can induce genetic bottlenecks, inbreeding accumulation, and allele loss, further weakening the genetic foundation of cultured populations (Ai et al., 2025). Therefore, protecting wild populations, optimizing broodstock management, and conducting continuous genetic monitoring are of great importance for maintaining germplasm stability and promoting selective breeding programs (Nousias et al., 2021; Li, 2022).

With the development of molecular biology technologies, research on genetic diversity in groupers has continued to deepen. Commonly used approaches include microsatellite markers (SSR), ISSR, mitochondrial DNA (mtDNA), DNA barcoding, as well as more recent high-throughput sequencing and environmental DNA (eDNA) technologies (Hassanien and Al-Rashada, 2020; Ai et al., 2025). Studies have shown that cultured populations generally exhibit lower genetic diversity compared to wild populations and often display significant genetic differentiation, mainly due to genetic mechanisms such as founder effects, genetic drift, and inbreeding. In addition, parent-offspring comparative studies based on microsatellite markers have revealed evident allele loss and genetic bottleneck signals during artificial breeding, highlighting the importance of genetic quality control in breeding programs. Molecular surveys at regional scales have also demonstrated significant genetic structure differences among geographically distinct populations, providing important evidence for resource conservation and stock enhancement programs (Tavakoli-Kolour et al., 2022; Nurdin et al., 2025).

This study aims to explore the research progress and existing issues in the genetic diversity of grouper germplasm resources. Although extensive studies have been conducted both domestically and internationally, limitations remain, including restricted sample coverage, the lack of a unified evaluation index system, and insufficient integration of multi-omics technologies, making it difficult to comprehensively characterize the overall genetic landscape of grouper germplasm resources. Taking marine-cultured grouper germplasm as the research subject, this study systematically reviews the theoretical foundations and technical systems for genetic diversity assessment and, combined with representative case studies, conducts a comprehensive analysis of current genetic diversity levels and existing challenges. The findings are expected to provide a theoretical basis for the scientific conservation and efficient utilization of grouper germplasm resources, offer references for optimizing molecular breeding strategies and developing improved varieties, and ultimately promote the high-quality and sustainable development of the grouper aquaculture industry.

2 Overview of Grouper Germplasm Resources

2.1 Classification of groupers and major cultured species

Groupers, in a broad sense, belong to the order Perciformes. Traditionally, they were classified under the family *Serranidae*, subfamily Epinephelinae. However, with advances in molecular phylogenetics, their classification has been progressively revised, and they are now recognized as an important group within the family *Epinephelidae*. This group is species-rich, with more than 160 species recorded worldwide, primarily distributed in tropical and subtropical waters, especially in the Indo-Pacific region (Ybanez and Gonzales, 2023). Nevertheless, due to both significant differences and certain convergent characteristics in body coloration, morphology, and ecological habits among species, traditional morphological methods have limitations in identifying closely related species, thereby affecting the accuracy of germplasm resource surveys and breeding practices.

With the development of molecular marker technologies, phylogenetic analyses based on mitochondrial genes such as Cyt b and COI have become important tools for grouper classification. Studies have shown that some morphologically distinct groups are not genetically independent; for example, Cromileptes is phylogenetically nested within the genus *Epinephelus*, revealing inconsistencies between traditional morphological classification and genetic relationships (Hassanien and Al-Rashada, 2020). Therefore, establishing a phylogeny-based classification system not only improves species identification accuracy but also provides a theoretical basis for pedigree management, hybrid design, and germplasm standardization.

In aquaculture applications, groupers have developed into high-value marine farming species. Globally, commercial aquaculture involves at least 47~48 grouper species and 15~16 hybrid combinations, with Asia playing a dominant role (Ybanez and Gonzales, 2023). In China, the main cultured species include orange-spotted