

Gametology and Factors Affecting Gamete Quality in Fish

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Abstract

Gamete quality is an important factor affecting reproductive success in fish, as it directly affects the success of fertilization, embryonic development, and larval survival. The review is concerned with gametology, the science of gametes, as it applies to teleost species of interest to aquaculture. This article discusses the structural organization of fish spermatozoa and eggs and the standardized quality assessment parameters including sperm motility, concentration, and seminal plasma biochemistry assessed using Computer-Assisted Sperm Analysis (CASA). A critical assessment of criteria for egg quality including fertilization rate, hatching rate, embryonic normality and larval survival. Summary of multifactorial effects on gamete quality including broodstock nutrition, environmental stressors, broodstock age and husbandry practices. These factors are emphasized as being important for inclusion in evidence-based broodstock management protocols to optimize reproductive output in aquaculture.

Keywords: Gametology, Fish spermatozoa, Egg quality, Sperm motility, CASA, Gamete evaluation

1. Introduction

The global aquaculture industry has expanded rapidly over the past few decades and now provides more than half of all fish eaten by humans. Despite advances in species domestication and genetic improvement, a persistent bottleneck limiting productivity is the poor quality of gametes produced by captive broodstock (Migaud et al., 2013). Gametology, the complete study of gametes and their role in sexual reproduction and the continuity of heredity, has an important interdisciplinary role at the intersection of reproductive physiology, cellular biology and genetics. In finfish aquaculture this field includes production, maintenance and activation of reproductive cells during fertilization, with the entire downstream productivity of a breeding program depending on gamete quality at the moment of union (Cabrita et al., 2009).

Fish spermatozoa differ greatly from their mammalian counterparts, with teleost spermatozoa lacking an acrosomal cap and depending on micropyle-mediated egg penetration (Jamieson, 1991). In the reproductive tract, sperm are immotile and are activated only on

contact with the external aquatic environment where motility lasts only seconds to minutes depending upon the species (Rurangwa et al., 2004). Fish egg quality, defined as the ability of a matured oocyte to be fertilized and develop normally (Bobe & Labbé, 2010), is influenced by broodstock age, nutritional condition, environmental conditions during oogenesis and timing of gamete collection (Kjørsvik et al., 1990). Broodstock nutrition, especially the provision of essential fatty acids, fat soluble vitamins and carotenoids (Izquierdo et al., 2001) directly affects the biochemical composition and functional competence of both sperm and eggs. Environmental factors, such as temperature, photoperiod, dissolved oxygen, and exposure to pollutants also influence gametogenesis and gamete quality.

2. Structure and Quality of Fish Sperm

2.1 Structural Organization

The fish spermatozoon is made up of three functionally distinct regions: the head, the midpiece and the flagellum. Teleost fish, unlike most other vertebrates, do not possess an acrosomal cap on the head of the sperm. This is directly related to the mechanism of egg penetration based on the micropyle, which is characteristic of fish reproduction (Jamieson, 1991). In most species, the flagellar axoneme has a canonical 9+2 arrangement of microtubule doublets, but some orders, such as the Anguilliformes and Elopiformes, tend towards a 9+0 configuration. In viviparous species, the larger sizes of the head and midpiece are a marker of evolutionary adaptation to the environments of internal fertilization.

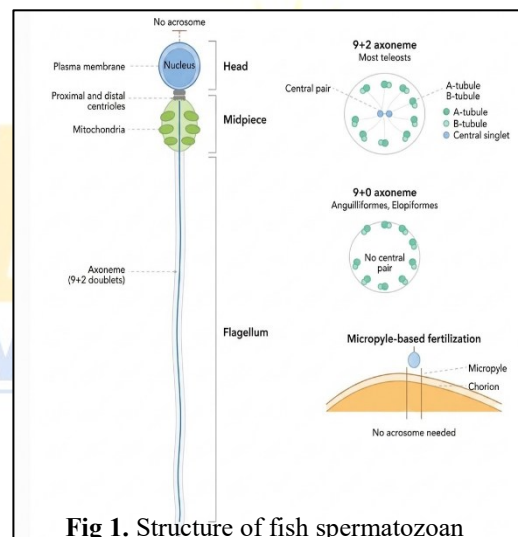


Fig 1. Structure of fish spermatozoon

2.2 Quality of Sperm

The reproductive viability of fish spermatozoa is defined as a standardized set of parameters, as defined in comparative fish reproductive biology (Rurangwa et al., 2004).

- **Motility (MOT):** The percentage of actively swimming spermatozoa. This is generally regarded as the best single predictor of fertilisation potential, with high quality samples generally above 80%.
- **Sperm Volume & Total Production (TSV/TSP):** Total seminal fluid volume and total sperm count per ejaculation, representing the overall reproductive capacity.

- **Concentration (SC):** Spermatozoa density per ml of seminal plasma calculated by hemocytometry or spectrophotometry.
- **pH & Osmolality:** The exact time of motility onset and its length are dictated by the acid and osmotic pressure of seminal plasma; deviations from species-specific optima inhibit or prematurely induce flagellar activity.
- **Total Protein Content (TPC):** The total protein concentration in seminal plasma is indicative of the biochemical environment that supports the spermatozoa.

These parameters are quantified by Computer-Assisted Sperm Analysis (CASA) and by live/dead fluorescent staining. CASA systems allow for objective measurement of kinetics including curvilinear velocity and progressive motility with high reproducibility between repeated measurements (Rurangwa et al., 2004). Standardisation of activation timing is also critical, as fish sperm motility decreases rapidly within seconds of activation; it is recommended that analysis is initiated within 6–8 seconds following activation.

2.3 Factors That Affect Sperm Quality

- **Diet:** Antioxidants such as vitamins C and E, and carotenoids in the diet contribute to protecting spermatogenic cells against oxidative damage while polyunsaturated fatty acids (DHA and ARA) help in maintaining the fluidity of the flagellar membrane and improving the fertilization ability (Izquierdo et al., 2001).
- **Environmental Conditions:** Seasonal variations in water temperature, photoperiodic variations, salinity variations and chemical pollutant exposure all synergistically act to alter seminal biochemistry and induce spermatozoal morphological abnormalities resulting in reduced fertilization potential.
- **Male Age:** Reproductive senescence gradually reduces the volume of sperm output and the quality of motility, but age-related effects in fish are less systematically documented than in females.
- **Activation Medium:** The ionic composition, pH, and osmolality of the medium used to initiate sperm motility determine the accuracy of kinetic measurements; species-specific formulations are essential for valid comparative assessments.
- **Duration of Measurement:** Temporal control of motility recording is critical. Longer observation windows yield progressively lower motility values. High speed camera capture of 0.5–2 s windows is optimal.

3. Classification, Structure and Quality of Fish Eggs (Ova)

3.1 Classification

The eggs of fish are generally divided into two groups, pelagic and demersal, according to their buoyancy in water. Pelagic eggs typical for marine broadcast spawners are positively buoyant, due to oil droplets associated with the yolk, high hydration and gelatinous surface coatings. Demersal eggs are common in freshwater taxa and are negatively buoyant, so that they settle on the substrate or adhere to benthic surfaces (Kjørsvik et al., 1990). The second axis of classification is between adhesive and non-adhesive eggs. Adhesive eggs contain surface glycoproteins that allow them to attach to substrates, while non-adhesive eggs are passively dispersed by water currents.

3.2 Structural Design

The chorion, an acellular, rigid coat of proteins and polysaccharides, forms the outermost structural layer of the fish egg and is synthesized in its entirety by the oocyte in teleosts. Below this is the vitelline membrane, encompassing the ooplasm and yolk mass. The main metabolic fuel for embryonic development prior to the beginning of exogenous feeding are yolk reserves, the abundance of which varies widely across species (Bobe & Labbé, 2010). Crucially, egg size and yolk content are independently regulated variables, each contributing to developmental success independently.

3.3 Evaluation of Egg Quality

Egg quality is the capacity of a fully matured oocyte to be fertilized and develop to normal morphology by embryogenesis (Bobe & Labbé, 2010). Poor egg quality clinically manifests as fertilization failure, developmental arrest, high embryonic mortality or teratogenic deformity. During the evaluation some parameters are considered:

- **Fertilization Rate:** An early indicator of viability, but high fertilization rates alone do not reliably predict normal embryonic progression in all species.
- **Hatching Rate:** The percentage of fertilized eggs that result in morphologically intact, viable larvae; a robust integrative measure of overall embryo quality.
- **Embryonic Normality:** Microscopic staging throughout the incubation period systematically assessing for developmental abnormalities, deformities or stage specific arrest.
- **Buoyancy & Larval Survival:** Buoyancy after hatching and early larval survival are integrative proxies of egg compositional quality which include lipid profile, carotenoid status, and hormonal conditioning.

3.4 Factors Influencing Egg Quality

- **Age of Broodstock:** Females in their prime reproductive age invariably yield eggs of greater fertilizability and developmental reliability; egg quality is significantly lower in both immature and senescent broodstock.
- **Nutritional Status:** The dietary composition of the broodstock directly controls the biochemical composition of oocytes and deficiency in essential fatty acids, fat-soluble vitamins or trace minerals may impair the structure of yolk lipid and reduce the success of development (Izquierdo et al., 2001).
- **Water Quality:** Physiological stress from sub-optimal temperature, decreased dissolved oxygen or increased ammonia levels during oogenesis impairs follicular development and integrity of egg composition.
- **Broodstock Management:** Disciplined conditioning protocols, correct sex-ratio maintenance, regular health evaluation and stress reduction are the basis of consistent high-quality egg production (Migaud et al., 2013).
- **Fertilization Technique:** Accuracy of sperm-to-egg ratio calibration, correct timing of gamete mixing and the use of species-appropriate activation media are procedural determinants of fertilization efficiency and subsequent embryo viability.

4. Conclusion

Gametology plays a pivotal role in improving reproductive efficiency and sustainable aquaculture production by ensuring high-quality sperm and eggs. Gamete quality is influenced by multiple factors, including broodstock nutrition, age, environmental conditions, water quality, and husbandry practices. Accurate evaluation using standardized techniques such as Computer-Assisted Sperm Analysis (CASA) and comprehensive egg quality assessment enables better broodstock selection and reproductive management. Integrating scientific knowledge of gamete biology with optimized breeding protocols can significantly enhance fertilization success, embryo development, and larval survival. Continued research on gamete physiology and quality assessment will further strengthen hatchery performance, genetic improvement, and long-term sustainability of the aquaculture industry.

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