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Host and donor influence on pearls produced by the silver-lip pearl oyster, *Pinctada maxima*

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ABSTRACT

The value of a pearl depends upon five major traits — pearl size, colour, lustre, shape, and surface. To determine host and donor oyster contributions to these traits, a large-scale mantle seeding experiment was conducted in which grafts from 56 donors were used to induce pearl production in 1099 hosts of the silver-lip pearl oyster, *Pinctada maxima*. Pearls were harvested two years after seeding and individually graded. The amount of nacre deposition, lustre, and two types of defects were associated with host traits, whereas all traits were significantly associated with the donor oyster. A number of correlations between pearl quality traits were also found. These results suggest that potential exists to increase pearl quality via the selective breeding of host and donor oysters, but reveals that careful attention must be paid to potential trade-offs in the design of such breeding programmes.

1. Introduction

The Indo-Pacific pearl industry is primarily based upon larger species within the *Pinctada* genus — *Pinctada maxima*, *Pinctada margaritifera*, and members of the *Pinctada fucata* species complex (Southgate and Lucas, 2008). Within the last decade, there have been regional pressures on the industry that have included the poor regulation of supply, environmental issues such as disease and pollution and the overfishing of wild stocks. Additionally, the entire industry has suffered in recent times from the current strained economic climate.

The majority of the pearling industry in Australia is based upon the silver (or gold)-lip pearl oyster, *Pinctada maxima*, and operates under a strict quota system (Southgate and Lucas, 2008). Therefore, increased profitability is reliant on the increase of pearl quality as opposed to an increase in the scale of pearl production. Recent adoption of hatchery-based technologies has allowed pearl producers to become less reliant on wild-caught oysters, and is a positive step towards the implementation of large-scale selective breeding programmes that target increasing the prevalence of desired pearl traits (Southgate and Lucas, 2008).

The production of cultured pearls involves the implantation of a circular nucleus and a piece of mantle tissue (saibo) into the gonad of a host oyster. The saibo grows around the nucleus to form a fully enclosed pearl sac that produces secretions, resulting in the deposition of nacre onto the nucleus (McDougall et al., 2013; Southgate and Lucas, 2008). Usually the saibo originates from a different oyster to that in which the pearl is grown, and there is some evidence that while many pearl characteristics (such as colour and lustre) are dictated by the saibo donor (Ky et al., 2013; McGinty et al., 2010; Tayale et al., 2012; Wada and Komaru, 1996; Zhifeng et al., 2014), the eventual size of the pearl is dictated by the host (Ky et al., 2013; Shi et al., 2013; Wada, 1986). Although the majority of genes expressed within the pearl sac originate from the donor (as expected given that the sac is thought to form via the proliferation of donor epithelial cells), some host transcripts of biomineralisation genes have also been detected (McGinty et al., 2012), indicating that the production of the pearl may be the result of a complex interplay of donor and host genomes.

The value of a pearl depends on five primary characteristics — lustre, colour, size, shape and surface. Large, round, lustrous pearls command the highest prices, and particular colours are preferred over others. For South Sea Pearls produced by *P. maxima*, silver-pink, silver, and gold pearls are highly desirable, whereas pearls exhibiting creamy or yellow tones are less so. The majority of cultured pearls possess surface defects to differing extents. These defects can significantly reduce the value of an otherwise high-quality pearl. Although pearls are generally given a single grade for the 'surface' category, a number of different types of defects can be observed. These include 1) spots — small, round indentations in the nacre, 2) calcification — raised opaque patches, 3) hammer — a macroscopic golf ball-like appearance over the surface, or 4) underskin — small wrinkles. Whether these defects have the same underlying cause is unknown.

Here, we conducted a large-scale pearl seeding experiment in *P. maxima* to investigate donor and host contributions to, and

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correlations between, pearl quality characteristics. This includes a particular focus on the different types of pearl defects that are generally treated as one trait. Understanding whether these characteristics correlate with host or donor traits is an important step towards increasing pearl quality by selecting the best oysters for the different elements of pearl production.

2. Methods

2.1. Experimental design

Adult specimens of *P. maxima* were sourced from the population at 80 Mile Beach, Western Australia. A mixture of wild caught (23 donors, 471 hosts; likely ranging from two to four years of age) and hatchery bred oysters (33 donors, 628 hosts; approximately two years of age) were used for the experiment. Donor tissue (saibo) was dissected from both mantle lobes of each donor and cut into approximately 3 mm^2 pieces as per usual industry practice. The number of pieces obtained was dependant on the size of the animal, with an average of 20 and a minimum of 16 pieces per individual. This saibo was used to seed a total of 1099 host oysters (wild donors were used to seed wild hosts, and hatchery donors to seed hatchery hosts). Each host was individually tagged, and the donor oyster (saibo source), nuclei size and host oyster size (dorso-ventral and anterior–posterior length) was recorded. Nuclei size depended on the size of the host oyster and ranged from 2.0 to 2.6 bu (standard industry measurement: 6.06 to 7.878 mm diameter). Graft cutting and seeding operations were each performed by a single experienced pearl technician. Oysters were placed into panels and returned to longlines as per standard practice.

Pearls were harvested 25 months after seeding. The gender (male, female, or non-reproductive) and host oyster size was recorded. Pearls were individually bagged, cleaned using mild detergent, and assessed by a single professional pearl grader. Pearls were assessed for shape, size, shine (lustre), shade (colour) and surface based upon the Five S's™ pearl classification system (Pearlautore International Pty Ltd, 2006; Table 1), with additional subdivision of the 'surface' category into the four types of defect (spots, hammer, underskin, calcification). The dorso-ventral and anterior–posterior measurements taken at seeding were subtracted from those at harvest to represent host shell growth.

Table 1
Pearl classification system used in this study.

Trait	Category	Definition
Shape	Round	Variation in diameter less than 2.5%
	Near round	Variation in diameter more than 2.5%, but shape is still round overall
	Drop	Vertical axis longer than horizontal axis, teardrop shape
	Oval	Vertical axis longer than horizontal axis, oval shape
	Button	Horizontal axis longer than vertical axis
	Baroque	Irregular or free form shape
	Circle	One or more parallel grooves etched around circumference
Size		Measured in millimetres, measurement taken at the widest point of the horizontal axis
Shine (Lustre)	A	Brilliant lustre producing a mirror reflection
	B	Good lustre producing a good reflection
	C	Average lustre: the reflection appears opaque
	D	Poor lustre: producing very little reflection
Shade (Colour)[a]	White range	White
		White pink
		White green
		Silver
		Silver white
		Silver pink
		Light silver
		Light silver green
		Pink
	Yellow range	Yellow
		Cream white
		Cream white pink
		Cream yellow
	Other	Fancy (mixture of several colours)
Surface (Spots)		None
		Light spots
		Spots
		Very spotty
		Deep spots
		Very deep spots
Surface (Hammer)		None
		Light hammer
		Noticeable hammer
Surface (Underskin)		None
		Noticeable underskin
Surface (Calcification)		None
		Light calcification
		Noticeable calcification

[a] Only colours found within this study are included in the table. Printed by permission of Pearlautore International Pty. Unauthorised publication whether in full or in part is a breach of copyright.

2.2. Statistical analysis

Host gender at harvest, size at seeding and growth were treated as fixed variables for statistical analysis, with the donor treated as a random variable unless otherwise stated. All analyses were performed using the program 'R' (R Core Team, 2014). A linear mixed-effects model was used to assess the effect of the fixed and random variables on nacre deposition, and a generalised linear mixed-effects model (family = binomial) for the presence or absence of underskin, both using the package lme4 (Bates et al., 2014). Analyses of ordered categorical response variables (lustre, hammer and calcification) were performed using cumulative link mixed models implemented in the package ordinal (Christensen, 2014). Colour, shape and spottiness are unordered categorical variables and were analysed using multinomial log-linear models in the package nnet (Venables and Ripley, 2002), with donor treated as a fixed variable.

The significance of fixed variables was tested by comparing the fit of an all-inclusive model with that of a reduced model for each variable using a chi-squared test. Where more than one variable was found to be significant, the fit of a model containing these variables was compared with models lacking each variable to determine whether significance was retained in the reduced model. Where donors were treated as a random variable, the conditional modes and variances were plotted for each donor. The 'donor effect' for a given donor was deemed to be significantly different from the mean if the confidence interval did not span 0.

Correlations between pearl quality traits were assessed using Chi-squared tests implemented in R. Due to the large number of comparisons, multiple testing corrections were applied by adjusting the p-value threshold of significance (0.05) by dividing by the number of comparisons performed in each test.

3. Results

A total of 671 pearls were harvested from the experimental animals, this number was less than expected due to losses during a major cyclone event. Host oyster dorso-ventral and anterior–posterior measurements were found to be highly correlated (data not shown), therefore 'size at seeding' and 'host shell growth' are represented by the anterior–posterior length only.