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RELATIONSHIP BETWEEN BODY WEIGHT, BODY MEASUREMENTS AND CARCASS CHARACTERISTICS OF NILE TILAPIA (*Oreochromis niloticus* L.)

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Abstract: This study was conducted to evaluate the relationship between the body weight (BW), body measurements and carcass characteristics to determine the usefulness of body measurements in prediction of BW and fillet and carcass weight of Nile tilapia (*Oreochromis niloticus* L.). In the study, a total of thirty-six adult male tilapia specimens were used. The fish were killed and weighed individually using an electronic scale. Six linear body measurements were recorded: total length (TOL), standard length (STL), body width (BWI), body perimeter (BPE), body height (BHE) and head length (HEL). Likewise, the fish were processed to determine the carcass weight (CWE), viscera weight (VIW), head weight (HEW), fillet weight (FIW), backbone weight (BAW) as well as carcass (CYI) and fillet (FIY) yields. The results of the study indicated that the mean values of BW, body measurements and carcass characteristics presented low to moderate variability, varying from 3.45% for TOL to 26.74% for HEW. The Pearson correlation coefficients ranged from moderate to high ($0.342 \leq r \leq 0.869$). All the linear body measurements, except HEL, showed positive correlations with BW ($P<0.001$). Also, BW showed positive correlations ($P<0.05$; $P<0.001$) with the CWE (r= 0.869), FIW (r= 0.638), VIW (r= 0.395) and BAW (r= 0.360). The results of the stepwise regression analysis revealed that BW can be moderately predicted using BHE and STL as the predictor's variable. Besides, BW was the traits of higher importance in the prediction of CWE (R^2 = 75.6%) and FIW (R^2 = 40.7%). These findings contribute to decision making related to breeding programs of this aquaculture species.

Key words: aquaculture, body weight, fillet yield, *Oreochromis niloticus*, prediction equations.

Introduction

Globally, the aquaculture sector plays a relevant role in the food industry, since it contributes to meet growing food demand and address nutritional deficiencies with lower environmental impact than others animal source products. In recent decades, world aquaculture has increased the availability of aquatic foods, growing from 13.1 million mt in 1990 to 82.1 million mt in 2018 (Garlock et al., 2022).

In Mexico, the growth rate of production and the value of aquaculture production for the period 2008-2018 registered a growth of 9.1%, going from 1.7 to 2.1 million mt, respectively (SADER, 2018). The increase in this volume has been with species such as shrimp, catfish, tilapia, trout, red snapper, among others. It should be noted that shrimp and tilapia are the species that especially drive the positive performance of this sector. According to CONAFAB (2021), 65,000 tons are produced in the country through controlled aquaculture; however, it is not enough to cover the demand since 75,000 tons are imported, placing Mexico as the second largest importer of tilapia in the world, after the United States.

Currently, Nile tilapia (*Oreochromis niloticus* L.) is a popular species in both aquaculture as well as capture fisheries, and is considered a nutritious and relatively inexpensive alternative for human consumption (Aguilar-Moreno and Aguilar-Aguilar, 2024). This aquaculture species has important characteristics such as rapid growth, resistance to disease, high adaptability to different environments, food, as well as water quality. In Mexico, the systems used for its breeding range from the most rudimentary (extensive) to technologically advanced farms (intensive) (Vega-Villasante et al., 2010). Its cultivation is more frequent in tropical areas, where concrete or other material ponds are established to carry out the sowing, pre-fattening and fattening of tilapia, usually near natural bodies of water such as rivers, lagoons and lakes (Aguilar-Moreno and Aguilar-Aguilar, 2024).

On the other hand, through genetic improvement of livestock species seeks the increase of economically important traits, such as the body weight (BW). This involves the selection and reproduction of the individuals that present the best performance for the desirable trait, which can be directly or indirectly measured by means of others that are correlated with it, as body measurements (LBM) (Oliveira et al., 2019). Due to the preference and popularity of tilapia production among farmers, comprehensive studies must be conducted on the relationship between the BW, LBM and carcass characteristics. Understanding these characteristics and their potential correlation will contribute to broader knowledge of tilapia breeding and management strategies (Allaman et al., 2013). Body shape, weight and relationship between body measurements has been studied because the relation not only fillet weight but also fillet and carcass yield (dos Santos et al., 2019).

Therefore, this study was conducted to evaluate the relationship between the body weight (BW), body measurements and carcass characteristics to determine the usefulness of body measurements in prediction of BW and fillet and carcass weight of Nile tilapia (*Oreochromis niloticus* L.).

Materials and Methods

Location and biological material

A total of thirty-six adult male tilapia with an age between 160 and 180 days were captured manually in different ponds of an aquaculture farm located in the community of Bécal, Calkiní, Campeche, México (20°24'55.1"N and 90°02'05.1" W at an altitude of 50 masl) and transferred to the Food Technology Laboratory of the Higher Technological Institute of Calkini for measurement and processing.

The study area presents a warm subhumid climate with summer rain (Aw). The average annual temperature and total annual precipitation ranged from 22.1 to 28.1°C and 853.3 to 1756.9 mm, respectively (INEGI, 2021). The animals studied were under the same culture conditions. Stocking density varied according to the growth stage of fish (100-120 fish/m^{-3} at the stocking stage and 20-50 fish/m^{-3} at the fattening stage). The ponds are made of geomembrane (6.0 m diameter × 1.2 m high) and are supplied with deep well water through a recirculation system, which is maintained at a neutral pH and an average temperature of 28.5ºC. Fish were fed three times a day with a daily ration of commercial feed (ADM® GROWFISH) corresponding to 1.5-2% of total body weight at the growing stage. Subsequently, it was gradually reduced to reach 1% of total body weight.

Morphometric measurements

The animals were killed by stunning and weighed individually using a digital analytical balance (Medidata®) with a precision of 0.01 g. All fish were processed according to the Official Mexican Standards (NOM-008-ZOO-1994, NOM-009-ZOO-1994, and NOM-033-ZOO-1995) established for the humane slaughter of animals intended for meat production.

Six linear body measurements were recorded following the methodology described by Fernandes et al. (2015) and dos Santos et al. (2019); these were: total length (TOL), standard length (STL), body width (BWI), body perimeter (BPE), body height (BHE) and head length (HEL) (Figure 1). The body measurements were measured using a tape measure graduated in cm and a digital calliper (Mitutoyo®) with an accuracy of 0.01 mm. To ensure minimal errors the measurements were done by a single operator.

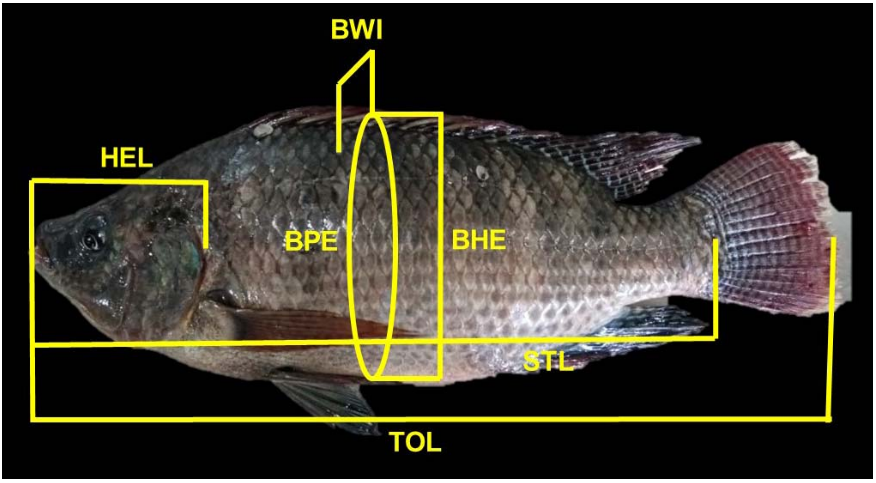

Figure 1. Schematic representation of the morphometric measurements taken in Nile tilapia (*Oreochromis niloticus* L.). TOL: Total length, STL: Standard length, BWI: Body width, BPE: Body perimeter, BHE: Body height, HEL: Head length.

Slaughter and carcass characteristics

The processing of the animals was carried out following the methodology proposed by Melo et al. (2013). Briefly, the fish were eviscerated to obtain the carcass weight (CWE) which consists in total weight of carcass with head minus the viscera. The latter were weighed separately to obtain the viscera weight (VIW). After, the skin was removed along with the flakes in the direction 'skull to tail'. The head was separated from the trunk by cutting in the line after the caudal end of the operculum and weighed to determine the head weight (HEW). With a filleting knife, the fillets were removed, without the two lateral ribs of the fish that are present longitudinally along the entire length of the spine and ribs and weighed to determine the total fillet weight (FIW). The backbone weight (BAW) without meat was also determined individually.

Carcass (CYI) and fillet (FIY) yields were determined as the percentage (%) of BW (whole fish).

Data analysis

Normal distribution of the variables was analysed according to the Shapiro-Wilk test. All data were analysed using descriptive statistics using the SAS software, version 9.4 (SAS Institute Inc., Cary, NC). Pearson correlation coefficients (r) were estimated using the PROC CORR procedure to evaluated relationship between BW, linear body measurements and carcass characteristics. The Stepwise regression analysis was used to obtain equations for predicting BW, CWE and FIW from BW and linear body measurements so that only the significant (*P*<0.05) predictor variables were included in the model.

Results and Discussion

Descriptive statistics of BW, linear body measurements and carcass characteristics of Nile tilapia are presented in Table 1. The mean BW was 523.35 ± 52.90, while mean linear body measurements were 31.29 ± 1.08 cm, 25.91 ± 0.96 cm, 4.38 ± 0.28 cm, 23.77 ± 0.87 cm, 10.07 ± 0.38 cm and 7.95 ± 0.40 cm for TOL, STL, BWI, BPE, BHE and HEL, respectively. In general, mean values of BW, linear body measurements and carcass characteristics exhibited moderate to high variability, ranged from 3.66% for BPE to 26.74% for HEW. According to Sam et al. (2020), the moderate variability in some traits as carcass characteristics in domestic animals indicate that these traits could respond to selection and should be exploited.

The results of BW and linear body measurements observed in this study were lower to those reported by Oliveira et al. (2019) for of tilapia male breeders. However, were higher compared to those reported by Melo et al. (2013) for tilapia with BW ranged to 400 to 599 g. The differences between the tilapia groups studied may be due to either genetic differences or environmental factors (Kosai et al., 2014). In addition, it is known that in fish farming variations in size among animals are generally related to competition for food within a population and the resulting feeding hierarchy (dos Santos et al., 2019).

Table 1. Descriptive statistics of body weight, body measurements and carcass characteristics of Nile tilapia (*Oreochromis niloticus* L.)

Traits	Mean	Standard deviation	Minimum	Maximum	CV (%)
BW (g)	523.35	52.90	418.00	657.00	10.10
TOL (cm)	31.29	1.08	29.40	34.20	3.45
STL (cm)	25.91	0.96	24.30	28.00	3.70
BWI (cm)	4.38	0.28	3.80	4.90	6.39
BPE (cm)	23.77	0.87	22.40	26.90	3.66
BHE (cm)	10.07	0.38	9.10	10.90	3.77
HEL (cm)	7.95	0.40	7.20	8.70	5.03
FIW (g)	197.25	24.75	148.00	263.70	12.54
VIW (g)	56.85	7.94	42.10	79.30	13.96
BAW (g)	149.97	35.12	91.30	226.70	23.41
HEW (g)	102.61	27.44	73.00	182.10	26.74
CWE (g)	363.88	46.75	286.60	513.80	12.84
CYI (%)	69.46	4.28	60.62	79.17	6.16
FIY (%)	37.75	3.52	29.43	46.40	9.32

CV: Coefficient of variation, BW: Body weight, TOL: Total length, STL: Standard length, BWI: Body width, BPE: Body perimeter, BHE: Body height, HEL: Head length, FIW: Fillet weight, VIW:

Viscera weight, BAW: Backbone weight, HEW: Head weight, CWE: Carcass weight, CYI: Carcass yield, FIY: Fillet yield.

The phenotypic correlation matrix between BW, linear body measurements and carcass characteristics of Nile tilapia is represented in Figure 2. In general, the correlation coefficient varied from moderate to high ($0.342 \leq r \leq 0.869$). All the body measurements, except HEL, showed positive correlations ($P<0.001$) with BW. This indicates that selection for any of these body measurements, in the order > BHE > STL > BPE > TOL > BWI, will lead to improvement in BW of Nile tilapia. Highest correlation were recorded between BW and BHE (r = 0.605). Similarly, it is an indication that this body dimension could serve as a predictor of BW under field conditions (Ogah, 2011). In addition, the results in the present study also showed that interrelationships exist between linear body measurements as correlation coefficients were positive and significant.

Similar finding were reported by da Silva et al. (2018) in Nile tilapia, GIFT-Epagri strain, where body weight showed highest correlations with total length (r = 0.968 and 0.956) and standard length (r = 0.957 and 0.950) for both males and females, respectively. According to Kosai et al. (2014), the length-weight relationship of fish is important in aquaculture, because it allows the estimation of average BW of the animals of a given length group by establishing a mathematical relation between the two. Also, is often used as an parameter of fatness, general well-being and regional comparison.

For its part, Hassanien et al. (2011) they reported a low and positive correlation between body thickness and body depth (r = 0.433), a high and positive correlation between body length and tail length (r= 1.00), as well as a high and negative correlation between head length and trunk length (r = -1.00) in cultured Nile tilapia.

Regarding the carcass characteristics, BW showed positive and significant ($P<0.05$; $P<0.001$) correlations only with the CWE (r = 0.869), FIW (r = 0.638), VIW (r = 0.395) and BAW (r = 0.360). The positive correlations recorded in this study for some carcass characteristics and BW indicate that these characteristics are influenced by the same genes in the same direction; that is to say, the traits may be under the same genetic influences (Okpeku et al., 2011). Thus, selection and improvement for BW will lead to improvement of carcass characteristics (Sam et al., 2020). Specifically, BWI indicated higher correlation with the majority of the carcass characteristics estudied, except that it negatively correlated with FIY (r = -0.584) and HEW (r = -0.376).

Meanwhile, FIW showed positive correlations ($P<0.001$) with BPE (r = 0.612), TOL (r = 0.464), STL (r = 0.390) and BHE (r = 0.354). The importance of slaughter traits, as fillet weight and yield, for the fish industry is well known (Fernandes et al., 2015). The fillet is the presentation of the final product that is most marketed by the fish processing industry, especially when compared to the gutted whole fish (Melo et al. 2013). In the study of Melo et al. (2013), the FIY of of Nile tilapia from different BW class had the highest correlation coefficients with the ratio body width/head length. In that study, other variables were important, such as the body height.

In another study by Oliveira et al. (2019), some characteristics of tilapia breeders presented a moderate correlation, such as between FIY and FIW (r = 0.55) in females and others presented a low correlation, such as between BW and ultrasound area (r = 0.03) in males. The authors also observed strongly correlated characteristics such as average daily gain and BW (r = 0.99) in females.

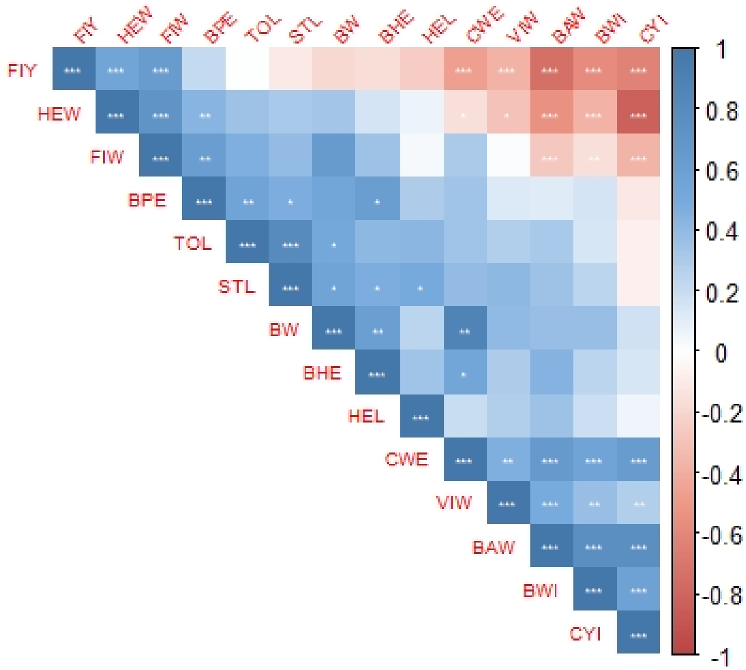

Figure 2. Heat map of Pearson's correlations (r) between body weight, body measurements and carcass characteristics of Nile tilapia. Blue color means high correlation (P<0.001), white color means mid-correlation (P<0.05), and red color means low correlation with negative direction.

Regression equations for predicting BW and carcass characteristics from body measurements of Nile tilapia using Stepwise regression analysis are presented in Table 2. The results showed that BW can be moderately predicted using BHE as the predictor variable (R^2 = 36.6%) (Eq. 1); however, predictive accuracy was improved slightly by adding the STL to the equation, since the value of the determination coefficient increased to 46.6% (Eq. 2). These results confirm the importance of standard length in identifying tilapia with better carcass yield, which depends on body weight (Melo et al. 2013).

For CWE, the results of the stepwise analysis revealed that BW was the variable of higher importance in the prediction of CWE in Nile tilapia, where this trait alone accounted for 75.6% of the total variation in BW (Eq. 3). However, the combination with BWI increased the proportion of the explained variance to 83.0% (Eq. 4). These findings confirm the fact that carcass traits in domestic animals can be predicted from BW with accuracy. This probably might be as a result of the positive and correlated relationships of carcass traits with BW used in predictions.

For the prediction of FIW, three equations were obtained, however, the best equation (Eq. 7) explained 67.3% of the observed variation and considered BW, BWI and BPE as predictors. Thus, selection for BW is the most appropriate alternative for gains in FIY and FIW as described by da Silva et al. (2018).

With regard to variance inflation factor (VIF) values obtained in this study, it can be inferred the existence of moderate collinearity, since VIF values greater than 10.00 indicate severe collinearity rendering the reliability of the predictive equation not effective (Ogah, 2011).

Table 2. Prediction equations for body weight and carcass traits from linear body measurements of Nile tilapia.

Eq. No.	Equations	R^2	MSE	VIF
Body weight (BW, g)				
1	BW (g)= -305.39 + 82.22×BHE	0.366	1831.29	1.000
2	BW (g)= -583.27 + 59.50×BHE + 19.55×STL	0.466	1591.49	1.278
Carcass weight (CWE, g)				
3	CWE (g)= -38.12 + 0.76×BW	0.756	550.64	1.000
4	CWE (g)= -197.39 + 0.67×BW + 47.61×BWI	0.830	395.98	1.155
Fillet weight (FIW, g)				
5	FIW (g)= 40.95 + 0.29×BW	0.407	374.37	1.000
6	FIW (g)= 171.56 + 0.37×BW + -39.04×BWI	0.585	270.51	1.155
7	FIW (g)= -22.91 + 0.28×BW + -37.59×BWI + 9.93×BPE	0.673	220.31	1.414

BW: Body weight, TOL: Total length, STL: Standard length, BWI: Body width, BPE: Body perimeter, BHE: Body height, HEL: Head length, FIW: Fillet weight, CWE: Carcass weight.

Conclusion

In conclusion, it is possible to predict body weight of Nile tilapia with moderate accuracy from some linear body measurements as the body height and standard length. Additionally, the positive and significant relationship observed between these variables suggests that an increase in any of these body measurements leads to an increase in body weight. Likewise, the body weight is the most important trait for determining carcass characteristics of Nile tilapia. Therefore, these findings contribute to decision making related to improving breeding programs of this aquaculture species.

Veza između telesne mase, telesnih mera i karakteristika trupa nilske tilapije (*Oreochromis niloticus* L.)

Rodrigo Portillo-Salgado, Alondra Y. Sánchez-Márquez, Julio E. Oney-Montalvo, Dany A. Dzib Cauich, Emmanuel de Jesús Chi-Gutiérrez

Rezime

Ovo istraživanje je sprovedeno radi procene odnosa između telesne mase (BW), telesnih mera i karakteristika trupa, kako bi se utvrdila mogućnost korišćenja telesnih mera za predviđanje BW i težine fileta i trupa nilske tilapije (*Oreochromis niloticus* L.). U istraživanju je korišćeno ukupno trideset šest odraslih mužjaka tilapije. Ribe su žrtvovane i pojedinačno merene pomoću elektronske vage. Evidentirano je šest linearnih telesnih mera: ukupna dužina (TOL), standardna dužina (STL), širina tela (BWI), obim tela (BPE), visina tela (BHE) i dužina glave (HEL). Takođe, ribe su obrađene da bi se odredila težina trupa (CWE), težina unutrašnjih organa (VIW), težina glave (HEW), težina fileta (FIW), težina kičme (BAW), kao i prinos trupa (CYI) i fileta (FIY). Rezultati su pokazali da srednje vrednosti za BW, telesne mere i karakteristike trupa pokazuju nisku do umerenu varijabilnost, varirajući od 3,45% za TOL do 26,74% za HEW. Pirsonovi koeficijenti korelacije kretali su se od umerenog do visokog ($0.342 \leq r \leq 0.869$). Sve linearne telesne mere, osim HEL, pokazale su pozitivne korelacije sa BW ($P<0,001$). Takođe, BW je pokazala pozitivne korelacije ($P<0,05$; $P<0,001$) sa CWE (r= 0,869), FIW (r= 0,638), VIW (r= 0,395) i BAW (r= 0,360). Rezultati postupne regresione analize pokazali su da se BW može umereno predvideti korišćenjem BHE i STL kao prediktorskih varijabli. Pored toga, BW je bila osobina od većeg značaja u predviđanju CWE (R2 = 75,6%) i FIW (R2 = 40,7%). Ovi rezultati doprinose donošenju odluka u vezi sa programima uzgoja ove vrste akvakulture.

Ključne reči: akvakultura, telesna masa, prinos fileta, *Oreochromis niloticus*, jednačine predviđanja.

Conflict of interest

The authors declare that they have no conflict of interest

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