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GENETIC CORRELATIONS TO MORPHOLOGICAL TRAITS OF SMALL ABALONE *HALIOTIS DIVERSICOLOR*

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ABSTRACT A total of 241 samples of small abalone (*Haliotis diversicolor*) from 8 full-sib families of market size were used in this experiment. Shell length (X_1), shell width (X_2), shell height (X_3), apex height (X_4), body weight (Y_1), muscle weight (Y_2), and shell weight (Y_3) were measured, and the correlation coefficient matrix was calculated. The shell shape traits were used as independent variables, then body weight and muscle weight were used as dependent variable for path analysis. Path coefficients, determination coefficients, and correlation index were calculated. The results showed that correlation coefficients between each shell shape trait and body weight, muscle weight, and shell weight were all significant ($P < 0.01$). For the 4 shell morphological traits, body weight (Y_1) had the highest correlation coefficient with shell length (X_1), and muscle weight (Y_2) had the highest correlation coefficient with shell width (X_2). The results of high correlation index would be useful for selecting important growth-related traits in genetic breeding program of small abalone.

KEY WORDS: abalone, *Haliotis diversicolor*, genetic correlation, morphological traits, path analysis

INTRODUCTION

Small abalone *Haliotis diversicolor* is naturally distributed along the coastal waters of East Asia, from Japan to the Philippines (Lindberg 1992), and is an economically important mariculture species in southern China and Taiwan. It has a short grow-out period and can grow to market size (55–70 mm in shell length) in 10–12 mo. However, since late 2000, small-abalone farmers have seen a decreased growth rate and mass mortality during the grow-out period. Selective breeding practices for growth rate have been conducted in recent years (You et al. 2009).

Estimates of genetic parameters for economically important traits are very useful and common in aquatic animal selection and breeding programs. Reliable estimates of genetic parameters can provide valuable information for determining reasonable breeding plans, and predicting selection response and breeding values of candidate traits (Wang et al. 2006). Genetic correlation is an important genetic parameter for animal breeding, which measures covariation between different traits. Genetic correlations between traits within ages or between the same traits at different ages provide an understanding of how the 2 traits are genetically determined by the same genes (Pérez-Rostro & Ibarra 2003).

Genetic correlations between growth traits in molluscs were first estimated for the European oyster *Ostrea edulis* by Toro and Newkirk (1990), who found a high genetic correlation between live weight and shell height at age. Toro et al. (1995) also reported a significant phenotypic correlation between the shell length and the live weight in the Chilean oyster *O. chilensis*. Ibarra et al. (1999) reported that estimates of the genetic correlation of the Catarina scallop *Argopecten ventricosus* between total weight and shell width varied widely between experiments (1.25 ± 0.22 in experiment 1 and 0.33 ± 0.31 in experiment 2). Deng et al. (2007) showed that genetic correlations of Pacific abalone *Haliotis discus hannai* between shell length and shell width were significantly positive at the early stage, which indicated that selection for shell length can result in a correlated response in shell width. However, there is no published information about genetic correlations for any traits in the small abalone.

In this research, grow-related traits were measured for 241 samples of small abalone and the correlation coefficient matrix was calculated between these traits. The results would be useful for selective breeding of small abalone.

MATERIALS AND METHODS

Experimental Animals and Measurement

Mature, male small abalone from a Japanese population and female small abalone from a Taiwanese population were used as parents to build the cross line in 2005; cross-bred offspring were then cultured at Dongshan Haitian Aquaculture Co., Ltd., Fujian Province (You et al. 2009). The cross-bred progeny were then collected as broodstock to establish 12 half-sib families and 36 full-sib families for genetic parameter estimates. A total of 241 samples of small abalone, which were randomly chosen from 8 full-sib families, were used in this experiment.

Shell length (X_1), shell width (X_2), shell height (X_3), apex height (X_4), body weight (Y_1), muscle weight (Y_2), and shell weight (Y_3) were measured at market size with 15-mo-old abalone. Shell length, shell width, shell height, and apex height were measured by vernier caliper (accuracy, 0.02 mm), whereas body weight, muscle weight, and shell weight were measured using an electronic balance (accuracy, 0.01 g).

Data Analysis

The shell shape was expressed as the proportion of shell length (L), shell width (W), and shell height (H). The proportions were calculated by L/(L + W + H), W/(L + W + H),

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TABLE 1.

Mean, SD, and coefficients of variation (CV) for 4 growth-related traits of small abalone ($n = 241$).

Traits	X_1 (cm)	X_2 (cm)	X_3 (cm)	X_4 (cm)	Y_1 (g)	Y_2 (g)	Y_3 (g)
Mean	5.76	3.76	1.21	1.22	21.03	9.68	6.21
SD	0.53	0.37	0.14	0.15	6.49	3.18	2.18
CV (%)	9.2	9.9	11.4	12.0	30.9	35.0	32.8

TABLE 3.

Pearson's correlation coefficient among 7 growth-related traits of small abalone ($n = 241$).

Traits	X_1	X_2	X_3	X_4	Y_1	Y_2
X_2	0.914*					
X_3	0.852*	0.844*				
X_4	0.852*	0.824*	0.953*			
Y_1	0.942*	0.928*	0.891*	0.886*		
Y_2	0.864*	0.874*	0.810*	0.798*	0.911*	
Y_3	0.902*	0.877*	0.880*	0.879*	0.963*	0.788*

* Correlation is significant at the 0.01 level (2-tailed).

and H/(L + W + H), respectively. The density was expressed as the proportion of whole body weight (BW), muscle weight (MW), and shell weight (SW) with respect to size. The proportions were calculated by BW/(L × W × H), MW/(L × W × H), and SW/(L × W × H), respectively. The correlation coefficient, path coefficients, and determination coefficients among these growth-related traits were calculated. The multiple-regression equation of the body weight (Y_1) and muscle weight (Y_2) were then obtained. All statistical analyses were conducted using SPSS version 11.5 (SPSS Inc., Chicago, IL), and significance for all analyses was set at $P < 0.05$ unless noted otherwise.

RESULTS

Mean, SD and coefficients of variation for 7 growth-related traits of small abalone are listed in Table 1. The results indicated that apex height varied widely in comparison with other shell morphological traits. Muscle weight varied widely compared with the other 2 weight-related traits.

Table 2 shows mean, SD, and coefficients of variation of parameters related to shell shape and density of small abalone at market size. With regard to parameters related to shell shape, the proportion of shell length, width, and height varied from 0.515–0.570 with a mean of 0.537, from 0.316–0.373 with a mean of 0.350, and from 0.101–0.132 with a mean of 0.113, respectively. It indicated that the proportion of shell height varied widely in comparison with the proportions of shell length and width. In the parameters of density related to growth traits, body weight varied from 0.580–1.033 with a mean of 0.781, muscle weight varied from 0.227–0.533 with a mean of 0.360, and shell weight varied from 0.184–0.330 with a mean of 0.230.

Significant phenotypic correlations were found among these 7 growth-related traits (Table 3). For the 4 shell morphological traits, body weight (Y_1) had the highest correlation coefficient with shell length (X_1), with a value of 0.942. Muscle weight (Y_2) had the highest correlation coefficient with shell width (X_2), with a value of 0.874. Shell weight (Y_3) had the highest correlation coefficient with shell length (X_1), with a value of 0.902. Among the 4 shell morphological traits, shell height (X_3) and apex height (X_4) had the highest correlation coefficient, with a value of 0.953. Shell length (X_1) had the best correlation compared with the other 2 shell morphological traits. Among the 3 weight traits, body weight (Y_1) had the highest correlation coefficient with shell weight (Y_3), with a value of 0.963.

Path analyses were conducted during this study. The direct and indirect effects of 4 shell morphological traits on body weight and muscle weight are shown in Tables 4 and 5. The path coefficients of shell length, shell width, shell height, and apex height on body weight were 0.4128, 0.3265, 0.1273, and 0.1437, respectively. The path coefficients of shell length, shell width, shell height, and apex height on muscle weight were 0.3116, 0.4437, 0.1167, and 0.0557, respectively. The indirect effects were both larger than direct effects in path analyses on body weight and muscle weight.

The determinant coefficients of shell morphological traits on body weight and muscle weight are shown in Tables 6 and 7. The determinant coefficients of shell length, shell width, shell height, and apex height on body weight were 0.3116, 0.4437, 0.1167, and 0.0557, respectively. The determinant coefficients of shell length, shell width, shell height, and apex height on body weight were 0.1704, 0.1066, 0.0162, and 0.0206, respectively. The determinant

TABLE 2.

Parameters related to shell shape and density of small abalone at market size.

	Parameters Related to Shell Shape			Parameters Related to Density		
	L/(L + W + H)	W/(L + W + H)	H/(L + W + H)	BW/(L × W × H)	MW/(L × W × H)	SW/(L × W × H)
Mean	0.537	0.350	0.113	0.781	0.360	0.230
SD	0.011	0.010	0.007	0.077	0.058	0.025
CV (%)	2.1	2.9	6.1	9.9	16.3	10.8

TABLE 4.

Direct and indirect effects of 4 shell morphological traits on body weight.

Shell Traits	Correlation	Direct Effect	Indirect Effect				
			$\sum$	X_1	X_2	X_3	X_4
X_1	0.942	0.4128	0.5292		0.2984	0.1084	0.1224
X_2	0.928	0.3265	0.6015	0.3772		0.1074	0.1184
X_3	0.891	0.1273	0.7637	0.3517	0.2756		0.1369
X_4	0.886	0.1437	0.7423	0.3517	0.2690	0.1213	

TABLE 6.

Determinant coefficients of shell morphological traits on body weight.

Shell Traits	X_1	X_2	X_3	X_4
X_1	0.1704	0.246	0.0895	0.1011
X_2		0.1066	0.07016	0.0773
X_3			0.0162	0.0349
X_4				0.0206

coefficients of shell length, shell width, shell height, and apex height on body weight were 0.0971, 0.1969, 0.0136, and 0.0031, respectively. The total determinant coefficients of morphological traits on body weight and muscle weight were 0.9328 and 0.7954, respectively.

Multiple linear regressions were conducted, then the regression equations of body weight (Y_1) and muscle weight (Y_2) were obtained as follows:

$$Y_1 = -32.658 + 3.828X_1 + 4.388X_2 + 5.851X_3 + 5.986X_4$$
$$Y_2 = -19.520 + 1.957X_1 + 3.432X_2 + 3.601X_4$$

DISCUSSION

Research about genetic correlations between growth traits in abalone species has been mostly on the Pacific abalone *H. discus hannai*. Genetic correlations on shell shape and growth-related traits in *H. discus hannai* were reported by Kobayashi and Fujio (1996). Parameters related to shell shape and density of small abalone were estimated and were used as indexes for comparison between cultured stock and wild stock. Deng et al. (2007) showed that, in Pacific abalone, genetic correlations of between shell length and shell width were significantly positive during the early stage, which indicates that selection for shell length can result in a correlated response in shell width. In our research, body weight showed a highly positive correlation with shell length, and muscle weight had a high correlation coefficient with shell width. Therefore, selection for shell length or shell width can result in indirect selection for body weight or muscle weight.

The path coefficient—measuring the importance of a given path of influence from cause to effect—is the ratio between the SD of the effect when all causes are constant except the one in question, the variability of which is kept unchanged, to the total SD (Gjedrem 2005). The methodology of path analysis is useful when observing the relationship between genotype and phenotype, and the relationships among traits. The methodology of path coefficients was first used by Hazel and Lush (1942) for developing selection index methods in animals, and has been used recently in many aquatic animals (Li et al. 2005, Li et al. 2007). In our research, path coefficient analysis revealed a strong relationship between shell morphological traits and weight-related traits.

This is the first report of genetic correlation to growth-related traits of small abalone. The results in our research indicate that shell morphological traits have a high positive correlation with body weight and muscle weight. This information is useful for effecting direct and indirect selection in growth-related traits of small abalone.

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TABLE 5.

Direct and indirect effects of 4 shell morphological traits on muscle weight.

Shell Traits	Correlation	Direct Effect	Indirect Effect				
			$\sum$	X_1	X_2	X_3	X_4
X_1	0.864	0.3116	0.5524		0.4055	0.0994	0.0470
X_2	0.874	0.4437	0.4303	0.2848		0.0984	0.0459
X_3	0.810	0.1167	0.6933	0.2655	0.3745		0.0531
X_4	0.798	0.0557	0.7423	0.2655	0.3656	0.1112	

TABLE 7.

Determinant coefficients of shell morphological traits on mussel weight.

Shell Traits	X_1	X_2	X_3	X_4
X_1	0.0971	0.2527	0.0620	0.0295
X_2		0.1969	0.0874	0.0407
X_3			0.0136	0.0124
X_4				0.0031

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