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Correlation and Path Coefficient Analyses of the Morphological Characteristics and Body Weight of *Penaeus monodon* (Crustacea, Decapoda, Penaeidae)

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Abstract

We collected 470 *Penaeus monodon* individuals from four populations (Indonesia, Thailand, Mozambique and China) to measure quantitative traits, including Body Length (BL), Carapace Length (CL), Carapace Width (CW), Carapace Height (CH), first, second, third and sixth pleon segment lengths (FSL, SSL, TSL and SISL, respectively) and Body Weight (BW). The correlation coefficients among the traits were calculated, and path analysis was conducted by taking BW as the dependent variable and the other eight morphometrics as independent variables. The results revealed the relationship between the independent and dependent variables, and showed that the correlations among traits were significant (P<0.01). The highest correlation found was between BL and BW (0.985), and the path coefficient between these two variables was 0.557, suggesting that BL was a major factor compared with the other morphometrics and had the strongest direct effect on BW. Based on path analysis, CL, CW and CH had smaller direct effects on BW compared with that of BL, but showed significant indirect effects on BW via BL. The multiple regression equation obtained to estimate body weight was BW=1.546BL+2.533CW-261.522. The results of this research help clarify the traits that should be considered and measured for improving the *Penaeus monodon* breeding.

Keywords: *Penaeus monodon*; Economic traits; Correlation analysis; Path analysis; Multiple regression equation

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Introduction

Penaeus monodon is one of the world's most commercially important cultured penaeid shrimp. About two decades ago, rapid development and expansion of prawn farming occurred throughout much of southeast Asia [1,2]. Since then, China has successfully used artificial breeding technology and directional selection to improve *P. monodon* yield [3-5]. Selective breeding is essential to increase efficiency and profitability of production, with body weight among the key selective breeding traits that drives profitability in *P. monodon* farming [6]. However, determining body weight is frequently difficult due to measuring locations, tools and environments, and thus morphological indicators such as body length and carapace length are often preferable and easier to obtain. Understanding the relationships between body weight and other morphological characteristics is therefore vital for selection [7].

Path coefficient analysis can be used to determine selection criteria by measuring the direct influence of one variable on another and by separating the correlation coefficient into direct and indirect effects, such as seen in several aquatic organism studies [6,8]. For example, Wang et al. [9] used path analysis on three-month-old juvenile turbot (*Psetta maxima*) to obtain the body weight multiple regression equation with body length, height and thickness as independent variables. Harue et al. [10] used multiple correlation analysis on farmed Red Sea carp to estimate the impact of standard length and weight on body fat content. Zhan et al. [11] used correlation, path and multiple regression analyses to establish the body weight linear regression equation for body length, head length and tail height in *Paralichthys olivaceus*. Debowski et al. [12] used multiple regressions to study the relationship between body fat content and body length and weight of *Salmo sala*. Ahmed et al. [13] used multiple correlation analysis to analyze body length and weight-related growth parameters of fish, whales and shellfish.

Detailed path coefficient and correlation analyses can help identify the relationships between body weight and morphological characteristics in *P. monodon*. In particular, path coefficient analysis can separate direct and indirect effects and measure the relative importance of the potential causal factors involved [14,15]. The objectives of the current study were to: (a) determine the impact of morphological traits on Body Weight (BW); (b) estimate correlation coefficients for phenotypic characteristics between Body Length (BL), Carapace Length (CL), Carapace Width (CW), Carapace Height (CH), pleon segment lengths and BW; (c) evaluate the relative contribution of each morphological characteristic on BW using path coefficient analysis; and (d) establish the relationship between all measured morphological characteristics and BW.

Materials and Methods

Sampling and data collection

We collected *P. monodon* specimens from four different populations (Indonesia, Thailand, Mozambique and China). Sampling sites, sampling localities, geographical coordinates and number of collected specimens are presented in **Table 1**. Nine morphometric measurements were made on each specimen **(Figure 1)**: BW, BL, CL, CW, CH and first, second, third and sixth pleon segment lengths (FSL, SSL, TSL and SISL, respectively). Body features were measured with a digital vernier caliper (Mitutoyo 500-744, Japan, accurate to ± 0.01 mm) and BW was obtained by using an electronic balance (Mettler Toledo 504, Switzerland, accurate to ± 0.0001 g).

Data statistics

Observed data of the nine morphometric measurements were used for Pearson's correlation (simple correlation) and path coefficient analyses. For each specimen, Pearson's correlation coefficient (*r*) was calculated between every two morphometrics to indicate the relationship between the two traits. Pearson's correlation and path coefficient analyses were performed using SPSS (version 19.0, SPSS Inc. 2010) and Excel 2003 (Microsoft Corporation, Redmond, WA, USA). The general form of the equation was used as follows [8]:

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 (y_i - \bar{y})^2}}$$

$$P_{yx_i} = \frac{bx_i\sigma_{x_i}}{\sigma_y};\ P_{x_iy_i} = P_{iy}r_{ij}P_{jy}\ (i \neq j);\ d_i = P_{iy}{}^2$$

$$d_{ij} = 2r_{ij}P_{ij};\ = \sum_{i=1}^{n} d_i + \sum_{i=1 \neq j}^{n}\sum_{j=1}^{n} d_{ij};\ R_i{}^2 = d_i + \frac{1}{2}\sum_{i=1 \neq j}^{n} d_{ij}$$

Where, r_{xy} is the correlation coefficient of x_i to y_i, x_i is the flag value of the independent variable, y_i is the flag value of the dependent variable, P_{yxi} is the direct path coefficient of independent variable x_i to dependent variable y_i, b_{xi} is the regression coefficient of the independent variable, σ_{xi} is the standard deviation of the independent variable, σ_y is the standard deviation of the dependent variable, P_{ij} is the indirect path coefficient that trait i generated through trait j, d_i is the direct coefficient of trait i to dependent variable y, d_{ij} is the indirect coefficient of trait i to dependent variable y through trait j, d is the total determination coefficient of all traits, and R_i^2 is the total determination coefficient of all traits to trait y.

The regression equation linear model of quality traits Y was as follows:

$$Y = b_0 + b_1x_1 + b_0x_i + b_2x_2 + \ldots + b_0x_i$$

Where, Y is the dependent variable, b_0 is a constant and b_i is the partial regression coefficient of independent variable x_i to dependent variable Y.

The mean, standard deviation and maximum and minimum of all *P. monodon* measurements were recorded. The coefficient of variation (CV%) was computed as: CV%=100 × SD/X, where SD is the standard deviation and X is the mean of the morphometric measurements of *P. monodon*.

Results

Descriptive statistics of the *P. monodon* samples are presented in **Table 2**. The coefficients of variation (CV) reflected the varying degrees within the samples. The CVs estimated for morphological characteristics within the samples were different from each other, with the CV estimated for BW the highest (42.98%), suggesting that BW exhibited considerable variation, which is an advantage for the selective breeding of *P. monodon*.

The correlations were highly significant for all variables (*P*<0.01, **Table 3**), indicating that the variables had important practical significance for correlation analysis. Results showed that BW was positively correlated with all other variables, and the order of relevance was $r_{BLBW} > r_{CWBW} > r_{CHBW} > r_{CLBW} > r_{SISLBW} > r_{FSLBW} > r_{SSLBW} > r_{TSLBW}$.

Table 1 Populations, sampling localities, geographical coordinates and number of collected specimens.

Populations	Locality	Latitude, Longitude	Number
Pop.1	Banda Aceh, Republic of Indonesia	05°30'N,94°40'E	193
Pop.2	Khanom, Kingdom of Thailand	09°12'N,100°03'E	130
Pop.3	Mozambique Channel	19°10'S,35°56'E	85
Pop.4	Sanya, China	18°47'N,109°26'E	62

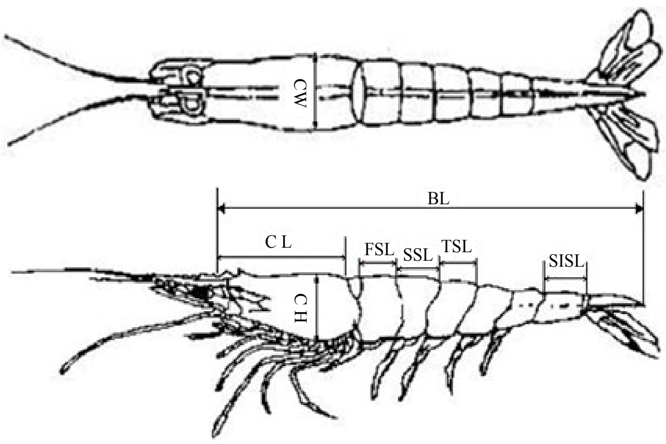

Figure 1 Morphometric measurements taken on each individual of *Penaeus monodon.*

BL: Body Length; CL: Carapace Length; CW: Carapace Width; CH: Carapace Height; FSL: First Pleon Segment Length; SSL: Second Pleon Segment Length; TSL: Third Pleon Segment Length; SISL: Sixth Pleon Segment Length

Table 2 Descriptive statistics of morphometric characteristics of *P. monodon* specimens.

Traits	Mean	SD	Range	CV (%)
BL	209.92	29.87	240.50-261.20	14.23
CL	66.40	13.15	45.57-86.31	19.80
CW	34.03	6.90	22.47-44.51	20.29
CH	38.51	7.34	25.56-50.42	19.06
FSL	21.68	3.36	15.25-28.18	15.48
SSL	18.96	2.47	13.27-24.71	13.01
TSL	18.93	2.63	14.54-24.89	13.92
SISL	28.33	3.55	21.81-34.94	12.54
BW	149.22	64.13	56.24-261.19	42.98

SD: Standard Deviation; CV: Coefficient of Variation; BL: Body Length (mm); CL: Carapace Length (mm); CW: Carapace Width (mm); CH: Carapace Height (mm); FSL: First Pleon Segment Length (mm); SSL: Second Pleon Segment Length (mm); TSL: Third Pleon Segment Length (mm); SISL: Sixth Pleon Segment Length (mm); BW: Body Weight (g)

Table 3 Correlation coefficients between morphological characteristics of *P. monodon.*

Variable	BW	BL	CL	CW	CH	FSL	SSL	TSL	SISL
BW	1.000								
BL	0.985	1.000							
CL	0.962	0.964	1.000						
CW	0.973	0.973	0.954	1.000					
CH	0.964	0.963	0.945	0.963	1.000				
FSL	0.868	0.871	0.866	0.866	0.867	1.000			
SSL	0.776	0.779	0.733	0.763	0.761	0.631	1.000		
TSL	0.817	0.829	0.766	0.811	0.795	0.692	0.740	1.000	
SISL	0.924	0.934	0.923	0.901	0.904	0.866	0.719	0.790	1.000

The significant correlation between BW and all other traits made it difficult to assess the major factors associated with BW from simple correlation analysis alone. Therefore, path coefficient analyses between each trait and BW, including endogenous and dependent or exogenous and independent variables, were performed to clarify the relationships. The results showed that CL and CW were highly significant and significant to BW, respectively **(Table 4)**, suggesting that these two morphological traits had strong direct effects on BW. The direct effect of BL on BW was obviously greater than the indirect effect of BL on BW through other traits. In addition, while the correlation coefficient between CW and BW was very large, the direct impact on BW was small. This indicated that the indirect effect of CW on BW (via other traits) was much larger than its direct effect, suggesting that CW affected BW through BL indirectly.

The determination coefficients of various traits on BW are shown in **Table 5**. The direct determination coefficients of BL, CL, CW and CH to BW were 31.0, 1.1, 3.3 and 1.3%, respectively. The indirect determination coefficients of CL, CW and CH to BW through BL were 5.7, 9.9 and 6.2%, respectively.

Based on the path analysis and multiple correlation analysis results, multiple regression of the main morphological characteristics was performed **(Table 6)**. BW was regarded as the dependent variable and the other traits as independent variables. The partial regression coefficients of BL and CW to BW were significant ($P<0.05$), and the multiple regression equation was: BW=1.546BL+2.533CW-261.522.

Predicted by the regression equation, no significant differences were found between the estimated and actual observed values. Thus, the above equation can be used conveniently and reliably in actual production.

Discussion and Conclusion

Phenotype correlation coefficients are used to comprehensively reflect relationships among variables. Since the influence of other variables is not eliminated, the direct effect of the independent variables on the dependent variables and their indirect effect through other independent variables may act against each other, and consequently phenotype correlation may be unable to accurately explain the relationship among all variables. Conversely, path coefficients are standardized partial regression coefficients that can differentiate direct and indirect effects without being influenced by other variables, and can therefore accurately reflect the relative importance of the results [16,17]. Our study showed that all nine quantitative traits of *P. monodon* showed positive correlations to each other, though the correlation coefficients between BW and BL (0.985), BW and CW (0.973), BW and CH (0.964) and BW and CL (0.962) were higher those between BW and SSL (0.776), BW and TSL (0.817) and BW and FSL (0.868). These results suggest that the four above mentioned variables exhibited a stronger influence on BW compared with the other traits, which is in accordance with the path coefficient results reported by Li et al. [18] and Zhang et al. [19] for *Exopalaemon carinicauda* and *Exopalaemon modestus*, respectively. However, correlation analysis alone cannot determine whether the traits with the largest correlation are the major factors that affect the dependent variables. Therefore, we used path analysis to not only reflect the relationship between variables, but also categorize the relationships between characteristics into direct and indirect

Table 4 Path analysis of the effects of various traits on body weight of *P. monodon.*

Trait	Correlation coefficient	Direct effect	Indirect effect								
			BL	CL	CW	CH	FSL	SSL	TSL	SISL	∑
BL	0.985^{**}	0.557**		0.103	0.178	0.111	-0.001	0.016	0.003	0.019	0.429
CL	0.962^{**}	0.107	0.537		0.175	0.109	-0.001	0.015	0.003	0.018	0.856
CW	0.973^{**}	0.183^{*}	0.542	0.102		0.111	-0.001	0.015	0.003	0.018	0.790
CH	0.964^{**}	0.115	0.536	0.101	0.176		-0.001	0.015	0.003	0.018	0.849
FSL	0.868^{**}	-0.001	0.485	0.093	0.158	0.100		0.013	0.003	0.017	0.869
SSL	0.776^{**}	0.020	0.434	0.078	0.140	0.088	-0.001		0.003	0.014	0.756
TSL	0.817^{**}	0.004	0.462	0.082	0.148	0.091	-0.001	0.015		0.016	0.813
SISL	0.924^{**}	0.020	0.520	0.099	0.165	0.104	-0.001	0.014	0.003		0.905

* Significant at *P*<0.05, ** Significant at *P*<0.01

Table 5 Determination coefficients of various traits on body weight of *P. monodon.*

Trait	Direct determination coefficient	Indirect determination coefficient								
		BL	CL	CW	CH	FSL	SSL	TSL	SISL	∑
BL	0.310		0.057	0.099	0.062	0.000	0.009	0.002	0.010	0.549
CL	0.011			0.019	0.012	0.000	0.002	0.000	0.002	0.046
CW	0.033				0.020	0.000	0.003	0.001	0.003	0.060
CH	0.013					0.000	0.002	0.000	0.002	0.017
FSL	0.000						0.000	0.000	0.000	0.000
SSL	0.000							0.000	0.000	0.001
TSL	0.000								0.000	0.000
SISL	0.000									0.000

Table 6 Partial regression coefficient test for various traits to body weight of *P. monodon.*

	Partial regression coefficient	Standard error	t	Significance
Intercept	-254.377	12.379	-20.548	0.000
BL	1.196	0.187	6.394	0.000
CL	0.523	0.299	1.746	0.084
CW	1.697	0.671	2.528	0.013
CH	1.008	0.526	1.916	0.058
FSL	-0.017	0.654	-0.026	0.979
SSL	0.519	0.631	0.822	0.413
TSL	0.093	0.684	0.136	0.892
SISL	0.353	0.853	0.414	0.680

effects, and thus determine the major factors affecting the BW of *P. monodon*.

In this study, the direct determination coefficient of BL (0.310) was the highest among all traits, while the direct determination coefficients of CW, CH, CL, FSL, SSL, TSL and SISL (0.033, 0.013, 0.011, 0.000, 0.000, 0.000 and 0.000, respectively) were much lower, suggesting that BL was the most important determinant of BW, consistent with the results of Yang et al. [20]. The phenotypic correlation coefficients of BL, CL, CW and CH with BW were basically the same, but the path analysis results suggested that the direct determination coefficients of these four phenotypes to BW had obvious differences. Specifically, CL, CW and CH influenced BW through BL indirectly, which indicated that the correlation between the variables did not accurately reflect their real relationship.

The main independent variable influencing a dependent variable can be determined when the sum of the multiple coefficient, or the sum of the single determination coefficient of variables to the dependent variable, or the sum of the pairwise coefficient are equal to or higher than 0.85. In this study, the summed (total) determination coefficient of BL and CW to BW was 0.952, indicating that BL and CW were the main characteristics that influenced BW. Hence, as far as *P. monodon* is concerned, morphological characteristics showed significant regression correlation with BW and indicated that path coefficient analysis was suitable for determining the real relationship between morphological traits and BW, as observed in Zhang *et al.* and Li *et al.* Due to the high genetic correlation between BL, CL, CW and CH, it would be appropriate to select BW and BL followed by CW as the main selection characteristics in the breeding of *P. monodon*.

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