Full Length Research Paper

Response to selection for shell length in the noble scallop, *Chlamys nobilis* (Reeve)

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The noble scallop, *Chlamys nobilis* is one of the most economically important fishery and aquaculture species in the southern coast of China. In the present study, we conducted a one generation mass selection for shell length in a cultured noble scallop stock with a selection intensity of 1.732, to examine their response to selection. The results show that the selected line grew faster than the control line in shell length (*P*<0.05), and survival of the selected line was significantly larger (*P*<0.05) at larvae, spat and grow-out stage. The current genetic gains were 0.1653 ± 0.0238 for spat and 0.1379 ± 0.0408 for grow-out, and realized heritability for shell length at spat and grow-out stages were 0.8285 ± 0.0997 and 0.4544 ± 0.1112, respectively. The results indicate that a large amount of genetic variance remains in the cultured scallop stock, improvement for growth traits can be achieved through only one generation of selection and mass selection on growth improvement was promising.

Key words: Noble scallop, *Chlamys nobilis*, genetic gains, realized heritability, shell length.

INTRODUCTION

Scallops comprise more than 300 species identified in worldwide oceans and occupy an economically important position in many coastal countries (Hu et al., 2009). Scallop adductor muscles are being considered as one of the most flavorful sea foods in markets due to their delicious taste and abundant nutrition. The noble scallop, *Chlamys nobilis* (Reeve), inhabiting the coastal waters of southern China, Japan and Indonesia, is one of the most economically important fishery and aquaculture species in the southern coast of China (Hu et al., 2009). The annual commercial landings of the noble scallop fluctuated around 20,000 metric tons in recent years. The rising consumption of scallop products and the decline of natural resource have led to increasing aquaculture practices and stock transfer of this species (Ma and Yu, 2009). At present, genetic improvement of cultured populations to obtain new strains suitable for culture (example strains with higher growth rates and resistance to disease) is crucial for the sustainability of the industry.

Selective breeding is a common and effective technique that has been widely applied in genetic improvement

of aquaculture stocks. In bivalves, a number of studies have been carried out to estimate genetic parameters and the response to selection in the last two decades in oysters, mussels, scallops and clams (Jones et al., 1996; Toro et al., 2004; Heffernan et al., 1991; Evans and Langdon, 2006; Zhang et al., 2008; Zheng et al., 2006; Deng et al., 2009). Most studies on response to selection have been positive and encouraging. For example, in common pearl oyster, *Pinctada fucata*, the shell height gains was 16.03% after one generation of mass selection (He et al., 2008). Family selection for live weight resulted in an increase of 9.5% after only one generation selection in the Pacific oyster, *Crassostrea gigas* (Langdon et al., 2003). Total weight of Sydney rock oyster, *Saccostrea commercialis* increased by 18% after mass selection of two generations (Nell et al., 1999). For scallops, positive or successful responses to selection for growth have also been found in the bay scallop, *Argopecten irradians irradians* (Zhang et al., 2008; Zheng et al., 2006), the catarina scallop, *Argopecten ventricosus* (Ibarra et al., 1999) and *Euvola ziczac* (Perez and Alfonsi, 1999).

Although, the noble scallops have been cultured in China for several decades, there have been no well-documented cases of selective breeding. We initiated a selective breeding program for improving adult or com-

mercial size of the noble scallop in China, as a positive association between shell length and the weight of adductor muscle has been identified (Liu et al., 2009). The aim of this study was to examine the response to selection for shell length in a cultured noble scallop population based on one generation mass selection.

MATERIALS AND METHODS

Brood stock and truncation selection

In autumn of 2008, a cultured stock of noble scallop, *C. nobilis* was selected to conduct mass selection experiments at a commercial scallop hatchery. The stock, which has been successively cultured in China for about 10 years (about 6 generations), descended from a wild population in Leizhou Peninsula, Zhanjiang, Guangdong Province, China. Two hundred individuals were randomly taken from the stock to obtain their estimates of size-frequency distribution of shell length. Base on that information, the critical value of shell length of the top 5% largest individuals was determined. Then, 100 scallop individuals were randomly taken from the stock to serve as parents for the control lines, and the same number of individuals that were larger than the critical value in shell length were selected from the stock to serve as parents for the selected lines.

Hatchery, nursery and culture conditions

In October 2008, 33 individuals with stage IV gonads, which were selected directly from parents for the control lines, were induced to spawn in one 1500 ml concrete tank using temperature and UV-radiation shock. To avoid polyspermy, groups of male scallops were first placed in another tanks (1500 ml) and allowed to release a large portion of the gametes and later transferred to the spawning tanks. When egg density reached about 100/ml, the breeders were removed and the fertilized eggs were allowed to develop into D-stage larvae. At about 30 h after fertilization, larvae were randomly taken out from the hatching tank and divided into three 1500 ml concrete tanks to form three groups of control lines (CL). On the same day, 49 parents for the selected lines were also induced to spawn, and three groups of selected lines (SL) were established using the same method as the CL.

Larval rearing conditions were maintained the same for all control and selected groups. The initial densities of each group were about 5 larvae per ml. With larval growth, the densities were kept the same by adjusting the water volume. The larvae were fed with *Isochrysis zhanjiangensis* from days 2 to 6, and then a mixture of *I. zhanjiangensis* and *Platymonas subcordiformis* (1:1), the concentrations ranged from 15 000 to 50 000 cells ml^{-1} according to larvae aging. The seawater used was sand-filtrated and sterilized by UV-radiation. Water was changed 30 to 50% everyday. The temperature of water was left to change with nature temperature and salinity at 28.9 to 29.8.

After 12 days of larval culture, when about 30% larvae developed to the eyed stage at a size of 170 to 190 μm, spat collectors (polyethylene nets) were placed into the tanks. About 5 to 7 days after the collectors were placed, all larvae had set and metamorphosed. Successfully metamorphosed spats were kept in the concrete tanks until they reached 1500 to 1600 μm, after which they were placed in polyethylene bags and transferred to an outdoor nursery area in the sea. During spat nursery, polyethylene bags were changed with spat aging and spats were sorted once every month to decrease the density. Three months later, all seeds were transferred to 10-layer grow-out cages at a density of 30 indi-

viduals per layer. During initial growth, all individuals within a line were mixed every month during maintenance and randomly distributed again in the layers. Scallops were reared to age of nearly 1 year. Average monthly water temperature over the grow-out period was 26°C, ranging from a low temperature of 14°C in February to a high temperature of 30°C in August.

Sampling and growth measurement

For spat, shell length of 40 scallops per group was randomly measured using a vernier caliper (0.02 mm accuracy) at 30, 40, 50, 60, 70 and 80 days after fertilization. Every 1 to 2 months at the grow-out stage, a random sub-sample of 30 scallops from each replicate was measured for shell length using a vernier caliper (0.02 mm accuracy). At our last sampling on day 330, a random sub-sample of 300 individuals from each replicate was measured.

The survival rates of larvae, spat and grow-out per group were measured on 30, 80 and 330 days after fertilization, respectively.

Data analysis

The spat percentage survival was calculated as the ratio between the total number of initial larvae in each group and the total number of spat on day 30 after fertilization, the spat percentage survival was calculated as the ratio of number on days 80 and 30 after fertilization, and the grow-out percentage survival as the ratio on days 330 and 80 after fertilization, respectively.

The intensity of selection (*i*) for the truncation selection was calculated as the difference in mean shell length between the selected parents and the base population divided by the standard deviation of the population (Ibarra et al., 1999; Falconer and Mackay, 1996). The current genetic gains (GG) were calculated according to the equations of Zheng et al. (2006). The realized heritability (h_R^2) was calculated by using the Equation (2) of Hadley et al. (1991):

GG = (X*s* - X*c*)/X*c* × 100%

$$h_R^2 = (Xs - Xc)/ iSc × 100\%$$

Where, X*s* and X*c* are the means of offspring of selected and control lines, respectively; *i* is the intensity of selection from a truncated standard normal distribution; and S*c* is standard deviation of control offspring.

Student's *t*-test was carried out to determine the significance of the difference in shell length, current genetic gains, h_R^2 and survival between the selected and the control groups. Analyses were done using Statistical Program for Social Sciences (SPSS) 12.0 software for Windows. Significance level for all analyses was set as $P < 0.05$.

RESULTS

Base population and selection intensity

Figure 1 shows the frequency distribution of the shell length of the randomly selected 200 parental individuals. Selection of the top 5% of the parents for the selected lines corresponded to a cut-off point of 75.96 mm. Thus, the intensity of selection was 1.732. T-test showed that shell length of parental scallops for the SL (76.53 ± 2.24 mm) was significantly bigger than that of CL (65.22 ± 6.53
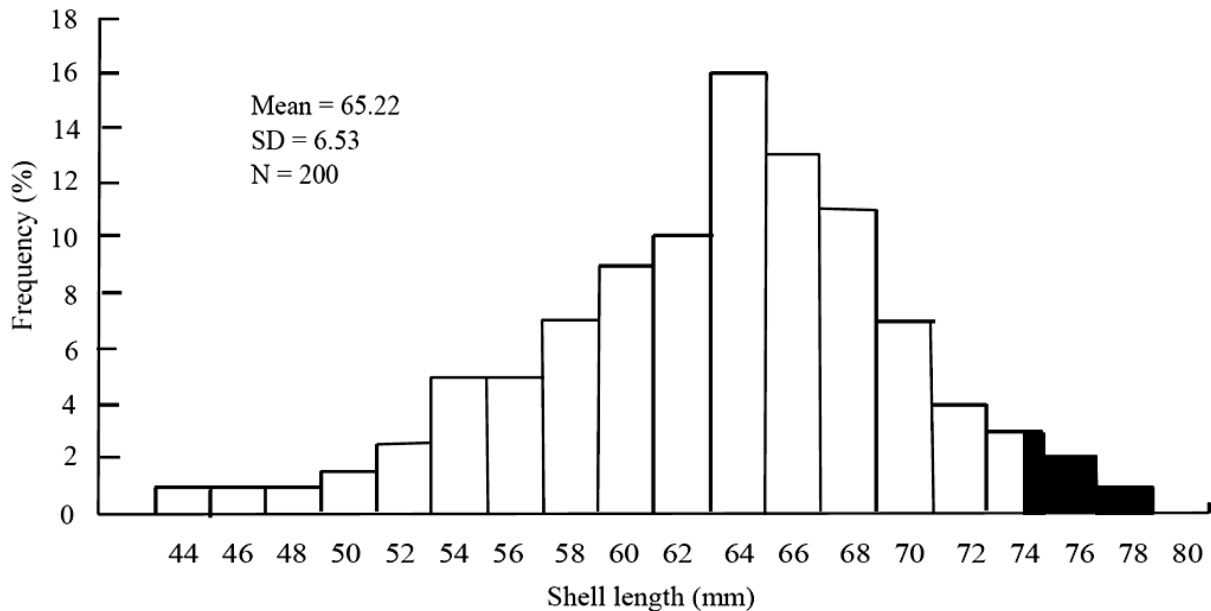
Figure 1. Shell length distribution of the parental noble scallop, *C. nobilis* population and parents (solid parts) selected for use in a truncation selection.

mm; *P* < 0.001).

Growth and survival

The survival rate and the growth data of the selected and unselected groups are given in Table 1. The survival rate of the SL was significantly greater than that of the CL at larvae, spat and grow-out stage (*P*<0.05). The mean shell length of the SL is significantly greater than that of the CL at all sampling dates throughout this study (*P*<0.05).

At our last sampling on day 330 post fertilization, scallops from SL and CL lines measured 54.92 ± 4.98 and 49.14 ± 8.28 mm in shell length, respectively. Shell length of the SL was 11.76% larger over that of the CL. In addition, the coefficient of variance of shell height was 9.07 for SL, smaller than 16.85 for CL. About 80% of the scallops in SL were larger than 50 mm in shell length, while only 42% of the scallops were larger than 50 mm in CL (Figure 2).

Genetic gains, response to selection and realized heritability

Genetic gains and realized heritability at different ages are listed in Table 2. Current genetic gains ranged from 0.1343 to 0.1864, averaging 0.1653 at spat stage. At grow-out stage, the genetic gains ranged from 0.0923 to 0.1856, with an average of 0.1379. The realized heritability ranged from 0.7057 to 0.9623, averaging 0.8285 at spat stage. At grow-out stage, the realized heritability ranged from 0.3422 to 0.6579, with an average of 0.4544.

T-test showed that the values of h_R^2 at grow-out stage were significantly smaller than that at spat stage. The results indicate that the selective effect was significant (*P*<0.05).

DISCUSSION

The improvement of the selected growth trait (shell length) in the present study is very encouraging after one generation mass selection. Mean shell length of the SL is significantly greater than that of the CL at all sampling dates throughout this study (*P*<0.05). Response to selection is a function of both additive genetic variance and strength of selection (Falconer and Mackay, 1996). All conditions for parent conditionings, larval culture, spat nursery and grow out were kept the same for all the CL and SL. In addition, the stocking density, which has been shown to have non-random effects on shellfish growth (Southgate and Beer, 2000; Taylor et al., 1997), was kept in low values and maintained the same at all culture stages. So, it can be concluded that significant differences are due to genetic factors.

The effects of selection are often inconsistent in different species and populations. Newkirk (1980) concluded that after one generation of selection in European flat oyster, *Ostrea edulis*, a 10 to 20% gain per generation is a reasonable expectation for growth. In common pearl oyster, *Pinctada fucata*, the shell height gains was 16.03% after one generation of mass selection (He et al., 2008). In bay scallop, *Argopecten irradians irradians*, the shell length gains was 17.56% after two generations of selection (Zheng et al., 2006). Family selection for live

Table 1. Mean shell length (mean±SD) and survival rate of selected and control line of noble scallop, *C. nobilis* (Reeve) measured at different ages.

Scallop age (day)	Shell length (mm)		Survival rate (%)	
	Select line	Control line	Select line	Control line
Spat				
30	0.39 ± 0.06[a]	0.33 ± 0.04[b]	10.67 ± 0.14[a]	7.23 ± 0.95[b]
40	0.69 ± 0.04[a]	0.59 ± 0.06[b]		
50	0.97 ± 0.05[a]	0.82 ± 0.11[b]		
60	1.40 ± 0.10[a]	1.18 ± 0.14[b]		
70	1.83 ± 0.12[a]	1.61 ± 0.18[b]		
80	2.28 ± 0.18[a]	2.01 ± 0.21[b]	67.87 ± 7.15[a]	46.5 ± 7.91[b]
Grow-out				
100	3.13 ± 0.05[a]	2.64 ± 0.43[b]		
140	10.86 ± 0.09[a]	9.71 ± 1.52[b]		
180	21.58 ± 0.16[a]	19.24 ± 2.75[b]		
250	32.10 ± 6.55[a]	26.93 ± 7.56[b]		
300	48.03 ± 6.36[a]	43.97 ± 6.85[b]		
330	54.92 ± 4.98[a]	49.14 ± 8.28[b]	91.87 ± 4.22[a]	76.5 ± 6.82[b]

Different superscript letters within the same line indicate significant differences ($P<0.05$).
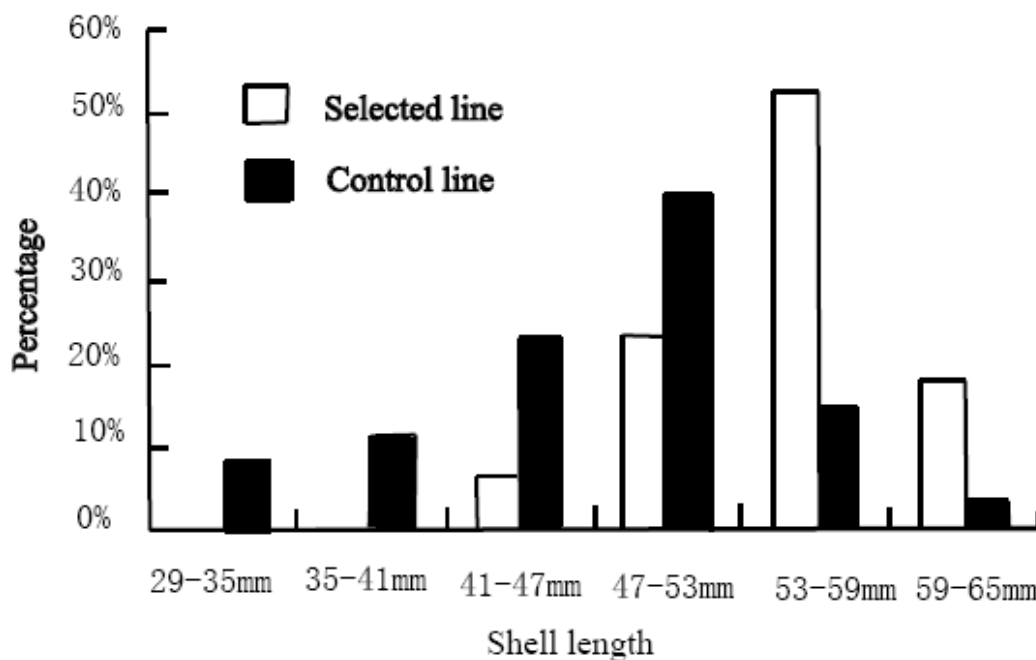
Figure 2. Size distribution of shell length of noble scallop, *C. nobilis* in the selected and control line on day 330 after fertilization.

weight also resulted in an increase of 9.5% after only one generation selection in the Pacific oyster, *Crassostrea gigas* (Langdon et al., 2003). In the present study, truncation selection led to a 15.16% (ranging from 9.23 to 18.64%) increase in shell length after one generation of mass selection. The estimated genetic gain is in agreement with expectations for other bivalves. All the studies indicate that selection response to faster growth is effective and improvement for growth traits can be achieved through only a few generations of selection.

Realized heritability of molluscan species for the selected traits had been reported in many studied.

Table 2. Current genetic gains (GG) and realized heritability (H_R^2) of shell height at different ages after one generation of selection in a stock of noble scallop, *C. nobilis* (Reeve).

Scallop age (day)	GG (%)	H_R^2
Spat		
30	0.1818	0.8661
40	0.1695	0.9623
50	0.1829	0.7873
60	0.1864	0.9073
70	0.1366	0.7057
80	0.1343	0.7423
Mean	0.1653 ±0.0238	0.8285 ±0.0997[a]
Grow-out		
100	0.1856	0.6579
140	0.1184	0.4368
180	0.1216	0.4913
250	0.1920	0.3948
300	0.0923	0.3422
330	0.1176	0.4030
Mean	0.1379 ±0.0408	0.4544 ±0.1112[b]

Different superscript letters within the same column indicate significant differences ($P<0.05$).

Though the estimated heritability may be influenced by some factors such as species or genetic background, development stage, etc (He et al., 2008), most heritability estimates in bivalves fall between 0.2 and 0.5 (Zheng et al., 2004). For larvae and juveniles, heritability estimates for shell length may vary greatly. For adults or commercial-size traits however, moderate realized heritability has been estimated in some bivalves. In the hard clam, *Mercenaria mercenaria* for example, heritability estimates for shell length ranged from 0.58 for prodissoconch I to 1.08 for 2-day-old larvae (Hilbish et al., 1993), and from 0.72 to 0.91 for juveniles (Rawson and Hilbish, 1990). Whereas, the estimated heritability for shell length was between 0.42 and 0.43 at grow-out stage (Hadley et al., 1991). Zheng et al. (2004) reported that heritability was different at different growth stages of the scallop, *A. irradians irradians*. In the first generation of one family selected for shell length, the realized heritability was 0.511, 0.338 and 0.341 at larvae, spat and grow-out stages, respectively but another family had significantly lower heritability (0.015, 0.040 and 0.080). In the bay scallop, *A. irradians concentricus*, the realized heritability of shell length was estimated to be 0.21 to 0.34 at grow-out stages (Heffernan et al., 1991; Crenshaw et al., 1991). In comparison with estimates for other bivalves, realized heritability of noble scallop *C. nobilis* at grow-out stage ranging from 0.3422 to 0.6579 is moderate.

Growth and survival rates, the indirect measures of final yield, are generally known as fitness-related traits. In the present study, survival of the select line was significantly larger than that of the control line, implying that there may be a positive genetic correlation between growth and survival in the stock of noble scallop. This was consistent with the result of other reporters in the literature that have considered the effects of selecting for increased bivalves body weight or growth on offspring survival. In *O. edulis* for example, Newkirk and Haley (1983) found that offspring of selected parents had significantly higher survival than offspring of unselected control parents. Jarayabhand and Thavornyutikarn (1995) found that survival of *Saccostrea cucullata* derived from parents selected for increased growth rate tended to be higher than survival of offspring derived from unselected control parents, though the trend was not significant. Ernande et al. (2004) found a strong positive correlation between growth and survival in one-year old Pacific oyster, *C. gigas* raised in France. Lastly, He et al. (2008) found that the survival of the selected line of pearl oyster, *P. fucata* was significantly larger than that of the control line in the grow-out stage. Contrary to the above results, inverse correlations between growth rate and/or body size and survival have been reported in a variety of taxa (Norry and Loeschcke, 2002; Miller et al., 2000; Bradford et al., 1999). In Pacific oyster for example, Boudry et al. (2004) selected for increase survival and showed no correlated response in individual body weight. Evans and Langdon, (2006) recently detected inverse relationships between adult midparent body weight and offspring survival in Pacific oyster in America.

The noble scallop *C. nobilis* (Reeve) is one of the most economically important fishery and aquaculture species in the southern coast areas of China. Our results indicate that a large amount of genetic variance remains in the cultured scallop stock, improvement for growth traits can be achieved through only one generation of selection and mass selection on growth improvement is promising.

ACKNOWLEDGEMENTS

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