GMR Genetics and Molecular Research
Online Journal
ISSN:1676-5680

Correlation of growth-related traits and their effects on body weight of the mud crab (*Scylla paramamosain*)

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Genet. Mol. Res. 12 (4): 4127-4136 (2013)
Received March 4, 2013
Accepted August 15, 2013
Published October 1, 2013
DOI http://dx.doi.org/10.4238/2013.October.1.3

ABSTRACT. In this study, we analyzed the correlation of 20 growth-related traits and their effects on body weight of *Scylla paramamosain*. The correlation coefficients in all trait pairs were significantly high, ranging from 0.551 to 0.999. Among 19 *X*-*Y* pairs, the correlation coefficient between traits X_1 and Y was the highest, whereas that between X_{13} and Y was the lowest. Path analysis indicated that only two traits (X_1 and X_{14}) can significantly affect body weight (Y) directly, with the path coefficients being 0.800 and 0.198, respectively. The determination coefficients (d_i) of traits X_1 and X_{14} to body weight were 0.640 and 0.039, respectively, and the total d_i was 0.965, indicating that both traits were the key factors affecting body weight. Moreover, traits X_1 and X_{14} were confirmed to be significantly related to body weight. Finally, a best-fit linear regression equation was constructed as $Y = 4.192X_1 + 2.242X_{14} - 169.737$.

Key words: *Scylla paramamosain*; Growth-related traits; Path analysis; Correlation analysis; Multiple regression equation

INTRODUCTION

Selective breeding schemes, which can improve economically important traits of cultured aquatic species (Neira et al., 2006; Nielsen et al., 2009; Bangera et al., 2011), have become more and more popular in aquaculture. Studies on phenotypic and genetic relationships among growth-related traits have been reported in many aquaculture species, including pearl oyster (*Pinctada martensii*; Deng et al., 2008), common carp (*Cyprinus carpio*; Wang, 2009), small abalone (*Haliotis diversicolor*; You et al., 2010), Japanese flounder (*Paralichthys olivaceus*; Tian et al., 2011), and sea urchin (*Strongylocentrotus intermedius*; Chang et al., 2012). So far, more statistical methods have been employed to estimate the relationships among economically important traits, such as correlation analysis, path analysis, and regression analysis. For example, using correlation and path analyses, Deng et al. (2008) reported that shell length, shell width, shell height, shell weight, and total weight were significantly correlated ($P < 0.05$), whereas shell weight had the largest positive and direct effects on total weight ($P_i = 0.6356$). Alicli et al. (2012) described the relationship between lower jaw fork length and round weight through a regression equation ($W = 1 \times 10^{-6} L^{3.46}$).

The mud crab (*Scylla paramamosain*) is a large carnivorous portunid crab, naturally distributed along the southeastern coastal region of China. This crab is considered to be an important marine species for fisheries resources and aquaculture in China, owing to its abundant fishing yields, fast growth rate, and high commercial values. China has a long history (more than 100 years) of farming *S. paramamosain* (Cowan, 1985; Shen and Lai, 1994). For the year 2011, the total culture area of *S. paramamosain* had expanded to more than 270 x 10^6 m^2, and the output reached more than 110,000 tons in China. In the past decade, scientific studies on *S. paramamosain* have mainly focused on its reproductive biology (Djunaidah et al., 2003; Zeng, 2007), culture biology (Nghia et al., 2007; Ut et al., 2007), functional genes (Rosa et al., 2008; Wang et al., 2012), population genetic diversity (Ma et al., 2011a, 2012; Shu et al., 2011), and molecular markers (Xu et al., 2009; Ma et al., 2011b,c). However, little information about traditional selective breeding or molecular marker-based selection is available for *S. paramamosain*, although the genetic differences among different F_1 families have been investigated by microsatellite markers (Cui et al., 2011).

In the present study, we analyzed the relationships of growth-related traits of the mud crab (*S. paramamosain*) using correlation analysis, estimated the contribution of growth-related traits to body weight using path analysis, and constructed a best-fit linear multiple regression equation using regression analysis. This study will provide useful information for better understanding the relationships among growth-related traits and for selective breeding of this important crab and other crustacean crab species.

MATERIAL AND METHODS

Crab sampling

A total of 149 specimens of *S. paramamosain* were captured randomly from four different locations in the southeastern coastal regions of China between December 2010 and October 2011: Wenzhou (N = 45), Shenzhen (N = 38), Zhanjiang (N = 39), and Wenchang (N = 27) (Figure 1 and Table 1).

Figure 1. Geographic locations of *Scylla parmamosain* sampled in this study. • = sampling location.

Table 1. Sampling locations, date and sex of *Scylla paramamosain*.

Location	date	Female	Male	Total
Wenzhou	September 2011	16	29	45
Shenzhen	December 2010	27	11	38
Zhanjiang	December 2010	20	19	39
Wenchang	October 2011	14	13	27
Total		77	72	149

Growth-related traits measure

In total, 20 growth-related traits were measured according to the methods of Keenan et al. (1998) and Gao et al. (2008), including carapace length (X_1), carapace width (X_2), internal carapace width (X_3), carapace frontal width (X_4), abdomen width (X_5), body height (X_6), carapace width at spine 8 (X_7), distance between frontal median spines (X_8), distance between frontal lateral spines (X_9), distance between lateral spine 1 (X_{10}), distance between lateral spine 2 (X_{11}), fixed finger length of the claw (X_{12}), fixed finger width of the claw (X_{13}), fixed finger height of the claw (X_{14}), meropodit length of peraeopod 1 (X_{15}), meropodit length of peraeopod 2 (X_{16}), meropodit length of peraeopod 3 (X_{17}), the 4th pereopod dactyl length (X_{18}), the 4th pereopod dactyl width (X_{19}), and body weight (Y). The former 19 morphological traits were measured to the nearest 0.02 mm with Vernier callipers. The body weight of the crab was measured to an accuracy of 0.01 g with a digital electronic balance.

Sex identification

The sex of specimens was identified based on the shape of the abdomen. The female crab has a wider and more globular abdomen, whereas the male crab has a narrow and straight abdomen (Ikhwanuddin et al., 2011).

Data analysis

The mean value and standard deviation of each trait were calculated using the software SPSS version 11.5. The coefficient of variation (*CV*) of each trait was estimated using the following formula: *CV* = (standard deviation / mean) x 100%. The path analysis was carried out using the software SPSS 11.5, as described by Du and Chen (2010). The correlation analysis and multiple regression analysis were also performed using SPSS 11.5. The multiple regression equation was constructed as follows: if the correlation variables Y, X_1, X_2, and X_3 exist in a linear equation, the regression equation is described as $Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3$, where Y is the dependent variable, X_1, X_2, and X_3 are the independent variables, b_0 is the constant, and b_1, b_2, and b_3 are the partial regression coefficients for Y on X_1, X_2, and X_3.

The determination coefficient was calculated using the alternative formulas: (1) $d_i = P_i^2$; and (2) $d_{ij} = 2r_{ij} \times P_i \times P_j$, where d_i is the effect of a single trait i on body weight, d_{ij} is the effect of traits i and j on body weight, P_i is the path coefficient of the single trait i to body weight, r_{ij} is the correlation coefficient between traits i and j, and P_j is the path coefficient of the single trait j to body weight.

RESULTS

Sex ratio in samples

Of 149 specimens examined, 77 were female and 72 were male (Table 1). The sex ratio (female:male) of this species was estimated at 1:0.94. No significant difference was found between the amounts of female and male compared with the ideal ratio 1:1 ($P > 0.05$).

Descriptive statistics of growth-related traits

The mean values, standard deviations, and coefficients of variation of the 20 growth-related traits are listed in Table 2. The coefficient of variation of body weight (Y) was the largest ($CV = 56.09\%$), whereas that of distance between lateral spine 1 (X_{10}) was the lowest ($CV = 16.91\%$). The standard deviation of body weight (Y) was the largest (SD = 51.71), whereas that of distance between frontal lateral spines (X_9) was the lowest (SD = 0.70).

Correlation coefficients among growth-related traits

The relationships among the 20 growth-related traits were estimated by correlation analysis and the results are shown in Table 3. A significantly positive correlation was detected in all 190 trait pairs (P < 0.01). The correlation coefficients (r) ranged from 0.551 (X_9 and X_{13}) to 0.999 (X_5 and X_7). A significantly positive correlation (P < 0.01) was observed between body weight (*Y*) and each of the other 19 morphological traits, with the r value ranging from 0.614 (between *Y* and X_{13}) to 0.979 (between *Y* and X_1).

Table 2. Descriptive statistics of growth-related traits of *Scylla paramamosain*.

Trait	Minimum	Maximum	Mean	Standard deviation (SD)	Coefficient of variation (*CV*, %)
X_1 (mm)	36.18	80.44	52.06	9.87	18.96
X_2 (mm)	55.92	120.78	79.15	15.16	19.15
X_3 (mm)	51.64	114.50	74.18	14.19	19.13
X_4 (mm)	22.22	44.10	30.27	4.84	15.99
X_5 (mm)	18.52	53.22	28.17	7.25	25.74
X_6 (mm)	21.28	47.06	31.04	5.87	18.91
X_7 (mm)	53.82	118.20	77.19	14.74	19.10
X_8 (mm)	2.60	6.68	4.13	0.78	18.89
X_9 (mm)	2.80	5.94	4.14	0.70	16.91
X_{10} (mm)	28.74	57.26	39.42	6.31	16.01
X_{11} (mm)	34.26	70.50	47.71	8.11	17.00
X_{12} (mm)	33.24	75.92	48.56	9.32	19.19
X_{13} (mm)	8.30	55.60	13.18	4.46	33.84
X_{14} (mm)	12.48	35.50	19.48	4.57	23.46
X_{15} (mm)	17.50	38.58	25.68	4.49	17.48
X_{16} (mm)	19.22	41.10	27.64	4.97	17.98
X_{17} (mm)	16.64	39.22	23.41	4.17	17.81
X_{18} (mm)	14.00	40.80	23.41	5.28	22.55
X_{19} (mm)	7.22	19.46	11.73	2.57	21.91
Y (g)	28.33	276.60	92.19	51.71	56.09

X_1 = carapace length; X_2 = carapace width; X_3 = internal carapace width; X_4 = carapace frontal width; X_5 = abdomen width; X_6 = body height; X_7 = carapace width at spine 8; X_8 = distance between frontal median spines; X_9 = distance between frontal lateral spines; X_{10} = distance between lateral spine 1; X_{11} = distance between lateral spine 2; X_{12} = fixed finger length of the claw; X_{13} = fixed finger width of the claw; X_{14} = fixed finger height of the claw; X_{15} = meropodit length of peraeopod 1; X_{16} = meropodit length of peraeopod 2; X_{17} = meropodit length of peraeopod 3; X_{18} = the fourth periopod dactyl length; X_{19} = the fourth periopod dactyl width; *Y* = body weight.

Path coefficients and determination coefficients

Of 19 morphological growth-related traits, only two (X_1 and X_{14}) showed significant effects on body weight directly (P < 0.05) (Table 4). Trait X_1 showed the largest direct effect (P_i = 0.800) on body weight, whereas X_{14} showed the lowest indirect effect (P_i = 0.179) on body weight. Trait X_{14} was the second leading factor affecting body weight, with the direct and indirect effects being 0.198 and 0.722, respectively. The multiple correlation coefficient (R^2) was 0.966 (higher than 0.85), indicating that X_1 and X_{14} were the key growth-related traits affecting body weight.

The determination coefficients of morphological traits to body weight are shown in Table 5. The determination coefficient of X_1 was the largest (0.640), the co-determination coefficient of X_1 and X_{14} was relatively less (0.286), and the determination coefficient of X_{14} was the lowest (0.039). The total determination coefficient (*d* = 0.965) of morphological traits to body weight was approximately equal to the multiple correlation coefficient (R^2 = 0.966) of morphological traits to body weight.

Table 3. Phenotype correlation coefficients among 20 growth-related traits of *Scylla paramamosain*.

Trait	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	X_{16}	X_{17}	X_{18}	X_{19}	Y
X_1	1	0.993**	0.998**	0.985**	0.952**	0.994**	0.997**	0.925**	0.939**	0.979**	0.990**	0.954**	0.616**	0.902**	0.953**	0.930**	0.948**	0.982**	0.982**	0.979**
X_2		1	0.997**	0.974**	0.954**	0.987**	0.996**	0.922**	0.926**	0.966**	0.982**	0.954**	0.625**	0.911**	0.950**	0.926**	0.942**	0.975**	0.980**	0.973**
X_3			1	0.981**	0.953**	0.992**	0.999**	0.924**	0.933**	0.975**	0.988**	0.955**	0.622**	0.908**	0.955**	0.932**	0.949**	0.980**	0.983**	0.978**
X_4				1	0.920**	0.977**	0.983**	0.925**	0.942**	0.995**	0.994**	0.940**	0.593**	0.878**	0.945**	0.929**	0.945**	0.970**	0.961**	0.959**
X_5					1	0.943**	0.950**	0.893**	0.881**	0.913**	0.935**	0.876**	0.568**	0.839**	0.848**	0.824**	0.856**	0.940**	0.940**	0.938**
X_6						1	0.991**	0.921**	0.935**	0.970**	0.982**	0.948**	0.610**	0.897**	0.948**	0.923**	0.941**	0.973**	0.974**	0.972**
X_7							1	0.922**	0.934**	0.976**	0.989**	0.954**	0.617**	0.905**	0.956**	0.933**	0.950**	0.980**	0.982**	0.975**
X_8								1	0.880**	0.918**	0.927**	0.869**	0.581**	0.826**	0.870**	0.851**	0.856**	0.894**	0.900**	0.901**
X_9									1	0.935**	0.935**	0.883**	0.551**	0.811**	0.897**	0.872**	0.896**	0.919**	0.915**	0.904**
X_{10}										1	0.993**	0.936**	0.590**	0.876**	0.941**	0.924**	0.943**	0.964**	0.952**	0.951**
X_{11}											1	0.948**	0.604**	0.895**	0.948**	0.929**	0.947**	0.974**	0.969**	0.964**
X_{12}												1	0.649**	0.963**	0.972**	0.954**	0.956**	0.946**	0.957**	0.956**
X_{13}													1	0.654**	0.642**	0.632**	0.629**	0.604**	0.627**	0.614**
X_{14}														1	0.910**	0.895**	0.899**	0.891**	0.917**	0.920**
X_{15}															1	0.975**	0.964**	0.941**	0.951**	0.940**
X_{16}																1	0.961**	0.923**	0.929**	0.916**
X_{17}																	1	0.959**	0.942**	0.931**
X_{18}																		1	0.977**	0.966**
X_{19}																			1	0.974**
Y																				1

X_1 = carapace length; X_2 = carapace width; X_3 = internal carapace width; X_4 = carapace frontal width; X_5 = abdomen width; X_6 = body height; X_7 = carapace width at spine 8; X_8 = distance between frontal median spines; X_9 = distance between frontal lateral spines; X_{10} = distance between lateral spine 1; X_{11} = distance between lateral spine 2; X_{12} = fixed finger length of the claw; X_{13} = fixed finger width of the claw; X_{14} = fixed finger height of the claw; X_{15} = meropodit length of peraeopod 1; X_{16} = meropodit length of peraeopod 2; X_{17} = meropodit length of peraeopod 3; X_{18} = the fourth periopod dactyl length; X_{19} = the fourth periopod dactyl width; Y = body weight. **Highly significant at the 0.01 level (2-tailed).

Table 4. Direct and indirect effects of morphologic traits on body weight of *Scylla paramamosain*.

Trait	Correlation coefficient (r_{ij})	Direct effect (P_i)	Total of indirect effect (Σ)	Indirect effect (r_{ij} x P_j)	
				X_1	X_{14}
X_1	0.979	0.800	0.179		0.179
X_{14}	0.920	0.198	0.722	0.722	

X_1 = carapace length; X_{14} = fixed finger height of the claw.

Table 5. Determination coefficients of morphologic traits to body weight of *Scylla paramamosain*.

Trait	X_1	X_{14}
X_1	0.640	0.286
X_{14}		0.039

X_1 = carapace length; X_{14} = fixed finger height of the claw.

Construction of multiple regression equation

The regression relationship between body weight and other morphological traits was estimated by the following steps: first by testing the significance of partial regression coefficients of different traits and then by stepwise removing nonsignificant morphological traits. The results indicated that body weight showed a significant regression relationship to only two traits (X_1 and X_{14}) (P < 0.01; Table 6). A best-fit linear multiple regression equation was constructed as follows: $Y = 4.192X_1 + 2.242X_{14} - 169.737$. The constant and partial coefficients of regression equation were tested by the *t*-test, which suggested a significant effect of them on body weight (P < 0.01; Table 7).

Table 6. Analysis of variance (ANOVA) of multiple regression equation of *Scylla paramamosain*.

Index	Sum of squares	d.f.	Mean square	*F*	P
Regression analysis	382111.28	2	191055.64	2045.19	0.000
Residual	13638.92	146	93.42		
Total	395750.21	148			
Multiple correlation	$R = 0.983$	$R^2 = 0.966$	Adjusted $R^2 = 0.965$	SD = 9.665	

Table 7. The *t*-test for constant and partial regression coefficients in multiple regression equation of *Scylla paramamosain*.

Index	Partial coefficient	Standard error	*t*-value	P
Constant	-169.737	4.359	-38.936	0.000
X_1	4.192	0.186	22.508	0.000
X_{14}	2.242	0.402	5.573	0.000

X_1 = carapace length; X_{14} = fixed finger height of the claw.

DISCUSSION

Estimation of the relationship among growth-related traits is an important issue for quantitative genetics and selective breeding. In the present study, we analyzed the correlation among 20 growth-related traits of *S. paramamosain* that showed abundant variation of these traits. Body weight (Y) had the largest variation ($CV = 56.09\%$), whereas the distance between lateral spine 1 (X_{10}) showed the lowest variation ($CV = 16.91\%$). These various phenotypic traits can provide considerable material for sustained improvement of the breeding process. Similar to the high variation of phenotypic traits, a high level of genetic diversity was observed by using microsatellites, single nucleotide polymorphisms, and mitochondrial DNA (Ma et al., 2011a,b, 2012). Morphological traits, such as body length and body weight, are often used as criteria for selecting excellent individuals in artificial breeding (Neira et al., 2006; Takeshita and Soyano, 2009). For *Pinctada martensii*, the shell length, shell width, shell height, and total weight were found to be significantly correlated to one another ($P < 0.05$) (Deng et al., 2008). For *Portunus trituberculatus*, the five growth-related traits of carapace length, carapace width, internal carapace width, body height, and body weight were confirmed to be significantly correlated to one another ($P < 0.01$) (Liu et al., 2009). In this study, all 20 growth-related traits were observed to be significantly positively correlated to one another ($P < 0.01$). This means that it is feasible to select one targeting trait through selecting other one or more traits in the *S. paramamosain* breeding process. The high correlation among traits may be resulting from pleiotropy in the determination of these traits (Falconer, 1981).

Path analysis is an effective method for multiple statistics, which can separate the total effects of independent variables on dependent variables into direct and indirect effects (Rodrigueza et al., 2001). In this study, out of 19 morphological traits, two (X_1 and X_{14}) showed significant direct effects on body weight ($P < 0.05$). The multiple correlation coefficient between morphological traits and body weight was high (more than 0.85) and approximately equal to the determination coefficient; hence, the traits X_1 and X_{14} could be considered as the key factors affecting the body weight of *S. paramamosain*. By using path analysis, the main factors affecting body weight have been observed in other aquaculture animals, such as *Eriocheir sinensis* (Geng et al., 2007), *Pinctada martensii* (Deng et al., 2008), and *Portunus trituberculatus* (Liu et al., 2009). In contrast, the multiple correlation coefficient for edible tissue weight of 2- and 3-year-old *Ruditapes philippinarum* was tested to be lower than 0.85, indicating that some other factors affecting edible tissue weight may be omitted (Huo et al., 2010). A best-fit linear multiple regression equation was successfully constructed for *S. paramamosain*, which can be easily used to estimate the body weight (Y) through the carapace length (X_1) and fixed finger height of the claw (X_{14}).

CONCLUSIONS

The high correlation among 20 growth-related traits was first tested in the important crab species, mud crab (*S. paramamosain*). In addition, two growth-related traits (X_1 and X_{14}) showed significant direct effects on body weight. Finally, a multiple regression equation was constructed relating body weight and the above two growth-related traits. This study will be useful for further research about the relationships among growth-related traits and for selective breeding of this important crab and other crustacean species.

ACKNOWLEDGMENTS

We thank Dr. Wei Song for assistance in partial sample collection. Research supported by the National Non-Profit Institutes (East China Sea Fisheries Research Institute;

#2011M05), the National Natural Science Foundation of China (#31001106), and the Science and Technology Commission of Shanghai Municipality (#10JC1418600).

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