Novel cultured pearls with ceramic nucleus and possible cause of their strong luster

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Cultured pearls with a ceramic nucleus (bead) represent a new type of saltwater cultured pearls that has recently emerged. Its growth process is similar to that of ordinary cultured pearls and the detailed process of producing them is outlined in the supplementary material. While they resemble Akoya cultured pearls in appearance, they often show a stronger luster (Fig.1). In pearl valuation, luster is one of the most important criteria, which may enable cultured pearls with ceramic nucleus to be a new type of high-quality cultured pearls. Therefore, the underlying reason for their enhanced luster requires investigation, possibly linked to their unique ceramic nuclei and the structure and reduced thickness of their nacre layers. This report explores a new method for cultivating superior cultured pearls at a lower cost, demonstrating the feasibility and advantages of using ceramics as the nuclear material for pearl cultivation.

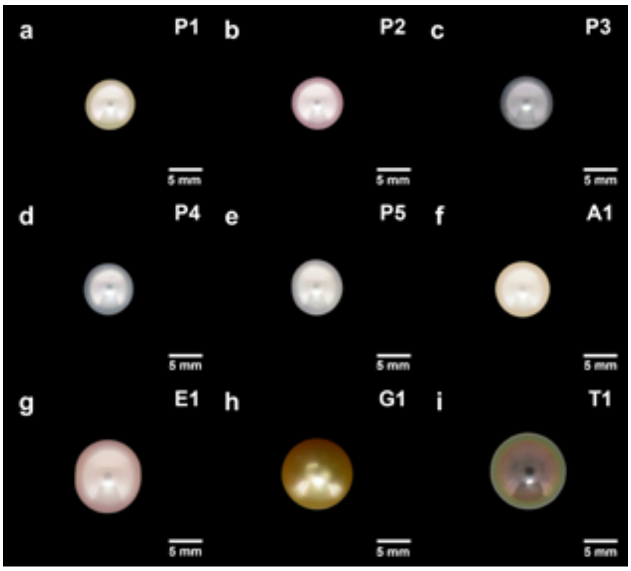

Fig. 1 Nine different pearl samples: (a-e) Novel cultured pearls with ceramic nucleus (P1-P5); Akoya cultured pearl (A1); Edison cultured pearl (E1); Golden cultured pearl from the South Sea (G1); Tahiti cultured pearl (T1), all with shell beads.

As technology continues to advance, a growing focus is placed on using non-destructive and rapid methods to detect and analyze pearls. Among these techniques, three-dimensional (3D) fluorescence and Energy Dispersive X-ray Fluorescence (EDXRF) are useful non-destructive testing methods to characterize pearls [L. Shi *et al.*, 2018, Y.J. Li *et al.*, 2023]. For this study, we analysed five cultured pearls with ceramic nucleus (samples P1-5) and four Akoya-type reference samples (A1, E1, T1, G1) using advanced characterization techniques such as EDXRF, 3D fluorescence spectroscopy, photoluminescence (PL) spectroscopy, UV-visible (UV-vis) spectroscopy, Fourier Transform Infrared (FTIR) Spectroscopy, and Scanning Electron Microscopy (SEM) (Fig.2). 3D fluorescence spectroscopy shows that the P1-5 (Fig.3a-e) and A1 (Fig.3f) are characterized by the presence of two fluorescence centers located at approximately 374/446 nm and 374/462 nm within the E_x / E_m range, which were distinctly different from those of the other pearl samples [Y.J. Li, C.Y.F. Chen and L.P. Li, 2023] (Fig.3g-i).The appearance of dual fluorescence peaks at 446 nm and 462 nm upon excitation at 374 nm is characteristic of humic acid luminescence [Y.J. Li and L.P. Li, 2023]. This indicates that the primary organic components of P1-5 and A1 include humic acid, distinguishing them from other samples. The presence of humic acid may lead to the fluorescence quenching of amino acids, such as tryptophan. The greater the concentration of humic acid, the more pronounced the fluorescence quenching phenomenon becomes [Z. Wang *et al.*, 2015], which leading to the weaker tryptophan luminescence of P1-5 and A1. Therefore, it can be concluded that the pearl oysters producing cultured pearls with a ceramic bead are consistent with those that produce Akoya pearls. Therefore, it can be concluded that the pearl oysters producing cultured pearls with a

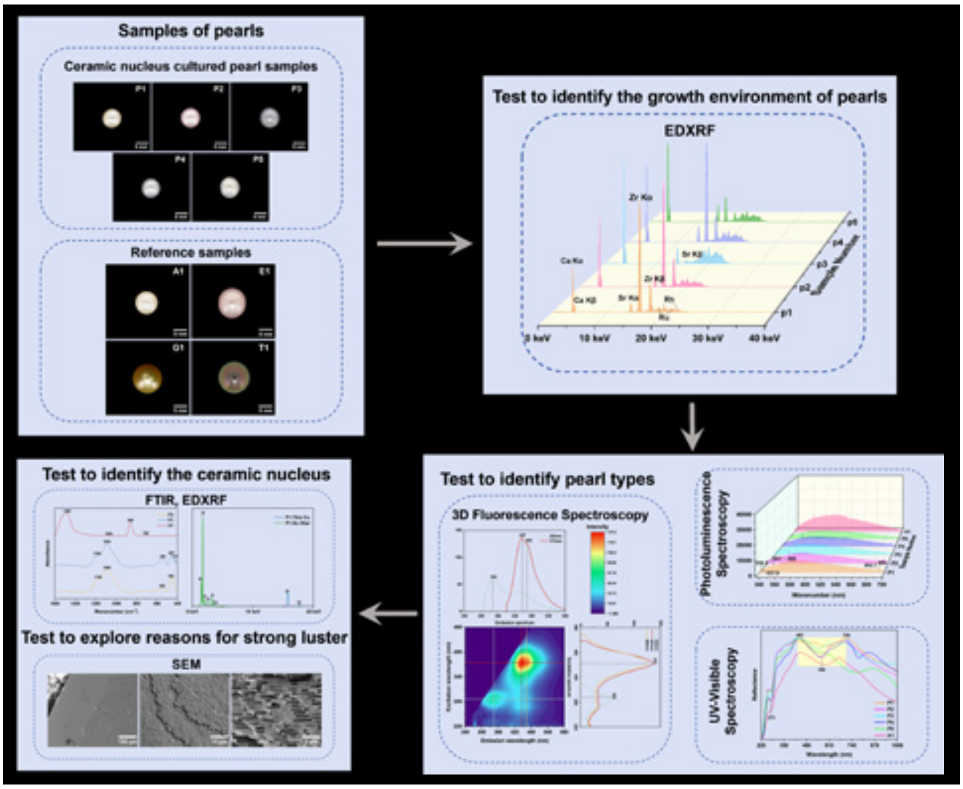

Fig.2 Flowchart of novel ceramic pearl analysis and testing.

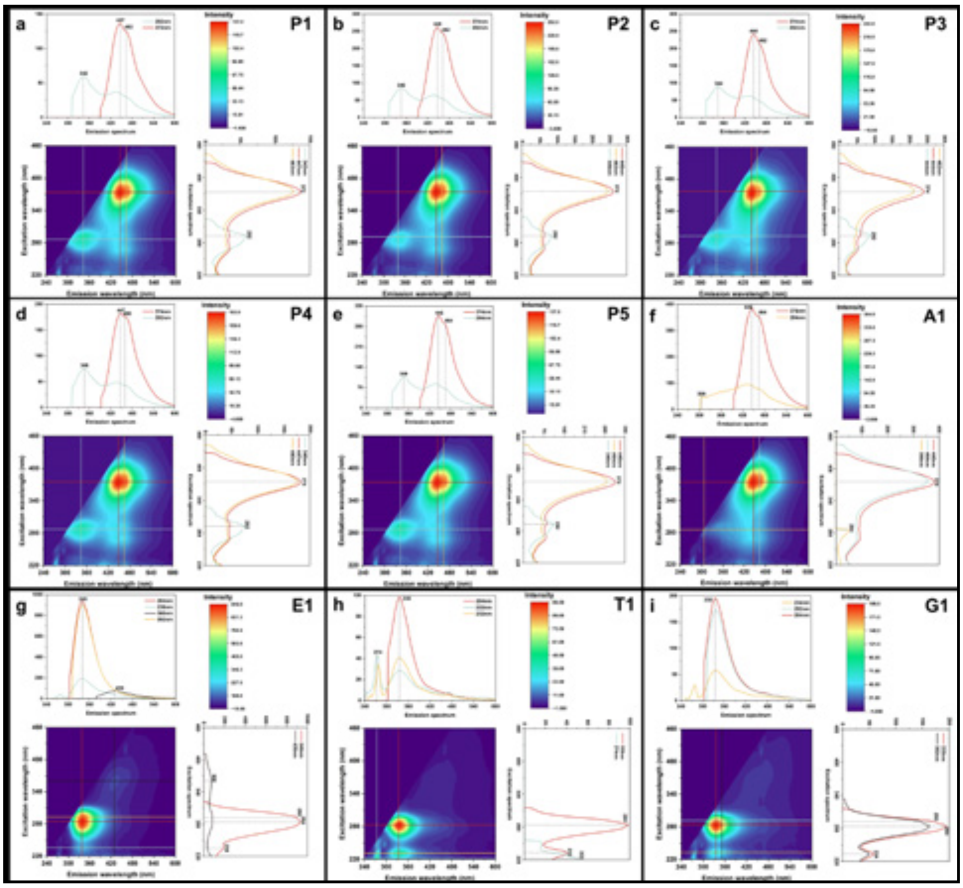

Fig.3 3D fluorescence spectra of (a-e) novel ceramic-nucleus cultured pearl samples P1-P5 and (f-i) reference samplesA1, E1, T1, G1.

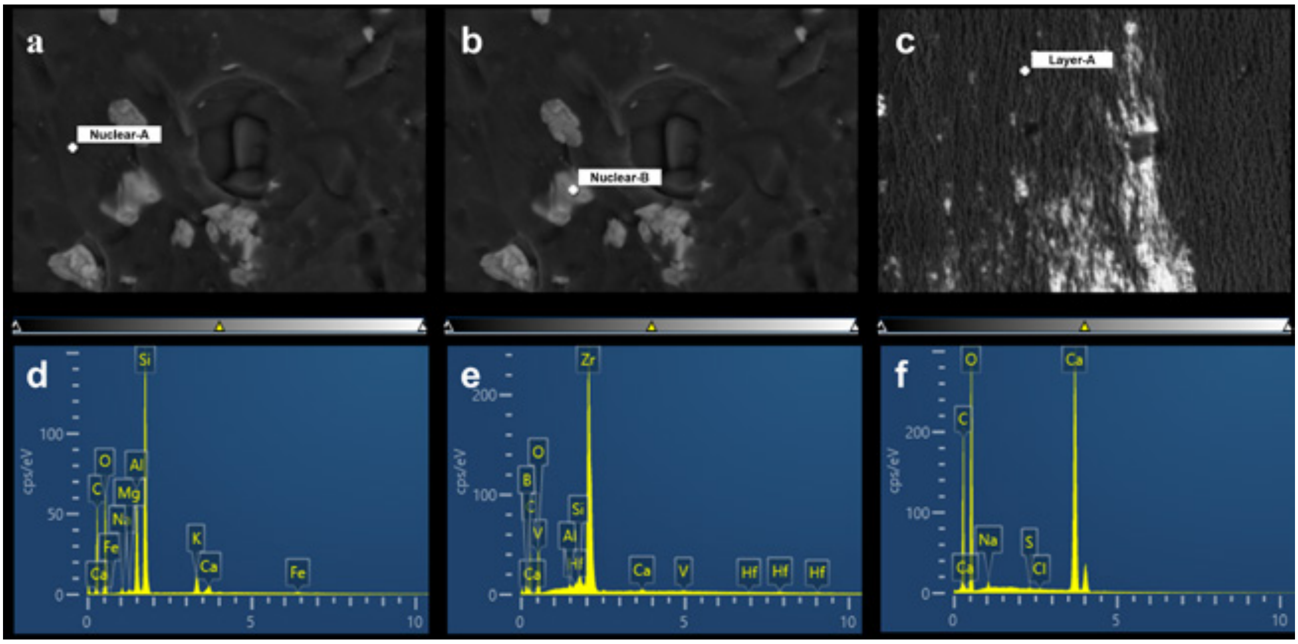

Fig. 4 (a-b) SEM images and (d-e) EDS spectrum of the bead of P1 at different positions; (c) SEM image and (f) EDS spectrum of the nacre layer of P1.

ceramic bead are consistent with those that produce Akoya pearls. Combing with the result of EDXRF which proves the cultivated environment of are sea water, we have confirmed that the mother oysters used for cultivating cultured pearls with ceramic beads are the same as those used for akoya cultured pearls (*Pinctada martensii* oyster). Based on our study, a key feature to differentiate cultured pearls with such a ceramic bead from traditional akoya cultured pearls using a bead from a shell (usually freshwater mollusc) can be found in the EDXRF testing. Our pearl samples with ceramic bead revealed strong and characteristic peaks of Zr due to the fact that their nacre layer was very thin and Zr (as a heavy element) from the bead material was easily detectable even through the nacre. This was confirmed by energy dispersive spectroscopy analyses of both, the nacre layer of the cultured pearl and the ceramic nucleus after cutting such a pearl into two halves (Fig.4). These analyses clearly confirmed that the abnormal Zr concentrations detected in EDXRF testing originated from the ceramic bead.

To further investigate the reasons for the stronger luster of cultured pearls with a ceramic bead, SEM analysis was conducted on the surface, and cross-section of the nacre layer [F. Fu *et al.*, 2014] (Fig.5). Obviously, the hexagonal aragonite platelets on the surface of our samples with ceramic beads (P1 and P3) exhibits a regular, relatively flat morphology, characterized by regular shapes and fewer cracks. But the interlayer of A1 possesses a lot of peeled aragonite debris, which increases surface diffuse reflection and easily reduces its luster (Fig.5d-i). From the perspectives of surface roughness, the strong bonding mechanism between the nacre layer and the ceramic nucleus was additionally analyzed: The uneven boundary between the layer and the nuclear indicates that the surface roughness of the ceramic bead is higher than that of the shell bead used in traditional Akoya-type pearl cultivation. (Fig.5a-c). Based on SEM analyses, we assume that the strong luster of the new cultured pearls originates from the use of ceramic nuclei, which facilitates the tight bonding of nacre layer and nuclei as well as the uniform growth and distribution of nacre layers. Additionally, the thinner nacre layer with an average thickness of 0.37 μm of these new cultured pearls with ceramic beads might be considered an advantage due to shorter cultivation time and lower production costs, although they might

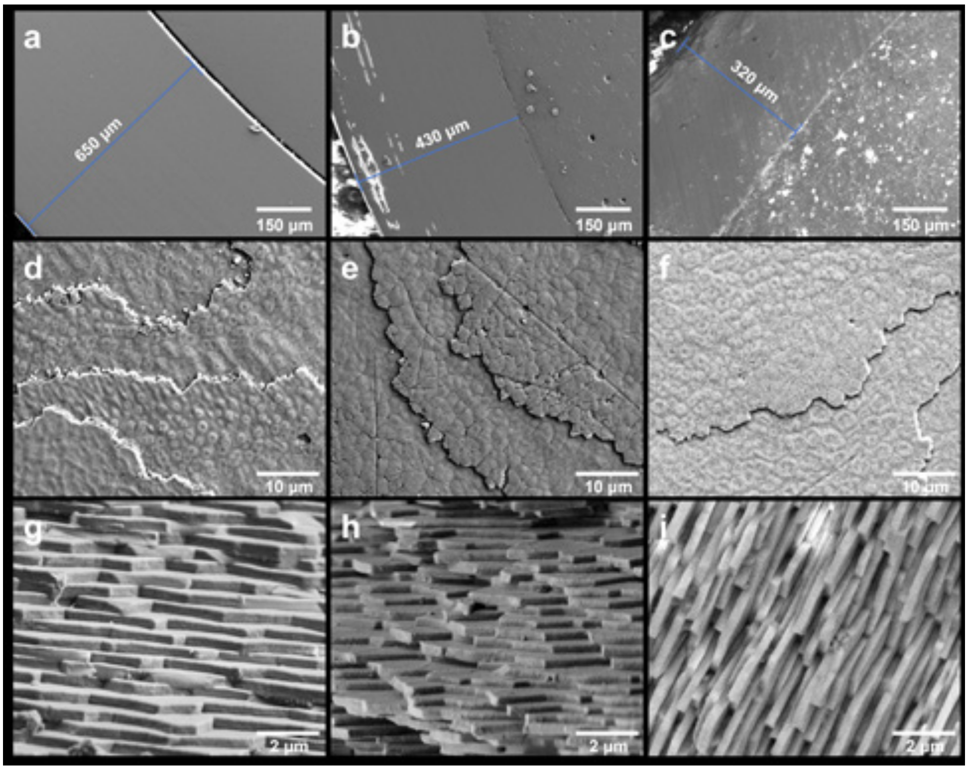

Fig.5 (a-c) SEM images of the nacre layer thickness of A1, P3 and P1, (d-f) SEM images of the surface structure of A1, P3 and P1 nacre layers, (g-i) SEM images of the cross-section of A1, P3 and P1's nacre layer.

be damaged easier than that of common cultured pearls. In summary, cultivating pearls with a ceramic nucleus may be an effective method for enhancing pearl luster, providing interesting ideas for pearl cultivation.

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