	0,68*	0,13	0,52	-0,29
BFY	0,66*	-0,01	0,50	-0,12	0,79**	0,35	0,61*	-0,09
BEFY	0,41	-0,26	0,25	-0,25	0,45	-0,42	0,34	-0,33

Legend: Meat volume of fillet 1 of deformed fish (VF1); meat volume of fillet 1 of normal fish (VF1 N); meat volume of fillet 2 of deformed fish (VF2); meat volume of fillet 2 of normal fish (VF2 N); meat volume of fillet 3 of deformed fish (VF3); meat volume of layer 3 of normal fish (VF3 N); total meat volume of deformed fish (TV) and Total meat volume of normal fish (TVN); Fillet yield (FY); Back fillet yield (BFY) and Belly fillet yield (BEFY).
* P-value < 0.05; ** P-value < 0.01

Table 4. Mean body areas head area (HA); tail area (CFA); fillet area (FA); belly area (TA); tail peduncle area (TP) and total body area (FULLA).

	HA	TA	FA	BA	TP	FULLA
DEFORMED	12,54	6,18[b]	4,87	26,22	1,83[b]	51,62
NORMAL	12,29	13,10[a]	4,83	27,35	2,86[a]	60,43

Key: Head area (HA); Tail area (TA); Fillet area (FA); Belly area (BA); Tail peduncle area (TP) and Total body area (FULLA). Unit of measure cm^2. Means of the same column followed by different letters differed by Tukey test (P<0.0 5).

Table 5. Correlation between body areas, fillet weights, and fillet yields.

		HA	TA	FA	BA	TPA	TBA
DEFORMED	**FW**	0,75**	0,61*	0,23	0,68*	0,80**	0,77**
	LFW	0,81**	0,55	0,30	0,77**	0,76**	0,82**
	BEFW	0,89***	0,63*	0,25	0,76**	0,79**	0,85***
	FY	0,66*	0,35	0,05	0,52	0,55	0,56
	LFY	0,45	0,12	0,13	0,42	0,45	0,40
	BEFY	0,65	0,44	-0,01	0,47	0,49	0,55
NORMAL	**FW**	0,07	0,21	0,43	0,27	0,11	0,33
	LFW	0,00	0,34	0,23	0,13	0,19	0,43
	BEFW	0,15	-0,04	0,59	0,42	-0,04	0,08
	FY	-0,40	0,26	-0,16	-0,25	-0,01	0,19
	LFY	-0,37	0,40	-0,41	-0,41	0,13	0,32
	BEFY	-0,07	-0,19	0,34	0,20	-0,20	-0,17

Key: Head area (HA); tail area (TA); fillet area (FA); belly area (BA); tail peduncle area (TPA); total body area (TBA); fillet weight (FW) loin fillet weight (LFW); belly fillet weight (BEFW); fillet yield (FY); loin fillet yield (LFY) and belly fillet yield (BEFY). Unit of measure cm^2. * P-value < 0.05; ** P-value < 0.01; *** P-value < 0.001.

Table 6. Correlation between fish diameter, morphometrics, fillet weight, and fillet yields.

	D1	D2	D3	TL	SL	W	H	HL	HH
FWD	0,68*	0,75**	0,94***	0,91***	0,91***	0,74**	0,69*	0,83**	0,84**
LFWD	0,78**	0,82**	0,94***	0,91***	0,93***	0,81**	0,82**	0,83**	0,92***
BEFWD	0,63*	0,70	0,87***	0,91***	0,90***	0,79**	0,71*	0,84**	0,82**
FYD	0,23	0,28	0,63*	0,56	0,60	0,53	0,25	0,49	0,40
LFYD	0,32	0,33	0,65*	0,48	0,56	0,47	0,28	0,44	0,45
BEFYD	0,12	0,19	0,48	0,49	0,49	0,50	0,18	0,41	0,27
FWN	0,84**	0,79**	0,66*	0,79**	0,90***	0,77**	0,82**	0,58	0,14
LFWN	0,74**	0,73*	0,51	0,74**	0,86***	0,68*	0,78**	0,48	0,21
BEWYN	0,73**	0,65*	0,70*	0,63*	0,71*	0,68*	0,65*	0,56	-0,01
FYN	0,14	0,17	-0,30	-0,14	0,14	-0,16	-0,04	-0,18	-0,32
LFWN	0,00	0,08	-0,43	-0,13	0,08	-0,21	-0,05	-0,26	-0,10
BEFYN	0,21	0,16	0,14	-0,04	0,10	0,06	0,00	0,09	-0,35

Legend: Circumference towards the fifth dorsal spine (D1); circumference towards the eleventh dorsal spine (D2); circumference between the dorsal fin and caudal peduncle (D3); Total length (TL); Standard length (SL); Width (W); Head length (HL); Head height (HH); Fillet weight deformed animals (FWD); Fillet loin weight deformed animals (LFWD); Belly fillet weight deformed animals (BEFWD); Fillet yield deformed animals (FYD); fillet yield deformed animals (LFYD); fillet yield belly deformed animals (BEFYD); fillet weight normal animals (FWN); loin fillet weight normal animals (LFWN); fillet weight belly normal animals (BEWYN); fillet yield normal animals (Rfilén); loin fillet yield normal animals (LFWN) and fillet yield belly normal animals (BEFYN). Unit of measure cm. * P-value < 0.05; ** P-value < 0.01 ; *** P-value < 0.001.

Ellipticity showed a statistical difference between deformed and normal fish, which showed greater ellipticity in the median and transverse planes (Table 7). No correlation was observed between fish shape and weights and the fillet yield of normal fish. However, for deformed animals, the transverse and median planes had a high correlation with fillet, fillet loin, and belly fillet weights, and only the median plane correlated with fillet yield (Table 8).

Deformed animals have interesting characteristics for good phenotyping since a large number of variables have a high and positive association with fillet yield and cuts. However, anomalous body morphology decreases fillet yield and raises head weight (Table 9).

Table 7. Averages of the ellipicities: midsagittal plane (Plamedio); transverse plane (Platrans), and frontal plane (Plafront).

	PLAMEDIO	PLATRANS	PLAFRONT
DEFORMED	0,41[b]	0,67[b]	0,35
NORMAL	0,45[a]	0,70[a]	0,37

Legend: Average plane observing the side of the animal (Plamedio); Transverse plane looking at the animal belly up (Platrans) and frontal plane observing the animal from the front (Plafront). Averages in the same column followed by different letters differ using the Tukey test (P<0.0 5).

Table 8. Correlation between ellipticities, fillet weight, and fillet yields.

	PLAMEDIO	PLATRANS	PLAFRONT
FWD	0,78**	0,78**	0,25
LFWD	0,71*	0,78**	0,44
BEFWD	0,75**	0,74**	0,21
FWN	-0,08	-0,58	-0,52
LFWN	-0,07	-0,47	-0,21
BEFWN	-0,09	-0,58	0,05
FYD	0,64*	0,45	-0,33
LFYD	0,57	0,48	-0,12
BEFYD	0,54	0,33	-0,40
FYN	0,28	0,29	-0,12
LFYN	0,21	0,35	-0,24
BEFYN	0,13	-0,06	0,16

Legend: Average plane observing the side of the animal (Plamedio); Transverse plane looking at the animal belly up (Platrans) and frontal plane observing the animal from the front (Plafront); fillet weight of deformed fish (FWD); loin fillet weight of deformed fish (LFWD); belly fillet weight of deformed fish (BEFWD); fillet weight of normal fish (FWN); loin fillet weight of normal fish (LFWN); fillet belly weight of normal fish (BEFWN); fillet yield of deformed fish (FYD); loin fillet yield of deformed fish (LFYD); fillet belly yield of deformed fish (BEFYD); fillet yield of normal fish (FYN); loin fillet yield of normal fish (LFYN) and fillet belly yield of normal fish (BEFYN). * P-value < 0.05; ** P-value < 0.01.

Table 9. Average fillet weights and fillet yields.

	FW	LFW	BEFW	FY	LFY	BEFY	HY	CY
DEFORMED	66,36	45,64	23,45	28,70[b]	19,08	9,62	25,83[a]	82,36
NORMAL	73,81	47,27	26,54	31,42[a]	20,15	11,29	22,81[b]	75,00

Legend: Fillet weight (FW); Loin fillet weight (LFW); Belly fillet weight (BEFW); Fillet yield (FY); Loin fillet yield (LFY); Belly fillet yield (BEFY); head yield (HY) and carcass yield (CY). Averages in the same column followed by different letters differ using the Tukey test (P<0.0 5).

Discussion

The effect of inbreeding in tilapia is very scarce in the literature and mostly associated with reproductive problems, producing infertile animals and impairing the genetic progress of breeding programs of the species (FESSEHAYE et al., 2009; PONZONI et al., 2010). The low number of papers on body deformities is due to the use of unrelated mating, consequently little reporting of morphological problems (EISSA et al., 2009).

The development of larvae with scoliosis or kyphosis is impaired due to the difficulty in capturing food and this can decrease the profitability of the culture since animals with anomalies are largely discarded or sold at lower cost (JAGIETTO et al., 2017). In the present study, there were no differences in relation to morphometry and meat volume in the gilt due to the standardization of weight to collect specimens without deformities, but it was possible to observe that the normal animals had a larger area of tail peduncle and tail, since the deformed ones did not have such morphological structures.

Cardoso et al. (2021), studying a method of collecting phenotypes in tilapia, found high phenotypic and genetic correlations between body weight and body areas. Body areas correlated with fillet weight and cuts only in crooked fish and only the head area of crooked fish correlated with total fillet yield. There was no phenotypic association between the variables studied in animals without anomalies.

Inbreeding promotes major changes in the body of fish, which can cause metabolic or physical changes, such as kyphosis, lordosis, absence of swim bladder, and fusion of bones, among others (GARCIA-CELDRÁN et al., 2016; BOGLINO et al., 2014). Besides the absence of a peduncle and caudal fin, it was noted in the present study that deformities generate visual morphological differences since deformed animals decrease the body ellipticity already demonstrated for the species (TRONG et al., 2013).

The search for tools and methods to estimate the fillet yield has been developed and morphometry, body area, fish circumference, and ultrasonography are collection methods already employed to fish (REIS NETO et al., 2012; REZENDE et al., 2023; SILVA et al., 2009). The application of morphometry and body diameter allowed corroborating with the works present in the literature, evidencing high correlations between the variables of fillet weight and phenotype collection method.

The crooked animals had a high and positive correlation between total fillet yield, lumbar fillet yield, and the circumference of the point posterior to the dorsal fin of the fish. Rezende et. al. (2023), standardizing the technique of collecting phenotypes of tilapia through ultrasonography, also observed that the point posterior to the dorsal fin has a higher association with variables linked to fillet yield in the species.

During body development in cichlids, morphological change is evident, and as the animal grows ellipticity increases and roundness decreases (MÉRIGOT, LETOURNEUR, LECOMTE-FINIGER, 2007). Fish shape is a factor of great importance for carcass processing, due to the standardization of the process and the product (SILVA et al., 2018; ROSSATO et al., 2021).

Studying the body shape of tilapia, Trong et al. (2013) observed that besides the height and width of the fish, the mid-sagittal plane has a high correlation with the weight of the animals confirming the positive correlation between size and body shape. However, the data found by the present study allows observing that deformed animals have less development with the body in the face of the lower ellipticity found.

Trong et al. (2013) and Mérigot, Letourneur, and Lecomte-Finiger (2007) did not aim to observe the correlation between fish shape and weight and yield of cuts, but only the shape of the fish. Normal animals do not have their ellipticity correlated with fillet weight or fillet yield, but deformed animals had high correlations between the transverse plane and fillet weight and its cuts, as well as the mid-sagittal plane, which also had a high correlation with total fillet yield.

The filet yield of the normal animals corroborates with those found by FRASCÁ-SCORVO et al., 2008 and RICHTER et al., 2021, ranging from 30 to 36% when operating with trained workers. The deformed animals had a lower filet yield than the normal group, due to the difficulty in processing the carcass and for presenting heads with more significant weights in the total weight of the animals, raising the carcass yield and generating a larger amount of waste at the end of the industrialization process.

Conclusion

Morphological abnormalities in the tilapia carcass result in lower fillet yield and a higher amount of waste at the end of the production process.

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