International Journal of Aquaculture, 2023, Vol.13, No.9, 1-7
http://www.aquapublisher.com/index.php/ija

Review and Progress Open Access

Analysis of the Morphology, Optical Properties and Internal Structure of Pearls

Zhong Yuanyuan
Oromia Hangzhou Songyang Biological Technology Co. Ltd., 310000, Hangzhou, China
Corresponding author Email: 3048511772@qq.com

International Journal of Aquaculture, 2023, Vol.13, No.9 doi: 10.5376/ija.2023.13.0009
Received: 06 Nov., 2023
Accepted: 24 Nov., 2023
Published: 14 Dec., 2023

Preferred citation for this article:
Zhong Y.Y., 2023, Analysis of the morphology, optical properties and internal structure of pearls, International Journal of Aquaculture, 13(9): 1-7 (doi: 10.5376/ija.2023.13.0009)

Abstract As rare and precious gemstones, pearls have consistently captivated hearts with their unique charm and noble identity. The beauty of their appearance and the mystery of their internal structure have prompted in-depth research into their formation process and characteristics. This review aims to explore the significance of analyzing the morphology and internal structure of pearls in scientific research and industrial development. In-depth research into the morphology and variations of pearls is conducive to scientifically identifying their authenticity and quality, thereby enhancing their value in the fields of jewelry art and decorative industries. By delving into the internal structure of pearls, scientific evidence can be provided for their processing and utilization, expanding their application value in gemology, materials science, and other domains. Simultaneously, this analysis holds vital importance for the conservation of pearl resources and the promotion of sustainable industry development. Looking ahead, the investigation of the morphology and internal structure of pearls will continue to attract the attention of numerous researchers, providing inexhaustible impetus for innovation and development in the pearl industry.

Keywords Pearl form; Internal structure; Optical properties

Pearls are organic gemstones produced by mollusks or bivalve mollusks through endocrine processes. Their natural beauty is inherent, and they are exquisite and precious adornments that require no artificial carving or processing. Pearls have soft colors, beautiful luster, delicate, and clean textures, each possessing its unique charm. They not only represent a form of jewelry art but also carry a rich historical and cultural significance and emotional value. The history of pearls can be traced back to ancient times, and people began to appreciate and use them thousands of years ago. In ancient legends and historical records, pearls are often praised as "natural treasures" and "teardrops of the moon," revered as symbols of nobility and good fortune. In ancient cultures, pearls were often endowed with mystical symbolism, considered sacred and pure, and were hailed as the "pearl of kings" and the "tears of the goddess," among other epithets. The beauty and mystique of pearls have captivated people's attention worldwide, making them treasures in various cultures.

With the continuous advancement of science and technology, our understanding of the morphology and internal structure of pearls has deepened. A comprehensive understanding of the morphological characteristics and internal structure of pearls holds significant importance in the fields of pearl identification, processing, and utilization, as well as in research areas such as gemology, materials science, and geology. The morphological characteristics of pearls primarily encompass aspects such as size, shape, color, and luster. These features not only determine the aesthetic and commercial value of pearls but also serve as the foundation for their various applications. On the other hand, the internal structure of pearls involves their layered structure, the distribution of organic and inorganic matter,, and microscopic structures and crystal forms. These structural features directly influence the stability, hardness, and wear resistance of pearls.

In terms of morphological characteristics, this review will elaborate on the morphological classification of pearls, exploring the patterns of size, shape, and color variations, and conducting an in-depth examination of their luster and surface features. As for internal structure, this review will provide a detailed analysis of the layered structure within pearls, investigating the distribution patterns of organic and inorganic materials, as well as the microscopic structure and crystal morphology of pearls. Additionally, this review will delve into the optical properties of pearls,

including their refractive index, dispersion, optical wave interference, as well as characteristics related to fluorescence and phosphorescence.

This review will primarily focus on the analysis of the morphological characteristics and internal structure of pearls to comprehensively reveal their formation mechanisms and allure. By delving deep into the morphology and internal structure of pearls in this review, it aims to provide a more accurate explanation and understanding of their formation process, offering a scientifically grounded basis for the identification, processing, and various applications of pearls. Furthermore, this review will also provide insights into the future direction of pearl research and industry development, with the aim of further advancing the field of pearl studies and contributing to its broad applications in disciplines such as gemology, medicine, and materials science. As a natural gem, the unique beauty found in the morphology and internal structure of pearls will continue to captivate the curiosity and research endeavors of countless individuals.

1 External Morphological Characteristics of Pearls

1.1 Classification of pearl morphology

Pearls are a highly diverse gemstone, and their morphology can be classified based on several factors. Depending on their source, pearls can be categorized into freshwater pearls and saltwater pearls. Freshwater pearls are primarily produced by mollusks in freshwater lakes and rivers, while saltwater pearls come from marine mollusks such as oysters and pearl mussels (Vitucci et al., 2018). Freshwater pearls are favored for their relatively abundant production and a wide range of colors, whereas saltwater pearls are preferred for their larger size and exquisite luster, making them the choice for high-end jewelry.

Pearls can also be classified based on their shape. Pearls can be categorized into various types based on their external form, such as round pearls, semi-round pearls, oval pearls, flat pearls, and button pearls, among others. Round pearls (Figure 1) are the most common shape, characterized by a naturally smooth and spherical appearance, making them the primary material for pearl necklaces and pearl earrings. Semi-round pearls and oval pearls are often used as complementary decorations in pearl necklace designs, adding vibrancy to jewelry pieces. Button pearls and flat pearls, on the other hand, are relatively rare, with flat and irregular shapes, and are frequently utilized in crafting distinctive pearl bracelets and rings.

Figure 1 The round pearls

1.2 Pearl's size, shape, and color

The size of pearls is one of the most visually apparent aspects of their morphology. Pearl size is typically measured by diameter, and the most common pearl sizes range from 2 to 10 mm. Among these, pearls with diameters between 2 mm and 5 mm are referred to as small pearls, those between 5 mm and 8 mm are classified as medium pearls, and pearls with diameters exceeding 8 mm are considered large pearls. With the advancement of technology and cultivation techniques, there are now giant pearls with diameters exceeding 10 millimeters.

In addition to size, the shape of pearls also influences their aesthetic appeal and practical value to some extent. Round pearls are the most valuable and popular shape, with their spherical appearance allowing light to reflect fully on the pearl's surface, creating a distinctive luster (McDougall et al., 2021). Semi-round and oval pearls, on the other hand, serve as complementary decorations in pearl necklaces, imparting a more dynamic and lively visual effect to the jewelry. Irregularly shaped button pearls and flat pearls offer pearls a more unique and distinctive design potential, often used in creating artistic pearl jewelry.

The color of pearls is one of their most captivating external features. Pearls come in a wide range of colors, including white, pink, gold, black, blue, and more (Figure 2). Among these, white pearls are the most common and traditional color, as well as one of the most popular. Pink pearls are often sourced from freshwater mollusks, and their warm color gives a sense of warmth and coziness. Gold pearls and black pearls are relatively rare, with rich and deep colors that add an air of mystery and nobility to pearl jewelry. Blue pearls, known for their unique color, garner significant attention and are frequently used in crafting luxurious and high-end jewelry pieces.

Figure 2 Multiple colored pearls

1.3 Pearl's luster and surface characteristics

The luster of pearls is one of their most significant and distinctive features. Luster refers to the ability of the pearl's surface to reflect and scatter light, creating a unique glow. Based on the characteristics of luster, pearls can be classified into two types: mirror luster and satin luster. Mirror luster refers to a bright and clear reflection on the pearl's surface, making it appear shiny and shiny, like a mirror. Satin luster, on the other hand, refers to a soft and rich glow on the pearl's surface, resembling the delicacy of satin.

In addition to luster, the surface characteristics of pearls also have an impact on their value. The smoothness and integrity of the surface are important indicators of the pearl's aesthetic appeal. Blemishes and imperfections on the surface can affect the luster and visual beauty of the pearl. Therefore, the quality and value of pearls are closely related to the degree of surface integrity and the presence of flaws to some extent. Through in-depth research on pearl luster and surface characteristics, people can gain a better understanding of the quality and features of pearls, providing a scientific basis for pearl identification and processing.

2 Optical Properties of Pearls

2.1 Optical characteristics and refractive index of Pearls

As a gemstone, the optical properties of pearls have a significant impact on their beauty and value. Pearls have a relatively high refractive index, which means that light undergoes refraction as it passes through the surface of the pearl, giving the pearl its bright luster (Fu, 2014). Refractive index refers to the degree of change in the speed of light as it propagates from one medium to another. Due to the unique structure of pearls, light undergoes multiple refractions and reflections within the pearl, creating its distinctive luster. Pearls of different colors have varying refractive indices, which is one of the reasons why pearls exhibit a rich array of colors.

2.2 Dispersion and optical wave interference in pearls

Dispersion in pearls refers to the phenomenon where light exhibits different degrees of deviation angles for light of varying wavelengths due to differences in refractive indices when passing through the pearl, resulting in the creation of a rainbow spectrum (Hao et al., 2010). This dispersion phenomenon gives pearls their captivating iridescent colors when exposed to sunlight or artificial lighting. Dispersion not only adds richness to the appearance of pearls but is also a crucial indicator for distinguishing genuine from imitation pearls. Within the internal structure of pearls, the interference of light waves is one of the significant factors contributing to dispersion. Minute optical wave interference causes light of different wavelengths to separate, resulting in the dispersion effect that gives pearls their unique radiance.

2.3 Pearl's fluorescence and phosphorescence

Pearls exhibit the phenomenon of emitting visible light when exposed to ultraviolet or specific wavelengths of light, known as fluorescence. Pearl fluorescence can manifest in various colors, including white, yellow, blue, green, and more (Figure 3). The occurrence of fluorescence is associated with certain elements within the pearl, which absorb energy when exposed to ultraviolet light and then re-emit it in the form of visible light. For instance, pearls containing copper elements may exhibit blue fluorescence under ultraviolet light, while pearls containing strontium elements may emit red or orange fluorescence. Trace elements such as lanthanum, barium, titanium, and others can also influence the fluorescence display in pearls. The presence of these elements allows pearls to display a rich array of colors under different lighting conditions, adding to their mystery and allure.

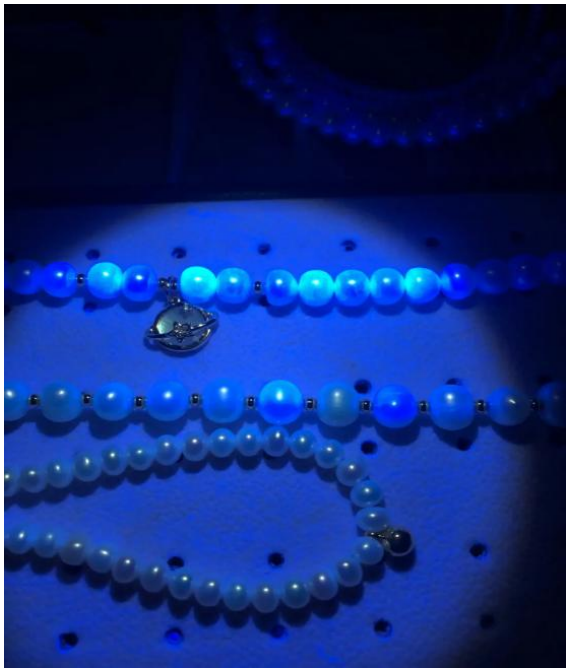

Figure 3 Fluorescence phenomenon of pearls

In addition to fluorescence, pearls also exhibit phosphorescence. Phosphorescence refers to the phenomenon where pearls, after being exposed to ultraviolet light in a dark room, continue to emit visible light for a certain duration after the exposure has ended. Phosphorescence can manifest in various colors, including green, white, blue, and others. The occurrence of phosphorescence is a result of certain components within the pearl absorbing ultraviolet light and subsequently releasing energy. By observing the fluorescence and phosphorescence display of pearls, a more comprehensive understanding of the pearl's internal structure and composition can be gained, providing crucial information for pearl identification and quality assessment. This holds significant importance for the development of the pearl industry, the creation of pearl jewelry, and innovations in jewelry craftsmanship. Additionally, in-depth research into the fluorescence and phosphorescence characteristics of pearls contributes to expanding the application value of pearls in fields such as materials science and optics.

3 Internal Structure of Pearls

3.1 Layered structure of pearls

Pearls are formed as mollusks secrete nacre, which consists of thin and closely packed layers. These layered structures give pearls their unique luster when light undergoes refraction and reflection. The layered structure of pearls typically appears in concentric circles, gradually stacking outward from the core (Hanser et al., 2018). There may be tiny gaps between these layers, allowing light to reflect between them, creating the distinctive luster characteristic of pearls.

Different types of pearls exhibit varying layered structures. South Sea pearls and Japanese pearls typically have more pronounced layered structures (Figure 4), while the layered structure of freshwater pearls is relatively simpler. The complexity of the layered structure is also closely related to the pearl's growth environment and physiological characteristics (Krzemnicki et al., 2010). In-depth research into the layered structure of pearls aids in the scientific identification of their authenticity and quality and provides a scientific basis for the processing and utilization of pearls.

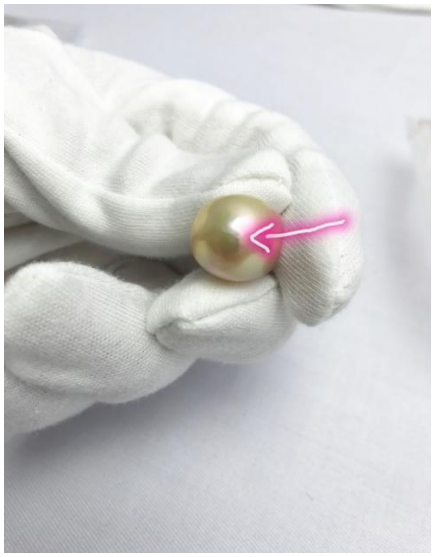

Figure 4 The layered structure of pearls

3.2 Distribution of organic and inorganic matter in pearls

Nacre, the substance that makes up pearls, is a composite material consisting of inorganic calcium carbonate and organic matter. Inorganic matter primarily consists of calcium carbonate crystals, constituting over 90% of nacre. Organic matter includes biological compounds such as proteins, polysaccharides, and lipids, accounting for the remaining portion of pearl matter (Li, 2017). Organic matter in nacre acts as a binding agent, facilitating the close arrangement of inorganic crystal structures and the formation of layered patterns.

Within pearls, inorganic and organic matter are not evenly distributed. Typically, the closer to the pearl's core, the higher the content of inorganic matter, while farther from the core, the content of organic matter is relatively higher (Wehrmeister et al., 2008). This distribution pattern results in a gradient effect in terms of color, luster, and hardness in pearls. Understanding the distribution patterns of inorganic and organic matter in pearls contributes to a better understanding of the pearl's growth process and formation mechanisms.

3.3 Microstructure and crystal morphology of pearls

Within nacre, inorganic matter exists in the form of calcium carbonate crystals. The structure and morphology of these crystals influence the optical and physical properties of pearls. Calcium carbonate crystals are primarily composed of aragonite crystals, with small amounts of magnesian calcite and dolomite crystals (Han et al., 2022). The growth of these crystals may be influenced by ecological conditions and biological factors, leading to potential differences in microstructure and crystal morphology among different types of pearls (Murr and Ramirez, 2012). Microscopic analysis techniques such as microscopy and X-ray diffraction can be employed to study the

microstructure and crystal morphology of pearls. These studies provide essential information for pearl identification and authentication while also contributing to a deeper understanding of the pearl's growth process and formation mechanisms.

4 Conclusion and Outlook

Pearls, as unique and precious gemstones, hold significant importance for scientific research and industrial development, particularly in the analysis of their morphological features and internal structures. In-depth studies of various aspects such as the classification, size, shape, color, luster, as well as the layering patterns, distribution of organic and inorganic matter, microstructure, and crystal morphology of pearls provide a comprehensive understanding of their intrinsic characteristics. This knowledge serves as a scientific basis for pearl identification and quality assessment. Furthermore, research into the optical properties of pearls, including refractive index, dispersion, optical interference, fluorescence, and phosphorescence, reveals their distinctiveness and opens new possibilities for their applications in fields such as gemology, medicine, and biomaterials.

The analysis of the morphological features and internal structure of pearls holds significant importance for the jewelry industry. A deeper understanding of the morphological characteristics of pearls enables jewelry designers to better utilize the different colors, sizes, and shapes of pearls to create a more diverse range of jewelry pieces, catering to the needs of various consumers. Furthermore, knowledge of the internal structure and optical properties of pearls contributes to the scientific authentication of pearls' authenticity and quality, thereby enhancing their value and position in the jewelry market. The analysis of the morphological features and internal structure of pearls also holds promising applications in the fields of medicine and biomaterials. Research indicates that pearls contain abundant organic components such as proteins and polysaccharides, which possess certain biological activity and biocompatibility, helping to promote cell growth and tissue repair. Therefore, pearls have vast potential applications in the fields of medicine and biomaterials, including their use in the preparation of biomedical materials and drug carriers, among others.

With the continuous advancement of science and technology and the deepening of pearl research, the analysis of pearl morphology and internal structure will continue to attract the attention of numerous researchers. People will gain a deeper understanding of the morphological features and internal structure analysis of pearls. Researchers are anticipating more innovations and breakthroughs, leading to broader avenues in pearl research. Simultaneously, the development of the pearl industry will also benefit from the application of these research findings. Researchers will further explore the potential applications of pearls in other fields, such as optics and nanomaterials. With the efforts of interdisciplinary cooperation, the analysis of pearl morphology and internal structure will continually provide new ideas and methods for the development of jewelry craftsmanship and resource conservation, making a greater contribution to the prosperity of the pearl industry.

However, the limitation of pearl resources and the ongoing development of the industry also remind us of the need to focus on conserving pearl resources and promoting sustainable industry growth. In future research, researchers need to enhance their in-depth studies of pearl morphology and internal structure analysis and continually expand their application value in various fields. At the same time, efforts should be intensified to protect and manage pearl resources, driving the sustainable development of the pearl industry. Only in this way can the unique charm of pearls be better harnessed, promoting the prosperity and development of the pearl industry, and contributing to the beauty and progress of human society.

Acknowledgements

I would like to express my gratitude to my colleague Ms. H.Q.K. ,for her valuable input and suggestions during the research process.

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