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CORRELATION AND PATH ANALYSIS OF MORPHOLOGICAL TRAITS AND BODY WEIGHT IN SILVER POMFRET (*Pampus argenteus*)

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ABSTRACT

Silver pomfret (*Pampus argenteus*) is an important economic fish for aquaculture industry in China and Southeast Asian countries. The relationship between twelve morphological traits of *P. argenteus* were studied at different growth stages [60-, 90-, 120-, and 360-days post hatching (dph)] by using correlation, path analyses, and multiple linear regression tools. The results showed that coefficient of variation of the body weight and trunk length traits remained stable and at a high level across all age groups (all above 20%), while other traits were the opposite. The body length and tail length traits had great direct effect on the body weight of *P. argenteus* at the first three growth stages (60, 90, and 120 dph). However, body length and body height traits had great direct effect in 360 dph, and the direct effect coefficient of caudal length was negative, indicating that the trait had a negative effect on body weight. Multiple linear regression analysis between morphological traits and body weight indicated that R^2 was greater than 0.84 across all age groups ($P \leq 0.05$). The optimal multiple linear regression equations, as determined with stepwise regression, were constructed with morphological traits as independent variables and body weight as dependent variables. These results elucidated the linear relationship between the body weight and various main morphological traits of *P. argenteus* at different growth stages. In actual production, during mass selection of *P. argenteus* with body weight as the main objective, the recommended as auxiliary selection traits were the body length, body height, tail length, and caudal length traits. These results can provide a reference basis for the measurement of target traits for the selective breeding of new varieties of *P. argenteus*.

Key Words: *Pampus argenteus*, morphological traits, correlation analysis, path analysis, multiple linear regression.

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INTRODUCTION

Silver pomfret (*Pampus argenteus*) (Euphrasen, 1788) belongs to Osteichthyes, Pereiformes, Stromaeoidei, Stromateidae, and *Pampus*, which is mainly distributed from the Indian Ocean to the western Pacific Ocean, especially the coastal areas of China, North Korea to Western Japan, the Bay of Bengal, and the Persian Gulf of India (Davis and Wheeler 1985; Zhao *et al.,* 2011; Mohitha *et al.,* 2015; AlMomin *et al.,* 2016). The *P. argenteus* is a marine economic fish, that has popularity among consumers due to delicious meat and high amount of unsaturated fatty acids *viz.* EPA and DHA (Xu *et al.,* 2012). However, in recent 30 years, the annual output of *P. argenteus* in China has been about 50,000 tonnes, all of which are marine fishing. The wild *P. argenteus* tends to be miniaturized at younger age (Li *et al.,* 2014). In order to meet the market demand of *P. argenteus*, the researchers worked on the artificial culture technology (Liao *et al.,* 2017; Akhter *et al.,* 2020; Al-Abdul-Elah *et al.,* 2021), however, the situation of *P. argenteus* "Leaving the sea will lead to its death" has not been broken that slows down the progress on artificial breeding research (Zhou and Yu 2017). In an effort to resolve these issues, our team developed a new technique of artificial breeding of *P. argenteus* (Weng *et al.,* 2017; Zhang *et al.,* 2022), it can lay a foundation for future genetic breeding of this fish species.

In the 1950s, China initiated research on artificial breeding and industrial cultivation technology of main mariculture species such as prawns, shellfish, and fish. The effort resulted in the cultivation of numerous exceptional new varieties, significantly advancing mariculture development (Bao *et al.,* 2002; Huang and Wang 2002; Hong *et al.,* 2018). Such as, *Penaeus chinensis* "Huanghai No.4", *Sinonovacula constricta* "Yongle No.1", *Pseudosciaena crocea* "Yongdai No.1". These new varieties have demonstrated substantial economic benefits. However, the selective breeding of new varieties for *P. argenteus* was still in its early stages. Consequently, our team initiated mass selection for *P. argenteus*, focusing on body weight as the target trait for selective breeding. This approach aims to cultivate a new variety with rapid growth and substantial size (Zhang *et al.* 2022; Huang *et al.,* 2023). Body weight is a common indicator in genetic breeding, and the path analysis of body weight combined with morphological traits can significantly enhance the efficiency of mass selection (Song *et al.,* 2017; Zhao *et al.,* 2017). The exploration of the relationship between morphological traits and body weight to identify target traits has been widely applied in selective breeding, particularly in aquatic species (Luxinger *et al.,* 2018; Lago *et al.,* 2019). For example, Dong *et al.,* (2018) analyzed the correlation between main morphological traits and body weight of *Siniperca chuatsi*, identifying total length and body height as having the most direct impact on body weight. Liu *et al.,* (2021) discovered a positive correlation between body diameter, body height, and live weight of *Strongylocentrotus intermedius* with gonad development scores. Wang *et al.,* (2016) established that the highest correlation coefficient between body length and body weight of *Lateolabrax maculatus* existed. Li *et al.,* (2019) determined the body weight of *Hexagrammos otakii* was influenced by body length, head length, total length, and body height traits. However, the manual measurement of morphological traits in *P. argenteus* posed challenges, as the species was easily frightened or harmed by such operations, hindering the cultivation process. Identifying morphological traits significantly linked to body weight would not only facilitate the protection of breeding objects but also enhance practical breeding efforts and improve efficiency.

Therefore, this study aimed to explore the correlation relationships among key morphological traits and identify effective indicators applicable in selective breeding programs for *P. argenteus*. Through correlation and path analyses, we examined the correlation relationships between body weight and various morphometric traits. Furthermore, multiple linear regression analysis was employed to construct optimal multiple linear regression equations. These findings offer valuable insights that can support selection activities in this species.

MATERIALS AND METHODS

P. argenteus **culture:** Twenty thousands *P. argenteus* larval was collected from May to June 2016 in the coastal waters of Taizhou, Zhejiang Province (Fishing Area No.209 of China). These larvae were then farmed at the Xiangshan harbor aquaculture and larva company limited, Ningbo, China. *P. argenteus* typically reaches sexual maturity at one year and exhibits normal reproductive behavior. In 2019, we randomly selected 3,000 fish fries from the third generation of artificial breeding. These fries were then transferred to the breeding base of Zhejiang Marine Fisheries Research Institute in Zhoushan City, Zhejiang Province (28°31′56″N, 122°12′24″E) and were cultured until 2022. Throughout the entire experiment, the experimental samples were cultured in indoor cement pools measuring 25 m^2, with a water depth of 1.4 m. The daily water exchange rate ranged from 100% to 220%, and appropriate micro-flow water conditions were maintained. The feed amounts constituted approximately 3-4% of the fish weight, with the pH value ranging from 7.8 to 8.2, water temperature between 15 °C and 28 °C, salinity maintained at about 25, and dissolved oxygen kept at 7 mg L^{-1}. *P. argenteus* is known to be sensitive to light, necessitating the control of light intensity with adjustable LED lamp. The light intensity was set to 100 lx at 6:30, 200 lx at 10:30-16:30, 50 lx at 16:30-22:30, and the lowest 5 lx after 22:30 in the evening (Tian 2014). The feeding information of *P. argenteus* from larval to weaning, pre-growth, and growing is described in Table 1 (Zhang *et al.* 2022).

Trait measurements: During the periods of 60, 90, and 120 dph, we randomly selected 50 *P. argenteus* specimens to measure the morphological traits. Additionally, we measured the morphological traits of 241 samples of 360-days *P. argenteus*. To standardize the measurements, *P. argenteus* was abstained from feeding one day before measurement. Initially, absorbent paper was used to remove surface water from *P. argenteus*, and their body weight (W) was measured using a digital electronic weight scale (accurate to 0.01 g). Subsequently, a digital camera was employed to capture images of the measured specimens. Digimizer Version 5.4.4 software was used to measure various morphological traits of *P. argenteus*, including total length (X_1), fork length (X_2), body length (X_3), body height (X_4), head length (X_5), snout length (X_6), eye diameter (X_7), trunk length (X_8), caudal length (X_9), caudal height (X_{10}), and tail length (X_{11}) (accurate to 0.01 mm). To avoid user bias, the measurements were conducted by the same researcher. The measurement methods for various morphological traits are shown in **Figure 1**.

Table 1. Feeding sequence and feeding amount of *P. argenteus* seedlings during the whole breeding stage.

Birth day	body length of the fish/mm	Bait Types	Feeding amount	Feeding time
Start feeding - 10 d	< 10	rotifer	3 - 10 individuals/mL	7.00 am, 10.30 am, 1.30 pm and 5.00 pm
10 - 18 d	10 – 15	rotifer	10 - 15 individuals/mL	
		Artemia nauplii	0.5 - 2 individuals/mL	
		jellyfish seedlings	umbrella diameter < 3 mm	
		3# YuBao Compound Feed	-	
18 - 23 d	15 – 18	Artemia nauplii	0.5 - 2 individuals/mL	
		copepods	0.5 - 1 individuals/mL	
		jellyfish seedlings	umbrella diameter < 5 mm	
		3# and 4# YuBao Compound Feed	-	
23 - 45 d	18 – 25	copepods	0.5 - 1 individuals/mL	
		jellyfish seedlings	umbrella diameter < 8 mm	
		4# and 5# YuBao Compound Feed	-	
45 - 60 d	> 25	jellyfish seedlings	umbrella diameter < 12 mm	
		5# YuBao Compound Feed	-	
60 - 90 d		6# YuBao Compound Feed	-	
> 90 d		7# YuBao Compound Feed	-	

Note: YuBao Compound Feed were purchased from Hayashikane Sangyo Co., Ltd. Feed Business Division Chofu Plant, Japan.

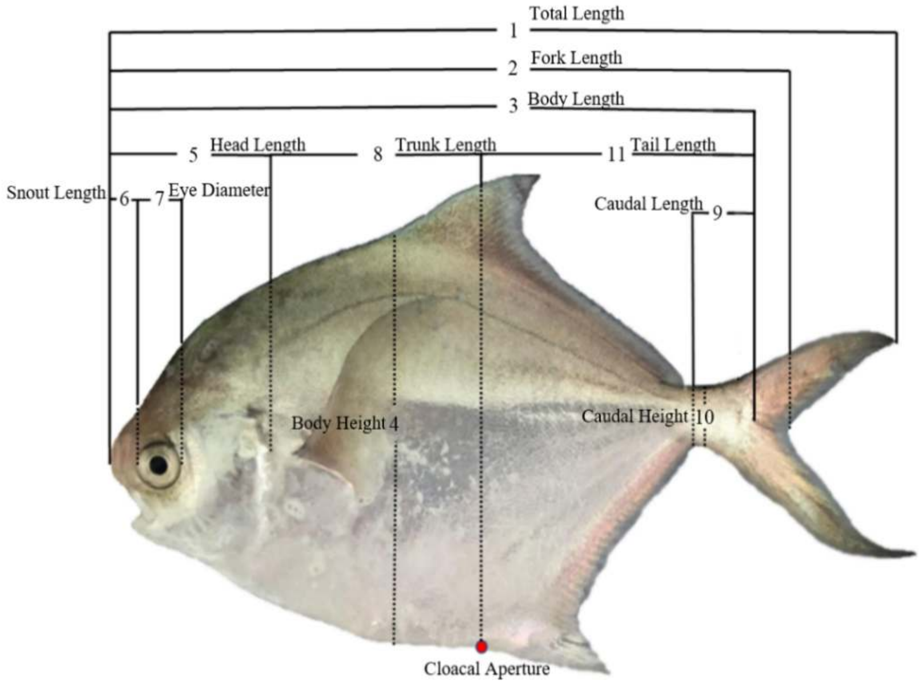

Figure 1 Measurement standard of various morphological characteristics of one-year-old *P. argenteus*.

Data analysis: The morphological data was analyzed using Microsoft Excel 2016 and SPSS 22.0. Prior to statistical analysis, a Kolmogorov-Smirnov test was conducted to assess data normality. For data exhibiting non-normal distribution, a base-10 logarithmic transformation (lg) was applied. Growth traits data was used to analysis using One-way ANOVA. A significance level of $P \leq 0.05$ was considered statistically significant, while $P \leq 0.01$ was deemed extremely significant. The coefficient of variation (CV) of each trait was calculated using the formula: CV = (standard deviation / mean) × 100%.

To explore the correlation relationship between morphological traits and body weight, Pearson coefficients were utilized for correlation analysis. Subsequently, multiple regression analysis was employed to determine the path coefficients between the measured morphological traits and body weight. Further, stepwise multiple regression was conducted to determine regression equations for the optimal prediction of body weight. In this analysis, the body weight trait served as the dependent variable while each measured morphological trait was treated as an independent variable. Non-significant morphological variables were progressively eliminated to establish multiple regression equations for body weight.

RESULTS

Descriptive result analysis of morphological traits of *P. argenteus:* During the four growth stages (60, 90, 120, and 360 dph), a preliminary analysis of the morphological data of *P. argenteus* was conducted. Among them, the coefficients of variation for the body weight and trunk length traits of *P. argenteus* were consistently above 20% at 60 and 120 dph, exceeding those of the other 10 morphological traits. Additionally, at 90 dph, only the coefficient of variation for the body weight trait in *P. argenteus* exceeded 20%. At 360 dph, the coefficients of variation for trunk length and snout length traits were above 20%, with the coefficient of variation for the body weight trait reaching 32.20%. This value was notably higher than that of the remaining morphological traits (Table 2). The K-S test indicated that the body weight of *P. argenteus* was non-normally distributed at 120 and 360 dph. Similarly, head length at 60 dph, body height at 120 dph, and total length, fork length, body length, body height, head length, and tail length at 360 dph were also non-normally distributed. Subsequently, all values were subjected to base-10 logarithms (lg) transformation, resulting in a normal distribution for all traits after the conversion.

Pearson correlation analysis: Pearson correlation analysis was conducted on the morphological traits of the different-aged *P. argenteus*. At 60 dph, there was no significant difference in the Pearson correlation coefficient between the trunk length and body weight traits of *P. argenteus* ($P > 0.05$). However, there were significant differences between the other 10 morphological traits and body weight ($P \leq 0.05$). After 90 days of hatching, except for the eye diameter trait, there were significant differences in Pearson correlation coefficients between the other 10 morphological traits and body weight ($P \leq 0.05$). At 120 dph, there were significant correlations between all 11 morphological traits and body weight ($P \leq 0.05$). At 360 dph, there was no significant difference in the Pearson correlation coefficient between the eye diameter and body weight traits ($P > 0.05$), but there were significant or extremely significant differences between the other 10 morphological traits and body weight ($P \leq 0.01$). Notably, the Pearson correlation coefficient between the body height and body weight traits was the highest, while the correlation between the eye diameter and body weight traits was the lowest (Table 3).

Path coefficients: The stepwise selection method was employed for multiple linear regression analysis on various morphological traits, treating each morphological trait as an independent variable and body weight as the dependent variable. SPSS 22.0 software was used to diagnose collinearity among independent variables. Morphological traits exhibiting serious collinearity or insignificant influence on body weight were eliminated ($P > 0.05$), while traits with extremely significant correlation with body weight were retained for multiple linear regression analysis. For 60-, 90-, and 120-dph *P. argenteus*, the body length and tail length traits were retained, while the other 9 morphological traits with serious collinearity were eliminated. For 360-dph *P. argenteus*, three morphological traits (namely, body length, body height, and caudal length traits) were retained, and their relationships with the body weight were extremely significant ($P \leq 0.01$). According to the composition effect, the correlation coefficient between morphological traits and body weight of *P. argenteus* was categorized into direct and indirect effects. In terms of direct effect, for 60-, 90-, and 120-dph *P. argenteus*, the body length trait had coefficients of 0.497, 0.662, and 0.573, respectively, and for tail length, the coefficients were 0.493, 0.345, and 0.397, respectively. For 360-dph *P. argenteus*, body length (0.507) had the greatest direct effect on body weight, followed by body height (0.481), and the direct effect coefficient of caudal length was negative (-0.076). For indirect effect, the trends were consistent for the three growth stages (60, 90, and 120 dph), with the indirect effect of body length trait being greater than that of tail length trait. For 360-dph *P. argenteus*, the indirect effect of caudal length was the largest (0.556), followed by body height (0.401) and body length (0.372). The Variance Inflation Factor (VIF) was utilized as a measure of collinearity among predictor variables within multiple regression, and the greater the value of VIF, the more serious its multicollinearity (O'Brien 2007). However, the VIF values of the retained morphological traits on body weight were lower than the empirical values (VIF = 10), which indicated that the estimation of direct effect and indirect effect of each retained morphological trait and the construction of the regression model did not exhibit multicollinearity. Therefore, the results were deemed reliable (Table 4).

Table 2. Descriptive statistics and normality of twelve morphological traits of *P. argenteus* at 60, 90, 120, and 360 dph.

dph	Parameters	*W*/g	X_1/mm	X_2/mm	X_3/mm	X_4/mm	X_5/mm	X_6/mm	X_7/mm	X_8/mm	X_9/mm	X_{10}/mm	X_{11}/mm
60	Mean	16.76	102.29	87.84	80.61	53.15	20.36	3.36	6.01	7.69	9.38	6.97	53.15
	SD	3.39	5.81	4.91	4.52	3.69	1.48	0.45	0.36	1.64	0.82	0.49	2.80
	CV/%	20.23%	5.68%	5.59%	5.61%	6.94%	7.29%	13.52%	6.00%	21.29%	8.69%	7.02%	5.33%
	K-S test Z	0.09	0.15	0.13	0.07	0.12	0.18	0.15	0.14	0.09	0.11	0.07	0.08
	P	0.20	0.09	0.20	0.20	0.20	0.01	0.06	0.15	0.20	0.20	0.20	0.20
90	Mean	21.38	111.87	95.41	86.62	56.30	20.85	3.46	6.32	9.37	9.86	7.67	56.41
	SD	4.32	7.88	6.33	5.82	4.07	1.69	0.47	0.44	1.90	1.33	.58	4.20
	CV/%	20.22%	7.05%	6.64%	6.72%	7.23%	8.09%	13.74%	7.02%	20.24%	13.54%	7.51%	7.44%
	K-S test Z	0.08	0.08	0.08	0.08	0.08	0.07	0.09	0.07	0.06	0.06	0.07	0.10
	P	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
120	Mean	27.74	134.37	115.26	105.66	68.44	24.71	3.99	7.13	12.57	11.98	9.62	68.38
	SD	7.80	9.97	9.10	8.92	6.00	1.67	0.52	0.59	2.93	1.47	0.81	6.07
	CV/%	28.12%	7.42%	7.89%	8.44%	8.76%	6.77%	13.09%	8.25%	23.27%	12.27%	8.50%	8.88%
	K-S test Z	0.16	0.11	0.12	0.11	0.14	0.08	0.09	0.08	0.09	0.08	0.08	0.06
	P	0.01	0.20	0.09	0.20	0.03	0.20	0.20	0.20	0.20	0.20	0.20	0.20
360	Mean	66.50	161.62	136.85	127.33	76.13	28.89	5.92	7.58	17.77	14.27	11.01	80.67
	SD	21.41	16.04	13.53	12.84	8.50	3.07	1.25	1.00	4.65	2.23	1.56	9.06
	CV/%	32.20%	9.92%	9.89%	10.08%	11.17%	10.63%	21.11%	13.19%	26.17%	15.63%	14.17%	11.23%
	K-S test Z	0.11	0.06	0.06	0.06	0.07	0.07	0.06	0.05	0.05	0.05	0.04	0.08
	P	0.01	0.02	0.02	0.04	0.01	0.01	0.07	0.2	0.09	0.08	0.2	0.01

W: body weight, X_1: total length, X_2: fork length, X_3: body length, X_4: body height, X_5: head length, X_6: snout length, X_7: eye diameter, X_8: trunk length, X_9: caudal length, X_{10}: caudal height, X_{11}: tail length, SD: standard deviation, CV: coefficient of variation, K-S test: Kolmogorov-Smirnov test

Table 3. Correlation analyses and significance test among morphological traits of *P. argenteus* at 60, 90, 120, and 360 dph.

dph	Traits	*W*	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}
60 d	X_1	0.925^{**}											
	X_2	0.920^{**}	0.966^{**}										
	X_3	0.954^{**}	0.939^{**}	0.942^{**}									
	X_4	0.866^{**}	0.802^{**}	0.781^{**}	0.835^{**}								
	X_5	0.439^{*}	0.466^{**}	0.495^{**}	0.522^{**}	0.295							
	X_6	0.825^{**}	0.820^{**}	0.818^{**}	0.868^{**}	0.646^{**}	0.103						
	X_7	0.365^{*}	0.332	0.286	0.305	0.580^{**}	-0.163	0.28					
	X_8	0.144	0.157	0.152	0.142	0.385^{*}	-0.074	0.069	0.202				
	X_9	0.397^{*}	0.373^{*}	0.325	0.404^{*}	0.451^{*}	0.197	0.299	0.500^{**}	0.04			
	X_{10}	0.441^{*}	0.372^{*}	0.378^{*}	0.372^{*}	0.412^{*}	0.195	0.269	0.372^{*}	0.214	0.204		
	X_{11}	0.953^{**}	0.886^{**}	0.895^{**}	0.925^{**}	0.837^{**}	0.438^{*}	0.796^{**}	0.290	0.229	0.377^{*}	0.515^{**}	

90 d	X_1	0.853^{**}										
	X_2	0.887^{**}	0.948^{**}									
	X_3	0.886^{**}	0.907^{**}	0.976^{**}								
	X_4	0.495^{**}	0.578^{**}	0.573^{**}	0.592^{**}							
	X_5	0.378^{**}	0.336^{*}	0.430^{**}	0.457^{**}	-0.151						
	X_6	0.859^{**}	0.873^{**}	0.928^{**}	0.942^{**}	0.486^{**}	0.242					
	X_7	0.272	0.431^{**}	0.424^{**}	0.459^{**}	0.780^{**}	0.052	0.300^{*}				
	X_8	0.393^{**}	0.492^{**}	0.495^{**}	0.504^{**}	0.366^{**}	0.219	0.453^{**}	0.367^{**}			
	X_9	0.322^{*}	0.463^{**}	0.515^{**}	0.579^{**}	0.227	0.320^{*}	0.566^{**}	0.293^{*}	0.366^{**}		
	X_{10}	0.795^{**}	0.736^{**}	0.729^{**}	0.689^{**}	0.289^{*}	0.320^{*}	0.695^{**}	0.142	0.306^{*}	0.249	
	X_{11}	0.944^{**}	0.793^{**}	0.834^{**}	0.819^{**}	0.440^{**}	0.322^{*}	0.812^{**}	0.218	0.345^{*}	0.256	0.792^{**}
120 d	X_1	0.883^{**}										
	X_2	0.930^{**}	0.961^{**}									
	X_3	0.939^{**}	0.944^{**}	0.983^{**}								
	X_4	0.699^{**}	0.716^{**}	0.772^{**}	0.791^{**}							
	X_5	0.543^{**}	0.643^{**}	0.630^{**}	0.641^{**}	0.307^{*}						
	X_6	0.925^{**}	0.879^{**}	0.927^{**}	0.942^{**}	0.738^{**}	0.375^{*}					
	X_7	0.374^{*}	0.279	0.327^{*}	0.360^{*}	0.592^{**}	0.066	0.335^{*}				
	X_8	0.363^{*}	0.357^{*}	0.404^{**}	0.376^{*}	0.355^{*}	0.14	0.387^{**}	0.097			
	X_9	0.699^{**}	0.748^{**}	0.780^{**}	0.798^{**}	0.683^{**}	0.459^{**}	0.764^{**}	0.330^{*}	0.249		
	X_{10}	0.807^{**}	0.796^{**}	0.800^{**}	0.797^{**}	0.636^{**}	0.444^{**}	0.781^{**}	0.416^{**}	0.285	0.717^{**}	
	X_{11}	0.925^{**}	0.854^{**}	0.918^{**}	0.922^{**}	0.695^{**}	0.526^{**}	0.909^{**}	0.275	0.461^{**}	0.679^{**}	0.763^{**}
360 d	X_1	0.874^{**}										
	X_2	0.872^{**}	0.965^{**}									
	X_3	0.879^{**}	0.965^{**}	0.991^{**}								
	X_4	0.884^{**}	0.871^{**}	0.865^{**}	0.871^{**}							
	X_5	0.514^{**}	0.584^{**}	0.618^{**}	0.627^{**}	0.506^{**}						
	X_6	0.135^{*}	0.228^{**}	0.247^{**}	0.256^{**}	0.089	0.741^{**}					
	X_7	0.094	0.201^{**}	0.201^{**}	0.220^{**}	0.125	0.491^{**}	0.493^{**}				
	X_8	0.564^{**}	0.540^{**}	0.551^{**}	0.564^{**}	0.566^{**}	0.101	-0.120	-0.071			
	X_9	0.480^{**}	0.574^{**}	0.594^{**}	0.620^{**}	0.504^{**}	0.413^{**}	0.211^{**}	0.313^{**}	0.288^{**}		
	X_{10}	0.601^{**}	0.548^{**}	0.577^{**}	0.574^{**}	0.606^{**}	0.296^{**}	-0.034	-0.141^{*}	0.398^{**}	0.255^{**}	
	X_{11}	0.782^{**}	0.894^{**}	0.913^{**}	0.916^{**}	0.772^{**}	0.499^{**}	0.173^{**}	0.182^{**}	0.252^{**}	0.591^{**}	0.509^{**}

**: very significant correlation ($P \leq 0.01$), *: significant correlation ($P \leq 0.05$). W: body weight, X_1: total length, X_2: fork length, X_3: body length, X_4: body height, X_5: head length, X_6: snout length, X_7: eye diameter, X_8: trunk length, X_9: caudal length, X_{10}: caudal height, X_{11}: tail length

Table 4. Direct and indirect effects of morphometric traits on body weight of *P. argenteus.*

dph	Traits	Correlation coefficient	Direct effect	Indirect effects				VIF
				X_3	X_4	X_9	X_{11}	
60	X_3	0.954^{**}	0.497	-			0.441	6.961
	X_{11}	0.953^{**}	0.493	0.445			-	6.961
90	X_3	0.886^{**}	0.662	-			0.288	0.33
	X_{11}	0.944^{**}	0.345	0.552			-	0.33
120	X_3	0.939^{**}	0.573	-			0.364	6.635
	X_{11}	0.925^{**}	0.397	0.526			-	6.635
360	X_3	0.879^{**}	0.507^{**}	-	0.419	-0.047	-	5.040
	X_4	0.884^{**}	0.481^{**}	0.439	-	-0.038	-	4.163
	X_9	0.480^{**}	-0.076^{*}	0.314	0.242	-	-	1.637

X_3: body length, X_4: body height, X_9: caudal length, and X_{11}: tail length

Multiple linear regression analysis: As the independent variables were progressively incorporated into the regression equation, the correlation coefficient *R* values of the regression equation steadily increased, as detailed in Table 5. Clearly, the model's fitting effect improved continuously, signifying that the inclusion of independent variables in the model could more accurately explain their impact on body weight. In addition, optimal multiple linear regression equations were formulated for the four growth stages. The partial regression coefficients (*i.e.,* non-standardized regression coefficients) of each independent variable were subjected to significance testing. The results showed that the intercept test results (-37.360, -40.369, 0.139, and -3.895) reached significant level ($P \leq 0.05$) at the 60, 90, 120, and 360 dph. Therefore, it can be inferred that the multiple linear regression equations were valid. Furthermore, F-tests were conducted to evaluate the multiple linear regression equations of these four growth stages, and the results showed that the regression equations of the four growth stages reached an extremely significant level ($P \leq 0.01$), indicating that the constructed regression equations were statistically significant (Table 6). From this, optimal multiple linear regression equations were constructed with morphological traits as independent variables and body weight as the dependent variables. The results are as follows:

$W = -37.360 + 0.373X_3 + 0.453X_{11}$ (60 dph, $R^2 = 0.940$)
$W = -40.369 + 0.703X_3 + 0.256X_{11}$ (90 dph, $R^2 = 0.930$)
$W = 10^{(0.139 + 0.008X_3 + 0.007X_{11})}$ (120 dph, $R^2 = 0.905$)
$W = 10^{(-3.895 + 1.644 \times \lg(X_3) + 1.227 \times \lg(X_4) - 0.005X_9)}$ (360 dph, $R^2 = 0.842$)

Table 5. The determinant coefficients of the morphological traits on body weight of *P. argenteus* *

dph	Model	*R*	*R* Square	Adjusted *R* Square	Std.Error of the Estimate
60	1	0.954^{a}	0.909	0.906	1.038
	2	0.972^{b}	0.940	0.94	0.828
90	1	0.944^{a}	0.891	0.888	1.445
	2	0.964^{b}	0.930	0.927	1.17
120	1	0.939^{a}	0.882	0.879	2.714
	2	0.952^{b}	0.905	0.901	2.455
360	1	0.884^{c}	0.782	0.781	10.016
	2	0.912^{d}	0.831	0.830	8.835
	3	0.914^{e}	0.842	0.833	8.760

a. Predictors: Constant, body length, b. Predictors: Constant, body length, tail length. c. Predictors: Constant, body height; d. Predictors: Constant, body height, body length; e. Predictors: Constant, body height, body length, caudal length; * dependent variate: body weight

Table 6. Regression coefficients of morphological traits on body weight of *P. argenteus*[*]

Dph	Model		Unstandardized Coefficients		Standardized Coefficients		Sig.
			B	Std.Error	Beta	*T*	
60	2	(Constant)	-37.36	2.821		-13.241	0.000
		X_3	0.373	0.088	0.497	4.228	0.000
		X_{11}	0.453	0.108	0.493	4.197	0.000
90	2	(Constant)	-40.369	2.54		-15.891	0.000
		X_3	0.703	0.072	0.662	9.827	0.000
		X_{11}	0.256	0.05	0.345	5.119	0.000
120	2	(Constant)	0.139	0.041		0.820	0.000
		X_3	0.008	0.001	0.798	7.377	0.000
		X_{11}	0.007	0.002	0.172	1.589	0.002
360	3	(Constant)	-3.895	0.174		-21.748	0.000
		X_3	1.644	0.174	0.544	9.403	0.000
		X_4	1.227	0.145	0.447	8.456	0.000
		X_9	-0.005	0.004	-0.075	-2.281	0.023

[*] Dependent variate: body weight, X_3: body length, X_4: body height, X_9: caudal length, and X_{11}: tail length

DISCUSSION

The observed high correlations between morphological traits in marine fishes with relatively fixed body shapes, such as *Pagrus major* (Kora *et al.,* 2000), *Paralichthys olivaceus* (Chen *et al.,* 2016), *Lateolabrax maculatus* (Wang *et al.* 2016), and *Nibea albiflora* (Zhu *et al.,* 2018), are consistent with the traits observed in *P. argenteus*. Like many marine fishes, the morphological traits of *P. argenteus* from juvenile to adult stage are highly correlated. However, in this study, we didn't mention the correlation relationship between body weight and other morphological traits of 30-dph *P. argenteus* as they had not yet reached the juvenile stage. At this stage, when *P. argenteus* is exposed to air or stimulated, it tends to secrete a significant amount of mucus on its body surface, which affected the accuracy of measurement to some extent because of its small body weight base. At the same time, *P. argenteus* without scales was easy to die after measurement, which may lead to unnecessary economic losses. Therefore, we focused on analyzing the correlation relationship between body weight and other morphological traits of *P. argenteus* at the four growth stages (60, 90, 120, and 360 dph). In this study, the CVs of the body weight and trunk length of *P. argenteus* were high, with the CVs for body weight steadily increased with age, while the CVs of the trunk length trait remained stable. The CVs for the remaining morphological traits measured exhibited variations with age, but these fluctuations were minor. High CVs indicate that a trait may possess sufficient genetic diversity to support selective breeding (Gjedrem and Baranski 2009), indicating that the body weight and trunk length traits of *P. argenteus* could be used as a potential breeding trait for selective breeding. Furthermore, through correlation analysis between morphological traits and body weight, we found that the body length and tail length traits of *P. argenteus* significantly correlated with body weight at the three growth stages (60, 90, and 120 dph), while body length, body height, and caudal length traits of 360-dph *P. argenteus* were significantly correlated with body weight. Although the Pearson correlations between retained morphological traits and body weight of *P. argenteus* were high, the retained morphological traits at the four growth stages were different. Considering that the experimental samples were cultured in the same pond with identical environmental factors, we speculated that the main reason was probably caused by genotype.

The path analysis method was employed to conduct a detailed examination of the direct and indirect effects on the morphological traits and body weight in *P. argenteus*. In this study, for the 60-, 90-, and 120-dph *P. argenteus*, the body length and tail length traits were retained, and we found that the direct effects of the same traits were larger than the indirect effects, with the direct effect of body length trait in the same period being greater than that of tail length trait. This indicated that both body length and tail length traits had significant influence on the body weight of *P. argenteus* during the initial three growth stages, with the body length trait being relatively more important. For 360-dph *P. argenteus*, three morphological traits (namely, body length, body height, and caudal length traits) were retained, and we found that the body length trait had the largest direct effect on body weight, followed by body height. Notably, the caudal length exhibited a negative direct effect coefficient, indicating a negative effect on body weight. Despite being the same group of fish, the correlation relationship between body weight and morphological traits changed with increasing age. Similar phenomena have been observed in other aquatic animals. For example, Liu *et al.,* (2018) studied the correlation relationship between morphological traits and body mass of *Scophthalmus maximus* at different growth stages and found that the path coefficients of total length, body height, body width, head length traits for body weight were significant at six months old, while the path coefficients of total length, body width, tail handle height traits were extremely significant at 14 months old. Zhan *et al.,* (2019) measured live body weight, body length, numbers of papillae, and numbers of tube feet of *Apostichopus japonicus* at 60, 80, 100, and 130 dph, revealing that the body length trait had the greatest direct effect on body weight across all age groups, while the numbers of tube feet had the greatest indirect effect on body weight. The direct effect of tube feet trait became more important with increasing age, while the effect of papillae trait showed the opposite trend. Therefore, purposeful analysis of the correlation between these traits can provide essential data support for genetic breeding of excellent varieties.

In the analysis of multiple linear regression, the standardized regression coefficients of two morphological traits (namely, body length and tail length traits) and body weight of *P. argenteus* reached extremely significant levels at 60, 90, and 120 dph ($P \leq 0.01$). The standardized regression coefficients of three morphological traits (namely, body length, body height and caudal length traits) and body weight of 360-dph *P. argenteus* reached significant levels ($P \leq 0.05$). These results indicated that the optimal multiple linear regression equations were statistical significance. It was appropriate to use morphological traits as independent variables for predicting and estimating body weight, a common practice in many marine fish studies (Liu *et al.,* 2010; Chen *et al.* 2016; Huang *et al.,* 2017; Liu *et al.* 2018). For instance, Liu *et al.,* (2016) thought it feasible to evaluate the body weight of *Pseudosciaena polyactis* using the body length, trunk length and caudal height traits as independent variables. Zhu *et al.* (2018) believed it reliable to estimate and predict the body weight of *Nibea albiflora* utilizing total length, body height, body thickness and tail length traits as independent variables. Fang *et al.,* (2021) considered that it was appropriate to estimate and predict the body weight of *Thunnus albacores* with total length, head length, maxillary length and pectoral fin length traits as independent variables. Therefore, it was feasible to select the body weight of *P. argenteus* using the retained morphological traits, that is, these four optimal multiple linear regression equations can describe the correlation relationship between morphological traits and body weight and can be used for the artificial breeding of *P. argenteus*. In the future, we will supplement the growth data of *P. argenteus* at 150, 180 dph and other growth periods to analysis the correlation relationship between morphological traits and body weight of *P. argenteus* in different growth stages more comprehensively, aiming to provide essential data for the selective breeding of *P. argenteus*. To summarize, this study thought that body weight should be the main objective, with body length, body height tail length, and caudal length traits as auxiliary selection traits in the breeding of new varieties of *P. argenteus*. The above analysis results provided a theoretical basis for determining the selective breeding measurement indicators of *P. argenteus*.

Conclusion: To enhance the breeding efficiency of *P. argenteus*, this study investigated correlations between morphological traits and body weight across different growth stages. These results indicated that, during mass selection of 60-, 90-, and 120-dph *P. argenteus* with body weight as the main objective, the recommended as auxiliary selection traits were the body length and tail length traits. Similarly, for mass selection of 360-dph *P. argenteus* with body weight as the main objective, the recommended as auxiliary selection traits included the body length, body height, and caudal length traits. Moreover, based on the data of the correlation between these morphological traits and body weight, optimal multiple linear regression equations were constructed for different growth stages. In summary, this refined approach provides tools to improve the reliability and effectiveness of breeding plans, and helping to strengthen the breeding practices of *P. argenteus*.

Conflict of Interest: The author declares no potential conflict of interest.

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