

Genetic Engineering in Aquaculture: Enhancing Aquatic Food Systems Through Genomic Innovation

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DESCRIPTION

Aquaculture has become one of the fastest-growing food production sectors in the world. As global populations continue to increase and demand for protein-rich foods rises, aquatic farming systems have gained considerable importance in supporting food security. Fish, shellfish, crustaceans, and other aquatic organisms contribute significantly to human nutrition and economic development across numerous countries. However, the expansion of aquaculture has introduced a variety of challenges, including disease outbreaks, environmental stress, feed efficiency limitations, reproductive management concerns, and resource constraints. In response to these challenges, genetic engineering has emerged as an influential scientific approach for improving aquaculture productivity, sustainability, and resilience.

The history of aquaculture improvement initially relied on selective breeding programs similar to those used in terrestrial agriculture. Farmers selected individuals exhibiting desirable characteristics such as rapid growth, disease resistance, or improved reproduction and bred them over successive generations. Although these methods produced valuable results, progress often required many years due to the biological characteristics of aquatic species. Genetic engineering introduced opportunities to modify specific traits more directly, enabling researchers to address challenges with greater precision and efficiency. Growth performance has been among the most extensively investigated targets of genetic modification in aquatic organisms. Faster growth can improve production efficiency, reduce resource consumption, and shorten cultivation periods. Scientists have identified genes associated with growth regulation and metabolic activity in several fish species. By modifying these genetic pathways, researchers have developed fish that exhibit enhanced growth rates compared with conventional populations. Such developments may contribute to increased food production while reducing the time required to bring aquatic products to market.

Feed utilization represents another important factor influencing aquaculture productivity. Feed costs often account for a

substantial portion of operational expenses in aquatic farming systems. Improving the ability of fish and shellfish to convert feed into body mass can increase efficiency and reduce production costs. Genetic engineering enables scientists to investigate genes involved in digestion, nutrient absorption, and metabolic regulation. Modifications affecting these processes may improve feed conversion performance and decrease resource requirements throughout production cycles. Disease management remains one of the most significant challenges confronting aquaculture industries worldwide. High-density farming environments can facilitate the spread of bacterial, viral, fungal, and parasitic infections. Disease outbreaks may result in substantial economic losses and reduced animal welfare. Genetic engineering has enabled researchers to identify genes associated with immune responses and disease resistance. Through targeted modifications, scientists seek to strengthen natural defense mechanisms and reduce susceptibility to common pathogens affecting aquatic species. Viral diseases have attracted particular attention due to their ability to spread rapidly within aquaculture facilities. Certain viral infections can affect entire populations within a relatively short period, creating serious production challenges. Researchers have explored genetic modifications that enhance antiviral responses or interfere with viral replication processes. These approaches aim to improve population health while reducing dependence on pharmaceutical treatments and other disease-control measures.

Salmon farming provides a notable example of how genetic engineering can influence aquaculture development. Salmon are among the most economically important farmed fish globally. Researchers have investigated genetic modifications associated with growth performance, disease resistance, and environmental adaptability in salmon populations. Studies involving genetically modified salmon have generated substantial scientific interest while also contributing to discussions regarding regulatory oversight, environmental safety, and public acceptance. Reproductive control represents another area where genetic engineering offers practical applications. In some aquaculture systems, uncontrolled reproduction can reduce growth performance, affect product quality, or create management difficulties. Scientists have developed genetic approaches that

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influence reproductive processes, enabling more effective control over breeding and population structure. Such methods may improve production efficiency while supporting responsible management practices.

Shellfish farming has also benefited from advances in genetic technologies. Oysters, mussels, clams, and other shellfish species contribute significantly to global aquaculture production. Researchers have investigated genetic factors associated with shell formation, growth, disease resistance, and environmental tolerance. Genetic engineering provides tools for modifying these characteristics and improving the resilience of shellfish populations exposed to changing environmental conditions. Conservation applications have also emerged within aquatic genetic engineering. Certain fish species face declining populations due to habitat degradation, overfishing, pollution, and climate-related pressures. Genetic technologies may assist conservation programs by supporting population recovery, preserving genetic diversity, and enhancing resilience to environmental stress. While conservation efforts continue to rely heavily on habitat protection and sustainable management, molecular tools provide additional options for addressing biodiversity challenges.

Gene editing technologies have further accelerated progress within aquatic biotechnology. Modern editing tools allow

researchers to modify specific genetic sequences with a high degree of precision. Unlike earlier genetic modification methods, contemporary techniques enable targeted alterations that reduce unintended effects and improve research efficiency. These capabilities have expanded opportunities for investigating biological functions and developing practical applications.

CONCLUSION

The application of genetic engineering to aquaculture illustrates the expanding influence of molecular biology in food production systems. By modifying genetic characteristics associated with growth, health, nutrition, and environmental adaptation, researchers have developed innovative approaches for addressing many of the challenges facing aquatic agriculture. Continued scientific investigation, responsible regulation, and international cooperation will shape the future of these technologies. As global demand for aquatic food products continues to increase, genetic engineering may play an increasingly important role in supporting sustainable aquaculture systems that contribute to food security, economic development, and environmental resilience..