

Relationship between Body Weight and Morphological Traits in Female and Male Spotted Scat (*Scatophagus argus*)

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ABSTRACT

The spotted scat (*Scatophagus argus*) is an economically important farm fish species found in Southeast China. Production of all-female spotted scat population with superior growth traits can significantly increase farmer's benefits due to its sexual dimorphism in growth. Herein, the sex ratio and differences in morphometric traits were observed between females and males in a full-sib population of *S. argus*. Then the correlation between these traits and their effects on body weight (BW) was analyzed. The results showed significant growth differences between males and females. The correlation coefficient between BW and the other 13 traits reached a very significant level, and the strongest correlation was observed in the body height (BH) (male) and body length (BL) (female). In females, BL, body thickness (BT), head length (HL), and BH had a significant and direct effect on BW. The determination coefficients of traits BL, BT, BH, and HL to BW were 0.163, 0.159, 0.057, and 0.018, respectively with the total value being 0.928. In males, the determination coefficients of six traits to BW were 0.124 (BH), 0.192 (BT), 0.053 (BL), 0.018 (OL), 0.0088 (HL), and 0.0092 (PA), with the total value being 0.855. Moreover, two best-fit linear regression equations were constructed in females and males respectively. This knowledge will provide useful and valuable information in better understanding of the differences between both sexes, relationships between morphometric traits, and selective breeding of *S. argus*. These models might also provide theoretical support for the indirect selection of traits that are difficult to select directly.

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Authors' Contribution

HC and YW curated the data. ZL, HC and HS performed analysis. GL and CZ acquired funding. HC, YW and WY conducted the research. SL and HS presented the methodology. GL provided the resources. HC and GL wrote the manuscript.

Key words

Scatophagus argus, Sexual dimorphism, Multiple regression equation, Correlation analysis, Path analysis.

INTRODUCTION

Many economic traits in aquatic animals are related to gender. They present obvious dimorphism in growth rate, sexual maturity, and morphology. Growth is one of the most valuable economic traits of fish genetic improvement, and many fish exhibit significant sexual dimorphisms in growth and body size. For example, female

individuals of bastard halibut (*Paralichthys olivaceus*) (Yoneda *et al.*, 2007), rainbow trout (*Oncorhynchus mykiss*) (Bye and Lincoln, 1986) and European seabass (*Dicentrarchus labrax*) (Saillant *et al.*, 2001) are larger than male individuals, while yellow catfish (*Pelteobagrus fulvidraco*) (Wang *et al.*, 2009) and Nile tilapia (*Oreochromis niloticus*) (Beardmore *et al.*, 2001) show opposite characteristics. Therefore, breeding of full-female or male population possesses greater significance to the hatchery production units. Evaluation of the effects of morphological traits on body weight (BW) using path analysis and multiple regression analysis comprises of the basic study on breeding. The results are used to optimize the breeding strategy, which can improve the economic value of aquatic living (Huo *et al.*, 2010).

In selective breeding, BW is the most direct target trait because of its intuitiveness and measurability (Wang *et al.*, 2016). However, correlation analysis can only measure the

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degree of association between different traits but the reason for the association is unknown. Therefore, it is necessary to perform path analysis together with correlation analysis (Hardwick and Andrews, 1980; Uckardes *et al.*, 2015). Studies on phenotypic and sexual dimorphism among growth-related traits have been performed in many aquatic species, including *Apostichopus japonicas* pearl (Zhan *et al.*, 2019), *Glossaulax reiniana* (Zhao *et al.*, 2014) *Pinctada martensii* (Deng *et al.*, 2008), *Exopalaemon carinicauda* (Zhang *et al.*, 2013a) and *Patinopecten yessoensis* (Chang *et al.*, 2008). In fish species, the main traits affecting the body weight of male tilapia were its full length, depth at caudal peduncle, body width and head length. Whereas the main traits affecting the female body weight were body width, body length, body height and full length (Zeng *et al.*, 2012). In *Cynoglossus semilaevis*, the body height of females had the highest direct impact on body weight (path coefficient is 0.535), while in males, the total length had the highest direct impact on body weight (Path coefficient is 0.407) (Liu *et al.*, 2015a).

Table I.- Morphological traits of *S. argus*.

Trait	Male (n=188)		Female (n=198)	
	Mean±SD ¹	CV ² (%)	Mean±SD	CV (%)
BW	74.79±11.57	15.47	85.60±17.05	19.92
TL	14.28±0.68	4.79	14.76±0.94	6.39
BL	12.11±0.61	5.03	12.53±0.84	6.71
BH	6.88±0.35	5.21	7.22±0.56	7.75
BT	2.96±0.36	12.35	3.10±0.34	11.12
PD	3.59±0.27	7.61	3.78±0.31	8.19
PV	3.88±0.31	8.22	4.08±0.41	10.07
PA	7.94±0.42	5.31	8.30±0.57	6.95
HL	2.95±0.17	5.98	3.10±0.25	8.04
OLO	1.58±0.12	7.81	1.67±0.16	9.79
OL	0.79±0.05	6.69	0.82±0.06	8.35
CPL	1.22±0.15	12.69	1.27±0.17	13.92
CPH	1.54±0.08	5.49	1.60±0.11	7.02
CL	2.17±0.12	5.73	2.22±0.15	6.79

¹SD, standard deviation; ²CV, coefficient variation. BW, body weight; TL, total length; BL, body length; BH, depth of body; BT, body thickness; PD, pre-dorsal length; PV, pre-ventral fin length; PA, pre-anal length; HL, head length; OLO, post-orbital length; OL, eye diameter; CPL, caudal peduncle length; CPH, depth at caudal peduncle; CL, caudal length.

Spotted scat (*Scatophagus argus*) is widely distributed in the mudflats, mangrove swamps, harbors, upstream swamps, estuaries, and marine habitats of Indo-Pacific region, including Southeast China. The adaptation to live in such ever-changing environment endows them with many biological attributes that are highly desirable traits for the cultured finfish (Sivan and Radhakrishnan, 2011; Barry

and Fast, 1992). The quality and taste of the fish rank it as an edible fish and the beautifully spotted rhombic body ranks it as a fascinating aquarium fish (Sivan *et al.*, 2007). Previous studies focused on the regulation of growth and reproduction of this fish species (Zhang *et al.*, 2013b; Liu *et al.*, 2015b; Mustapha *et al.*, 2018; Jiang *et al.*, 2019). There is little information about the characteristics of morphological traits available in spotted scat. Although artificial breeding of *S. argus* has been reported, family breeding is lagging due to the lack of systematic selection breeding research. *S. argus* usually exhibits significant differences in economically important growth traits between both the sexes. Female individuals generally show a faster growth rate with larger size than males, so fishermen can obtain higher prices in the market (Wang *et al.*, 2018; Deng *et al.*, 2018). Therefore, the objectives of this work were: 1) to determine the association between BW and biometric traits *viz.* body length (BL), body thickness (BT), head length (HL), depth of body (BH), eye diameter (OL), pre-anal length (PA), pre-ventral fin length (PV), post-orbital length (OLO), caudal peduncle length (CPL), pre-dorsal length (PD), depth at caudal peduncle (CPH) and caudal length (CL) using correlation analysis; 2) to construct a mathematical equation for prediction of BW from biometric traits by multiple regression analysis; and 3) to reveal direct and indirect effects of biometric traits on BW using path analysis. The study will help fishermen for the selection of useful biometric traits during breeding to improve BW.

MATERIALS AND METHODS

Experimental materials

The larvae of *S. argus* were hatched at Yucheng aquaculture Co., Ltd. in Zhuhai, Guangdong, China. The hatching was carried out in a circular fiberglass tank (0.9 m diameter and 1.0 m height) and then transferred to a cement tank (5.8 m×4.8 m×1.8 m) for cultivation. Spotted scats at one year age were used in this study. A total of 386 individuals (females=198 and males=188) were collected for the experiment. The sex of *S. argus* was identified based on the gonadal morphology. Animal experiments were conducted in accordance with the relevant guidelines and have been approved by the Animal Research and Ethics Committees of Fisheries College of Guangdong Ocean University (201903004).

Morphometric traits measurement

One day before the experiment, fish were ceased to be fed and anesthetized using MS-222 (Sigma, Saint Louis, MO) with a concentration of 100 mg/L. According to the measurement standard of morphological characteristics reported as the previous report (Gandhi *et al.*, 2013), a

total of 14 morphometric traits were measured, including BW, BH, PD, PV, PA, HL, OLO, OL, CPL, CPH, BT, BL, CL and TL. Electronic balance was employed to measure individual BW for both the sexes and were accurately measured to the 0.01 g resolution, while the other 13 morphological traits measured to the accuracy of 0.01 cm resolution with ImageJ (<https://imagej.nih.gov/ij/>; accessed February 2021) (Fig. 1). The picture of the fish was obtained from Taiwan Fish Database (<https://fishdb.sinica.edu.tw/>; accessed February 2021).

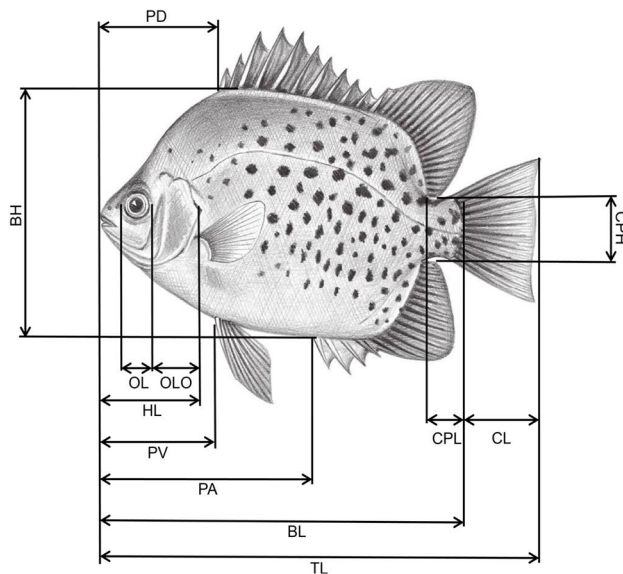


Fig. 1. Morphometric characteristics of the *Scatophagus argus*.

Statistical analysis

The statistical analysis of the tested data was done using SPSS statistical package version 20.0 (SPSS Inc., Chicago, IL, USA). Data normality test was carried out using the Shapiro-Wilk test. The coefficient of variation (CV) of each trait was calculated using the following formula:

$$CV = \frac{\text{Standard deviation}}{\text{Mean}} \times 100\%$$

Data for morphometric traits were analyzed using t-tests with statistical significance at $P < 0.05$ and high significance at $P < 0.01$ (Shi *et al.*, 2019).

The path analysis was conducted using SPSS version 20.0 software as described by Du and Chen (2010). Referring to the methods of the Pearson correlation analysis (two-tailed and P -value), the correlation coefficient of each morphological characteristic was divided into direct and indirect effects on BW. The regression relationship between BW and other morphological traits was estimated by first testing the significance of partial regression

coefficients of different traits and then by stepwise removing the non-significant morphological traits. The coefficient of determination was calculated by correlation and path analysis, which also determined the coefficient of single or multiple traits to BW. Stepwise multiple regression analysis was used to identify those parameters that significantly contributed to weight traits and optimal multivariate regression equations were established for estimation of BW (Zhao *et al.*, 2014). The below multiple linear regression equation was adopted:

$$Y = a + b_1 X_1 + b_2 X_2 + b_3 X_3 + b_4 X_4 + b_5 X_5 + b_6 X_6 + b_7 X_7 + b_8 X_8 + b_9 X_9$$

Where, Y is dependent variable (BW), a is intercept, $b_1 - b_9$ is coefficient of regression, and $X_1 - X_9$ is independent variables (biometric traits).

The TL-BW and BH-BW relationship of *S. argus* was described for each gender using the method potency equation as stated below:

$$W = aL^b$$

Where, W is BW, L is TL or BH, and a and b are constants.

The coefficient b showed the type of weight increase (isometric, $b = 3$; positively allometric, $b > 3$; and negatively allometric, $b < 3$). The data showed that there was a significant difference when $P < 0.05$ and a high significance was reported when $P < 0.01$. All charts were drawn by means of GraphPad Prism version 8 software and online tools (<http://gcloud.taogene.com>; accessed February 2021).

RESULTS

Morphometric traits of *S. argus*

The differences in morphometric traits between female and male *S. argus* are shown in Figure 2. It was observed that 14 morphometric traits which were measured showed highly significant differences between both the sexes ($P < 0.01$). As a whole, females were significantly bigger than males. In both sexes, the CV values of BW and TL were the highest and lowest among 13 traits, respectively. The CV values of each morphological trait ranged from 4.792% to 15.472% in males and 6.392% to 19.926% in females.

Figure 3 shows the correlation coefficients among the 14 morphological traits of *S. argus*. Except for BT-PV, BT-OL and CL-OL in females and BW-OL, BT-PV BT-OL and CL-OL in males were not significant, other trait-pairs showed significant positive correlation ($P < 0.01$). All 13 morphometric traits were found to correlate significantly with BW in both the sexes, except for BW-OL in male. The highest correlation coefficient of BW was found in TL (female) and BH (male), with a value of 0.870 and 0.792, respectively.

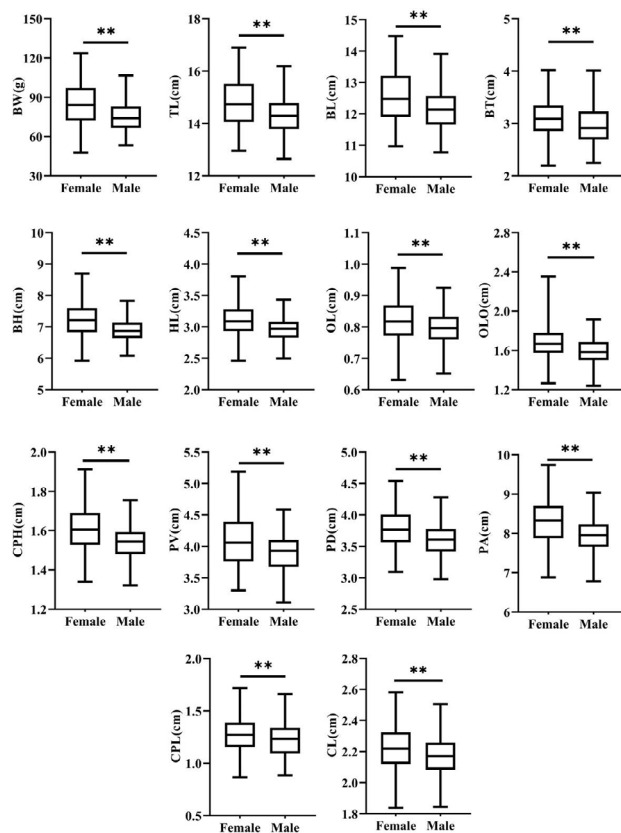


Fig. 2. Growth traits of female and male *Scatophagus argus*.

The direct and indirect effects of the different morphometric traits on BW were evaluated using the path correlation analysis. The morphological traits that showed significant direct effects on BW varied between both the sexes (Table II). In females, four traits (BL, BT, HL, and BH) showed significant direct effects on BW ($P < 0.05$), which ranged from 0.133 (HL) to 0.404 (BL). BL had the largest indirect effect (0.784). In males, six traits (BH, BT, BL, OL, HL, and PA) showed significant direct effects on BW that ranged from -0.133 (OL) to 0.439 (BT). BH had the largest indirect effect (0.926). In both males and females, the indirect effects of all morphometric traits on BW were greater than the direct effects.

The determination coefficients of the morphometric traits on BW are listed in Table III. In the females, the determination coefficient of BL was the largest (0.163), whereas that of the HL was the lowest (0.018). The co-determinant coefficient of BL and BH on BW was found to be the highest, with a value of 0.173. In the males, the determination coefficient of BT was the largest (0.192), whereas that of the OL was the lowest (0.0082). The co-determinant coefficient of BH and BL on BW was found to be the highest, with a value of 0.133. The total determination coefficients in females and males were approximately equal to the multiple correlation coefficients (R^2) (Table IV) thus indicating that these traits significantly affect the BW of female and male *S. argus*.

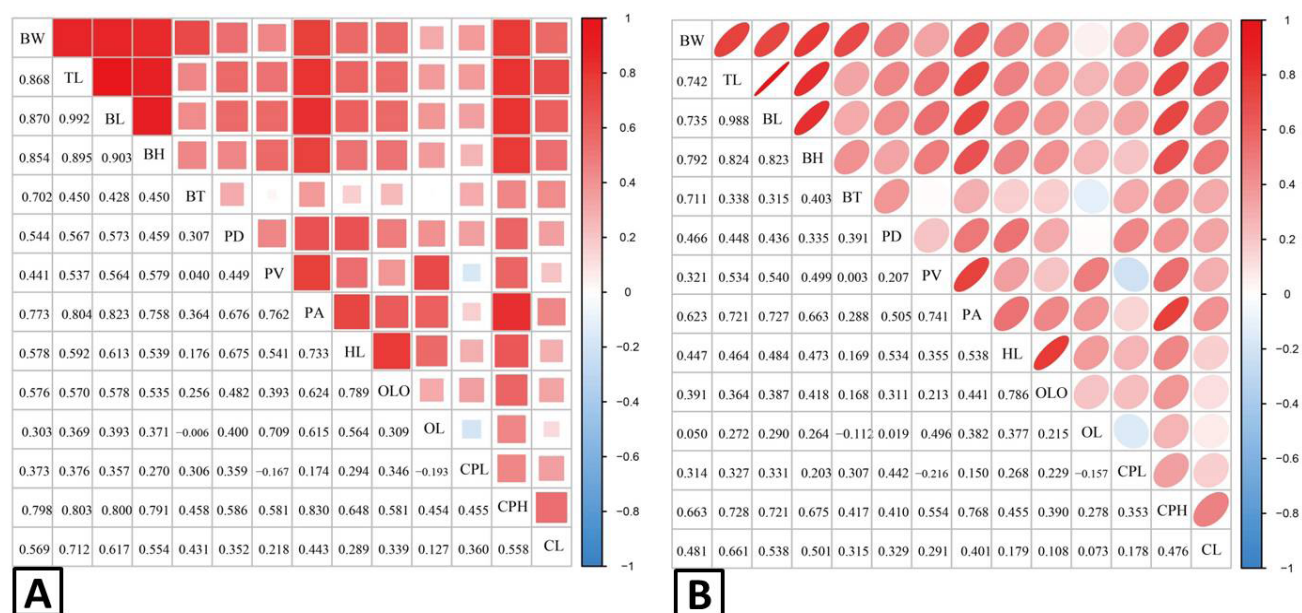


Fig. 3. Phenotypic correlation coefficients among 14 growth traits in *Scatophagus argus*. A, female; B, male.

Table II.- Direct and indirect path coefficients of morphological trait to body weight in female and male *S. argus*.

Gender	Trait	CC ¹	DE ²	IE ³							
				BL	BT	HL	BH	TIE ⁴			
Female	BL	0.868	0.404		0.173	0.247	0.365	0.784			
	BT	0.702	0.399	0.171		0.070	0.180	0.421			
	HL	0.578	0.133	0.081	0.023		0.071	0.176			
	BH	0.854	0.238	0.215	0.107	0.128		0.450			
Male		CC	DE	BH	BT	BL	OL	HL	PA	TIE	
	BH	0.792	0.353		0.142	0.290	0.093	0.167	0.234	0.926	
	BT	0.711	0.439	0.177		0.138	-0.049	0.074	0.126	0.466	
	BL	0.735	0.230	0.093	0.072		0.067	0.111	0.167	0.510	
	OL	0.050	-0.133	-0.054	0.015	-0.039		-0.050	-0.051	-0.178	
	HL	0.447	0.094	0.038	0.016	0.046	0.035		0.051	0.185	
	PA	0.623	0.096	0.039	0.028	0.070	0.037	0.052		0.225	

¹CC, correlation coefficient; ²DE, direct effect; ³IE, indirect effect; ⁴TIE, total of indirect effect. For abbreviations of morphological traits, see Table I.

Table III.- The determination coefficients of morphological traits in male and female fish.

Gender		BL	BT	HL	BH	TDC ¹				
Female	BL	0.163	0.138	0.066	0.173	0.928				
	BT		0.159	0.019	0.102					
	HL			0.018	0.034					
	BH				0.057					
Male		BH	BT	BL	HL	OL	PA	TDC		
	BH	0.124	0.125	0.133	-0.025	0.031	0.045	0.855		
	BT		0.192	0.064	0.013	0.014	0.024			
	BL			0.053	-0.018	0.021	0.032			
	HL				0.018	-0.009	-0.010			
	OL					0.008	0.010			
	PV						0.009			

¹TDC, total determination coefficients. Diagonal data are the direct determinant coefficients of single morphological traits on body weight, and above diagonal data are the indirect determinant coefficients of double morphological traits on BW. For abbreviations of morphological traits, see Table I.

The regression relationship between the morphometric traits and BW of female and male *S. argus* was estimated using a stepwise multiple-regression analysis (Supplementary Table SI). In females, we found that four traits (BL, BT, HL, and BH) showed significant relationships with BW ($P < 0.01$; Table IV; Supplementary Table SII). A best-fit linear multiple regression equation was constructed as follows:

$$Y(BW) = -158.521 + 8.177X_1(BL) + 19.676X_2(BT) + 9.060X_3(HL) + 7.235X_4(BH)$$

While in males, trait BW showed a significant regression relationship to six traits (BH, BT, BL, HL,

OL, PA, and PV) ($P < 0.01$; Table IV; Supplementary Table SIII). A best-fit linear multiple regression equation was constructed as follows:

$$Y(BW) = -113.535 + 11.370X_1(BH) + 13.863X_2(BT) + 4.363X_3(BL) - 28.798X_4(OL) + 6.140X_5(HL) + 2.631X_6(PA)$$

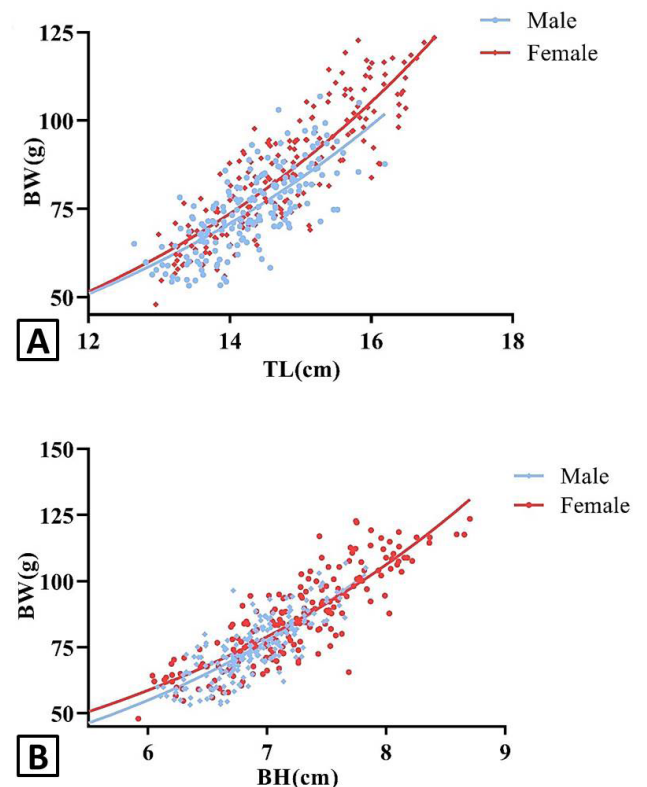


Fig. 4. Length-weight (A) and height-weight (B) relationship between female and male *Scatophagus argus*.

The constants and coefficients of regression equations were tested by the *t*-test, which suggested a significant effect on BW ($P < 0.05$; Table IV; Supplementary Table SIV) in both the sexes.

Table IV.- Analysis of variance (ANOVA) the *t*-test for constant and partial regression coefficients in multiple regression equation of male and female *S. argus*.

Gender	Index	R^2	Partial coefficient	SE	t-value	<i>p</i>
Female	Regression analysis	0.911				0.00
	Multiple correlation					
	Constant		-158.52	5.84	-27.102	0.00
	BL(X1)		8.17	1.08	7.518	0.00
	BT(X2)		19.67	1.19	16.455	0.00
	HL(X3)		9.06	1.87	4.846	0.00
	BH(X4)		7.23	1.54	4.680	0.00
Male	Regression analysis	0.855				
	Multiple correlation					
	Constant		-113.53	7.63	-14.875	0.00
	BH(X1)		11.37	1.69	6.704	0.00
	BT(X2)		13.86	1.01	13.661	0.00
	BL(X3)		4.36	1.04	4.163	0.00
	OL(X4)		-28.79	7.05	-4.082	0.00
	HL(X5)		6.14	2.28	2.684	0.008
	PA(X6)		2.63	1.22	2.147	0.033

The TL-BW and BH-BW relationship between female and male S. argus

Analysis of the TL and BW of *S. argus* in both the sexes showed strong correlations (Fig. 4A). The power regression equations for females and males were $y=5.24 \times 10^{-2} X^{2.74}$ and $y=12.14 \times 10^{-2} X^{2.41}$, respectively. The power regression equations of BH and BW in females and males *S. argus* were $y=1.07 X^{2.21}$ and $y=0.81 X^{2.34}$, respectively (Fig. 4B). The regression coefficient *b* differed non-significantly from isometric growth ($b=3$) in both the sexes ($P > 0.05$), thus exhibiting an isometric growth.

DISCUSSION

Even if enhancing production is one of the key objectives in aquaculture, due to the effects of genetic

linkage, pleiotropy and environmental factors (Wang *et al.*, 2016; Fu *et al.*, 2015; Toro and Newkirk, 1990), it has been proven difficult to achieve satisfactory results in the selected programs, only taking BW into account. However, BW is highly correlated with many other morphological traits (Pérez-Rostro and Ibarra, 2003). Herein, abundant variation was investigated in the 14 morphological traits of *S. argus*. The highest CV was found in the BW trait (15.472 and 19.926% in males and females, respectively), while TL was the lowest in males (CV = 4.792%) followed by females (CV = 6.392%). This high variation in growth traits can provide sufficient materials for economic performance selection (Jiang *et al.*, 2014).

Females were significantly bigger than males when considering 14 traits (BW, TL, BL, BH, BT, PD, PV, PA, HL, OLO, OL, CPL, CPH and CL; $P < 0.01$). This is also in line with the previous research result (Gupta, 2016). This result indicated that females grew significantly faster and bigger than the males in *S. argus*. Similar phenomena were found in bastard halibut (*Paralichthys olivaceus*) (Yoneda *et al.*, 2007), rainbow trout (*Oncorhynchus mykiss*) (Bye and Lincoln, 1986) and European seabass (*Dicentrarchus labrax*) (Saillant *et al.*, 2001). In contrast, males grew faster and bigger than the females in case of yellow catfish (*Pelteobagrus fulvidraco*) (Wang *et al.*, 2009) and Nile tilapia (*Oreochromis niloticus*) (Beardmore *et al.*, 2001).

Correlation analysis indicated that all 13 morphometric traits were significantly correlated with BW in case of both males and females belonging to *S. argus* ($P < 0.01$), thus suggesting its feasibility to pick one target trait by selecting other traits in the artificial breeding of *S. argus* (Ma *et al.*, 2013). Morphological traits are ordinarily employed as a reference for selection in artificial breeding programs (Wang *et al.*, 2016; Liu *et al.*, 2016). In sutchi catfish (*Pangasianodon hypophthalmus*), full length, head width, body width, and depth at the caudal peduncle are closely related to the BW (An *et al.*, 2013). In pompano (*Trachinotus ovatus*), full length, body height, body width, and tail stalk height were found to be the main traits affecting the quality of BW (Cheng *et al.*, 2016).

Using only the correlation coefficient between the morphological characteristics and BW may not fully explain all aspects of the relationship within them, and it necessitates investigation of the causes of these relationships (Xiao *et al.*, 2011). The results of path analysis and regression analysis showed that four (BL, BT, HL, and BH) and six (BH, BT, BL, OL, HL, and PA) morphological traits have significant direct effects on BW ($P < 0.05$) in females and males, respectively. The multiple correlation coefficients between morphological traits and BW were high (more than 0.85) in both females and males, and approximately equal to the determination coefficients.

Furthermore, the four and the six morphological traits could be considered as the key factors affecting BW in both female and male of *S. argus*. According to Wang *et al.* (2013), the main factor affecting BW is the trait that makes individuals have larger geometric spaces. This conclusion has also been verified in aquatic organisms, such as turbot (*Scophthalmus maximus*) (Wang *et al.*, 2008), pompano (*Trachinotus ovatus*) (Ou *et al.*, 2013) and Chinese mitten crab (*Eriocheir sinensis*) (Geng *et al.*, 2007). This may be due to the large geometric space, which is conducive to the accumulation and storage of fat, protein, and other nutrients. In this study, the direct effect of BT on BW was found to be greater than the indirect effect in female spotted scat suggesting that *S. argus* may increase the body surface area through BT, thereby increasing the accumulation of nutrients. The reason for this result may be because of the development of the female ovary that results in swollen abdomen.

CONCLUSIONS

In this study, we investigated the differences in morphometric traits between females and males, the correlation between 14 morphometric traits, and the direct and indirect effects of morphological traits on BW in *S. argus*. Using these methods, four and six morphometric traits were identified having significant effects on the BW of females and males. A multiple regression equation was constructed with respect to the BW and morphological traits in females and males separately. This knowledge will provide useful and valuable information in better understanding of the differences between sexes, relationships between growth traits and artificial selective breeding in *S. argus*, and other closely related species through identification traits related to BW and other important economic traits.

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Supplementary material

There is supplementary material associated with this article. Access the material online at: <https://dx.doi.org/10.17582/journal.pjz/20210305150335>

Statement of conflict of interest

The authors have declared no conflict of interests.

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