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Genetics of Pearl Oyster in Relation to Aquaculture

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Abstract
Basic information on the genetics of the pearl oyster is described for producing pearls with a better quality by scientific breeding of this interesting and important aquaculture species of mollusk. Reduction of resources, caused mainly by overfishing, has motivated the production of seeds in hatcheries and the breeding of stocks. Shell coloration is a trait that can be easily recognized and its inheritance has been studied. Strains with a white prismatic layer and those with a non-yellow pearl layer of shell have been experimentally produced by selective breeding. Shell size has also been improved in selection experiments. Experiments on hybridization and inbreeding depression were conducted to estimate the combining ability for crossbreeding and the effect of inbreeding in selective breeding. Triploid pearl oysters were produced experimentally, by treating fertilized eggs with chemical or physical shocks, and evaluated for their aquaculture potential. The growth rate to mostly sterile triploid animals improved after the maturation stage of the life cycle whereas some of the triploids produced abnormal gametes. Further studies should be focused on gametogenesis and other important physiological characteristics for the application of triploidy to aquaculture.

Discipline: Fisheries/Aquaculture
Additional key words: heritability, inbreeding, selective breeding

Introduction

There is a long history of the use of pearls as jewels by man. Natural pearls have been collected by fishermen in the tropical and freshwater regions worldwide for many centuries. Overfishing has resulted in the decrease of the populations of valuable aquatic mollusks such as pearl oysters. Since the Japanese developed the technique of induction of pearls in cultured populations of pearl oysters, *Pinctada fucata* has become the most important and popular species for pearl production[15].

In Japan seeds of this species had been collected from the wild set after World War II using cedar leaves. Most of the seeds of the Japanese pearl oyster are still produced naturally and collected from wild spat. Artificial seed production was started about three decades ago in some hatcheries, which led scientists and farmers to initiate scientific breeding of this species in Japan. Basic information on the genetics and breeding of the Japanese pearl oyster and related species is described in this article.

Major traits for breeding

Traits studied for the breeding program in pearl oyster include shell width, shell convexity and color of shell nacre. The strategy of the breeding program for these traits in the

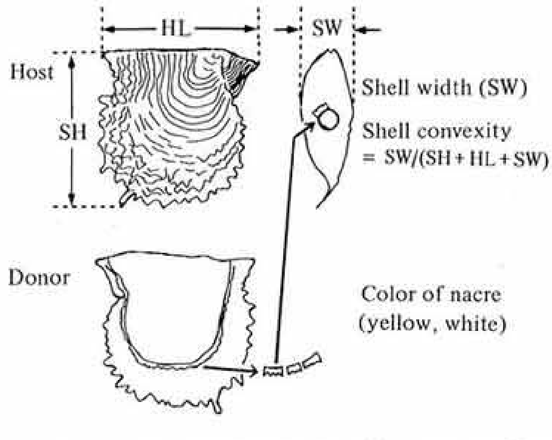


Fig. 1. Traits on which the breeding program has been focused in the pearl oyster in relation to pearl production

pearl industry is shown in Fig. 1. In order to produce pearls of better quality, it is necessary to use a host (animal into which the nucleus is inserted) with a large shell width and a donor (animal from which a piece of mantle is dissected and transplanted to the host animal) with good coloration of shell nacre.

Qualitative genetics

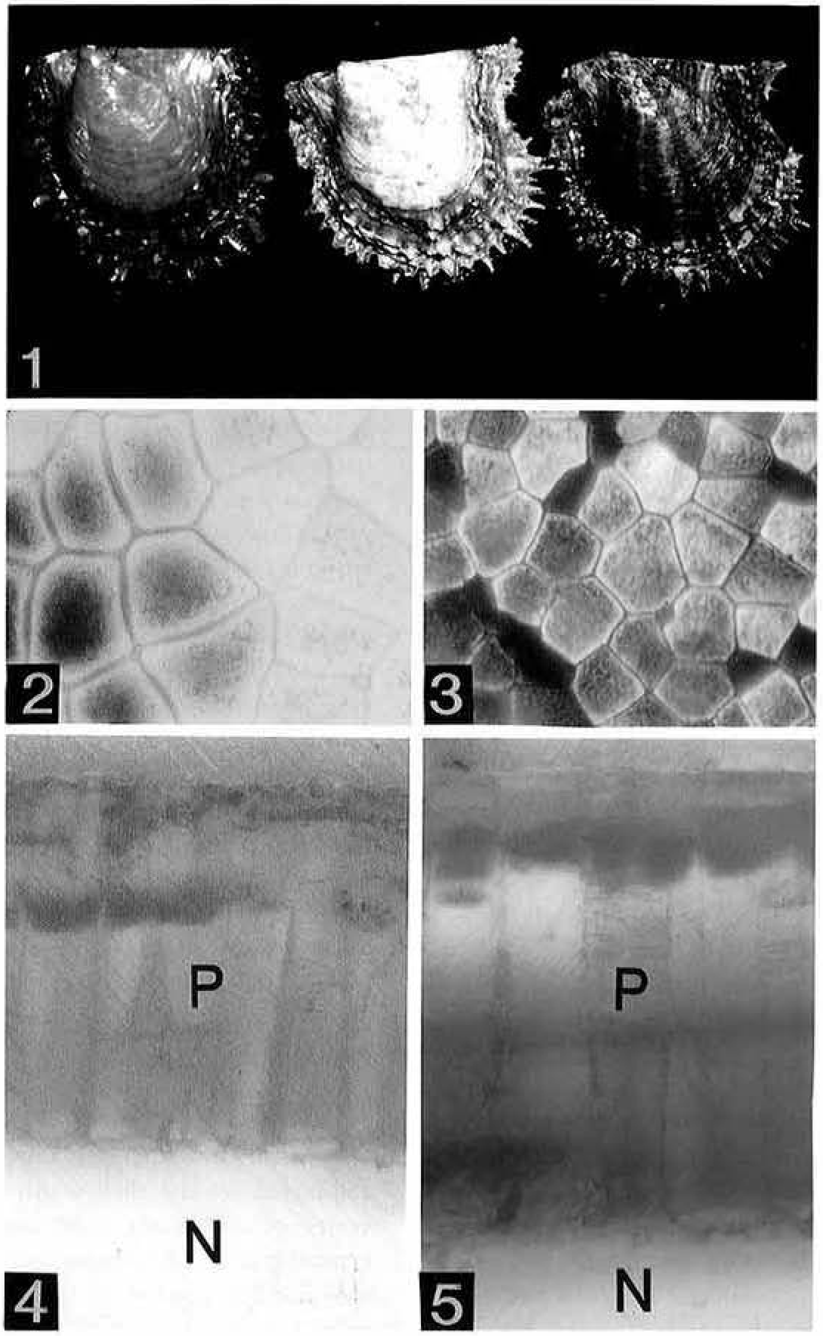
The external color of the bivalve shell is mainly associated with the pigments contained in the prismatic layer of the shells. The most common external color of this species is brown purple with dark brown spots or stripes. Sometimes red, yellow or white specimens without spots or stripes are observed. White specimens that were rare in wild populations have recently become more frequent in artificial seeds (Plates 1-5). Breeding experiments suggested that the white coloration is inherited under the control of recessive gene(s)[12]. All the offsprings from matings with white parents were white with a few exceptional brown types which may have been introduced accidentally from other matings. Meanwhile only the brown type of shells was obtained from the parental cross of white female × brown male. A 3:1 ratio of brown and white specimens was obtained from the F_2 of these matings. These ratios can be observed in crosses of brown heterozygous and white homozygous parents for a simple mendelian character. Preliminary studies showed that the amount of yellow pigments in the pearl layer (nacre) of the shell was smaller in white specimens than in brown ones[12]. These findings could be useful for the production of more valuable pearls lacking yellow pigments as described below.

The variation in the coloration of nacre is important in the pearl industry because the nacre color is closely related to the color of pearls. The mechanism of coloration seems very complicated. One reason for the color variation is the variable interference of light when it passes through crystals of nacre. Only the yellow color has been studied exclusively among the wide variety of nacre colors, because it is very important for the pearl industry. Most pearls contain yellow pigment in the nacre and they are less expensive than the pearls with other colors. Experimental transplantation of the mantle piece[5] showed that yellow pearls were mostly produced from the pearl sac formed by the mantle tissue from the animals with yellow nacre. Selection experiments showed that this trait may be inherited.

Quantitative genetics

1) Selection experiments

Regarding the shell size, selection trials were conducted on the shell width and shell convexity of 3-year-old pearl oysters for three generations[7,8]. Divergent selection in which only one line selected for the direction to small value was raised in the first generation showed that the selection of shell width was more suitable for the improvement of shell width than that of shell convexity. Variation in the selection response was attributed to sampling error and genetic drift since a small number of parents and offsprings were used in each



Plates 1-5. Shell coloration of the pearl oyster (N: Nacre, P: Prismatic layer)
1. Three major color types of the shell (color of prismatic layer),
2. Prismatic layer of white type of shells observed at the edge of shell,
3. Prismatic layer of brown type of shells observed at the edge of shell,
4. Transverse thin section of the white type of shell,
5. Transverse thin section of the brown type of shell.

Table 1. Realized heritabilities of shell width and shell convexity estimated from the selection response in two experiments at 3 years of age[11)]

Trait		Generation	Heritability[a)]		
			Large	Small	Both
Shell width	Experiment I	0 – 1st	–	0.245	–
		1st – 2nd	0.345	0.127	0.213
	Experiment II[b)]	0 – 1st	0.460	0.009	0.231
Shell convexity	Experiment I	1st – 2nd	0.128	0.333	0.215
		2nd – 3rd	0.095	–	–
	Experiment II	1st – 2nd	0.368	0.274	0.318
		2nd – 3rd	0.092	0.735	–

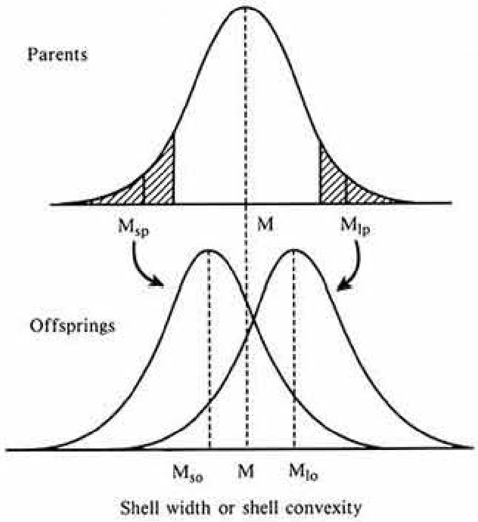
a): Calculation of heritability(h^2):

Large: $h^2 = (M_{lo} - M)/(M_{lp} - M)$,
Small: $h^2 = (M_{so} - M)/(M_{sp} - M)$,
Both: $h^2 = (M_{lo} - M_{so})/(M_{lp} - M_{sp})$.

where

M : Mean value of the base population from parents with small or large values of shell width (SW) on shell convexity (SC) were selected,
M_{lp}: Mean value of the parents selected for large SW or SC,
M_{sp}: Mean value of the parents selected for small SW or SC,
M_{lo}: Mean value of the offsprings from the parents selected for large values,
M_{so}: Mean value of the offsprings from the parents selected for small values.

b): Estimated at 2 years of age.



cumulative selection differentials were 0.467 for the shell width and 0.350 for the shell convexity[8)]. Realized heritabilities were also estimated from the selection response in these and other experiments on the shell traits based on the values in the respective generations as shown in Table 1[11)].

Effective responses were observed in the selection experiment on the yellow nacre color of shells for three generations[9)] (Fig. 2). Selection response in experiments had been effective, showing that the frequency of the more desirable shells without yellow pigments (white) increased by the third generation to 80% from a base population with 20% of non-yellow pigments. Transplantation of the mantle tissue was carried out using animals from the second generation of selection and yellow pearls were produced at a higher rate in the group of oysters selected for yellow nacre than in those for nacre without yellow pigments[9)]. Since no significant difference was observed in the mortality of pearl oysters or in the rate of pearls with a low grade between the two groups, these results suggested that pearls without yellow pigments could be produced efficiently by selective breeding. However the weight of the pearls produced from the group selected for the yellow color was heavier than that from groups selected for pearls without yellow

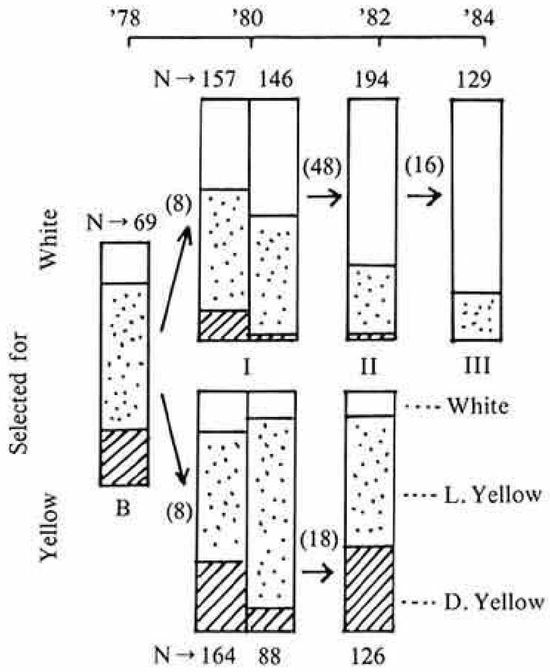


Fig. 2. Changes in the frequencies of color of the nacre in selection lines of the pearl oyster
: Shells with dark yellow nacre,
: Shells with light yellow nacre,
: Shells with white nacre.
Shells were observed with the naked eye in 1978, 1980, 1982 and 1984.
Selection and spawning were performed in 1978, 1980 and 1982.
Figures in parenthesis indicate the number of parents which were selected and spawned. N indicates the number of offsprings observed[9].

pigments[9]. It may thus be necessary to determine whether the phenotypic correlation between the weight of pearls and coloration is of genetic or environmental origin because the weight of pearls is another important component of pearl quality.

2) Heritability estimation

The heritabilities of growth at the larval stage at different ages were estimated by analysis of variance using the samples from two sets of factorial matings[14]. The estimated average values were 0.335, 0.181 and 0.078 at ages 5, 10 and 15 days, respectively. Heritabilities of several adult attributes were estimated by the analysis of three full sib families[6]. However, the estimates in this report were based on very small sample sizes. The standard errors were large and the genetic variance was not clearly separated into additive and non-additive components. Further studies should be carried out for obtaining more reliable estimates of the heritability of these traits by the development of a more sophisticated program.

3) Intraspecific hybridization

Hybridization of geographical strains or selected strains has been performed to estimate the extent of hybrid vigor or general combining ability to produce useful strains[7]. The shell width and viability (survival) were improved in the crossed lines compared to inbred lines. Survival rate of crossbred lines was higher than that of inbred lines and in the third generation of the inbred lines the survival was less than 50% beyond 34 months of age. Shell width was also larger in the crossbred lines than in the inbred lines. The improvement of the shell growth and viability by intraspecific hybridization are examples of hybrid vigor. In other experiments on intraspecific hybrids, two selected lines were hybridized and the shell traits and survival rate of the crossbred and random control lines were compared. One of the parental lines was the strain selected for 5 generations for yellow shell coloration and larger shell width and the other line was that selected for larger shell convexity. The results revealed an apparent improvement in shell traits and survival rate in the crossed lines[7].

4) Inbreeding

The extent of inbreeding was estimated on the basis of the genetic variability at four electrophoretically detectable polymorphic loci in several lines which had been selected for six generations. Since the effective number of parents was small in this study, inbreeding may be the cause of the loss or reduction of the general variability. An excess of heterozygotes was observed in many lines[10].

The influence of inbreeding in this species has been reported. Wada[7] observed an unusually high mortality in the 3rd generation of a selected inbred line which may be due to inbreeding depression. Another possible case of inbreeding depression was reported[17] in the strains bred for white prismatic layer of shells in commercial farms.

Triploidy

1) Induction of triploidy

Various treatments of eggs including the application of cytochalasin B (CB), heat or cold shock have been examined for the induction of triploidy in pearl oyster[2,13]. The most effective procedure for inducing triploidy was the treatment of eggs with 0.5 mg/*l* CB from 20 to 50 min after insemination which yielded 100% triploid juveniles[13]. Caffeine (13 mM) was also reported to be effective for inducing triploidy when combined with heat shock[1]. The treatments of eggs with these shocks resulted in major damage to development, hatchability and metamorphosis of embryos and larval growth. These abnormal developments may be partly due to the aneuploidy induced by the treatments.

2) Growth and sexual maturity of triploids

Triploids became much larger after maturation (ca. 1 year of age) compared with the diploids presumably because the energy for maturation was converted to growth[4]. Similar results were also reported in the Chinese species[3]. However we observed that the average value of the shell width was smaller in the triploid population than in the diploid population at the juvenile stage.

Some triploid Japanese pearl oysters produced spermatozoa and oocytes, although the number of gametes in the gonads was substantially reduced compared with the diploid animals[4]. Seasonal histological observation of gonads revealed that many triploids produced mature gametes in the spawning season for diploids. The spermatozoa dissected from triploid testis showed abnormal DNA contents compared with normal diploid spermatozoa. The Chinese species, *Pinctada martenseii*, was reported to be sterile without any gonadal development in triploid animals[3] although histological illustrations have not been presented. It is necessary to determine whether triploid gametes are released and whether they affect natural or cultured populations before the application of triploidy to aquaculture in nature[16]. Also further studies should be focused on other important characteristics of the triploids.

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