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The application of copepods in the hatchery production of finfish larvae

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Abstract

The primary barrier to scaling up the commercial production of both established and prospective marine fish species lies in the delivery of an effective live feed during the critical first feeding stage of larval development. To increase the diversity of farm-raised marine species, it is essential to provide a live diet that is nutritional, appropriately sized, and capable of triggering a strong feeding instinct in larvae. Copepods, which represent approximately 80% of the ocean's zooplankton and stand as the most abundant metazoans on the planet, serve as a fundamental bridge in the marine food web, transferring energy from primary producers to higher-order predators like fish. Consequently, they are a natural dietary choice for many marine finfish larvae. Research consistently indicates that copepods offer a superior nutritional profile compared to *Artemia sp.*, aligning more closely with the biological needs of developing larvae. Furthermore, because they can be utilized in various life stages from nauplii for initial feeding through to copepodites for later stages copepods represent an exceptionally versatile and effective live feed solution for the aquaculture industry.

Keywords: Live feed, aquaculture, artemia, zooplankton, marine, shellfish

Introduction

To grow the seafood, bait, and aquarium industries, it is essential to improve the techniques used for raising marine fish. At present, the variety of marine species cultivated is restricted, and results remain inconsistent. The primary challenge hindering the commercial scale-up of existing species as well as the introduction of new ones is providing the correct live nutrition during the initial larval development stage. This window is vital for ensuring that larvae grow and thrive. For the industry to diversify, it must identify feed that offers specific nutritional profiles, comes in the right dimensions, and triggers a strong prey drive in young fish. This document explores the advantages and drawbacks of utilizing copepods, brine shrimp, and rotifers for this purpose (Cortney *et al*., 2012) [6].

"Live feed refers to the diverse array of vegetation (phytoplankton) and microorganisms (zooplankton) that sustain commercially significant fish populations. As zooplankton depend on phytoplankton, these microscopic plants represent the bedrock of the aquatic food chain. Free-swimming organisms are especially vital in this context, as their motility triggers predatory instincts in fish larvae, prompting them to hunt. Consequently, these living organisms are indispensable for achieving productivity in aquaculture. Although larvae are biologically predisposed to consume these tiny organisms, such resources are frequently limited in pristine, clear waters. In contrast, ponds with a distinct green pigmentation signal an abundance of phytoplankton, suggesting a robust nutritional environment. Within these habitats, zooplankton serve as the primary dietary staple for larvae, with copepods being particularly noted for meeting the intricate nutritional needs of growing marine fish (Jan *et al*., 2003) [12].

In natural settings, zooplankton represent a fundamental nutritional source for fish. The transfer of energy within pelagic ecosystems follows a transition from phytoplankton to zooplankton, traversing both classical food chains and microbial pathways (Ragumaran *et al*., 2022) [17]. The efficacy of energy transition at the primary producer-herbivore junction is determined by both the abundance and the caliber of available food (Brett and Muller, 1997) [2]. Factors such as algal dimensions, digestibility, biochemical makeup, and the presence of secondary metabolites are critical indicators of food quality.

Furthermore, the growth of zooplankton is closely linked to the fluctuating quality of the available phytoplankton community. Certain algae can actively promote zooplankton development by emitting biochemical signals or producing essential nutrients like vitamin E (α-tocopherol). The feeding efficiency of zooplankton is dictated primarily by food density, nutritional quality, and ambient water temperature. Zooplankton serve as a concentrated reservoir of amino acids, minerals, fatty acids, and vital enzymes. Specifically, live zooplankton are rich in enzymes such as proteases, amylases, esterases, and exonucleases, which facilitate easier digestion and support larval development. Due to their high protein content and overall nutritional profile, these organisms are considered a superior food source for fish cultivation (Ogino, 1963) [16]."

Copepods, a highly diverse and abundant group of tiny crustaceans, inhabit virtually all aquatic ecosystems, ranging from freshwater bodies to marine environments across all depths (Bjornberg 1986; Dahms 2000) [1,7]. Serving as essential secondary producers, they occupy a critical position in aquatic food webs (Rajkumar, 2006) [18]. In marine settings, they are widely recognized as a premier live food source for the development of fish, shrimp, and various other aquatic species (Santhanam, 2002) [19]. Consequently, the mass production of copepods in hatchery settings is a pivotal strategy for overcoming nutritional limitations in aquaculture (Szlauer and Szlauer, 1980) [22], mirroring their function as a primary dietary component for fish larvae within natural pelagic food chains (Cheng *et al*., 1999, 2001) [3,4]. For those in the aquaculture industry, mastering copepod cultivation is a fundamental skill, as these organisms are vital for the healthy growth of fish fry (Lee *et al*., 2005) [13].

The practice of rearing copepods has seen significant advancements in reliability since the 1960s, with researchers successfully domesticating roughly 60 distinct species (Mauchline *et al*., 1998) [14]. One of the most long-standing examples of success is the *Acartia tonsa* culture established at the Technical University of Denmark, which was derived from the Oresund strait in 1981 (Stottrup *et al*., 1986) [20]. To foster global collaboration and knowledge exchange between researchers, industry professionals, and the general public, the World Copepod Culture Database was launched in 2006 at Roskilde University (http://copepod.ruc.dk/main.htm). This repository features current methodologies and documentation for approximately 30 recorded copepod cultures.

Biology of copepod

The term "copepod" originates from the Greek elements *kope* (oar) and *podos* (foot), a nod to the flattened, oar-like appendages these creatures utilize for propulsion. As the most expansive and varied lineage of crustaceans, they comprise more than 210 families, 2,400 genera, and upwards of 24,000 documented species. Given their diminutive stature, it is highly probable that a vast number of species have yet to be catalogued by science.

These organisms occupy an incredible spectrum of environments. While many are planktonic and drift through the global oceans, others are benthic, thriving within layers of microalgae or navigating the tiny crevices between marine sediment particles. Some have even adapted to extreme subterranean conditions, such as groundwater systems or the intense environment of deep-sea hydrothermal vents. Furthermore, roughly 33% of marine copepod species have evolved to exist as parasites or symbionts living in association with other hosts.

In the realm of mariculture, practitioners primarily rely on free-living copepods from the Cyclopoida, Harpacticoida, and Calanoida orders. While a typical adult copepod measures between 1 and 2 mm (0.04 to 0.08 inches), their size varies significantly; standard free-living varieties generally span 0.2 to 15 mm (0.008 to 0.59 inches), whereas certain specialized parasitic species can grow to an astonishing length of 300 mm (12 inches) (Michael *et al*., 2019) [15].

Life cycle of copepods

Most copepods share a cylindroconical body structure, characterized by a broader front section. Their anatomy is divided into two primary regions: the cephalothorax a fusion of the head and the initial thoracic segment and a leaner abdomen. Sexual dimorphism is common, with males typically being smaller than females. During the mating process, the male uses his first antennae to secure the female, after which he attaches spermatophores to her seminal receptacles using a specialized adhesive. Once fertilized, the eggs are either dispersed directly into the water or carried by the female in an ovisac. Upon hatching, the larvae emerge as nauplii. These undergo five or six naupliar stages before transitioning into copepodites. Development continues through five distinct copepodite phases, with the organism molting at each interval to progress to the next level of maturity. Depending on the species and environmental conditions, the complete life cycle can range anywhere from a few days to an entire year.

Types of copepods

In aquaculture, the three predominant free-living copepod orders utilized are Calanoida, Cyclopoida, and Harpacticoida. While Calanoids and Cyclopoids typically inhabit the water column as plankton, Harpacticoids are generally found living on the seafloor or other substrates. These crustaceans are versatile particulate feeders, consuming a diverse diet that includes micro-zooplankton, phytoplankton, various protozoa, detritus, and even other metazoans, including fellow copepods.

Because of their immense oceanic populations, copepods serve as a vital nutritional source for marine fish larvae with small mouths, which specifically target the tiny naupliar stages measuring between 50 and 100 µm. In hatchery settings, various calanoid and harpacticoid nauplii which can range from 38 to 220 µm in width are commonly used as starter feed. Copepods generally exhibit two distinct swimming styles: a consistent, slow drift generated by their mouthparts, and a series of sudden, rapid leaps powered by prosome appendages. This "jumping" behavior is a critical trigger for stimulating feeding responses in larval fish.

Reproduction is primarily sexual, with males often employing specialized first antennae to grasp females during copulation. Egg-laying strategies vary; some calanoids broadcast eggs individually, while other calanoids, along with cyclopoids and harpacticoids, typically brood their offspring in external sacs. Certain calanoid species can produce diapause or subitaneous resting eggs, which remain dormant for a period and offer potential for hatcheries to stockpile a reliable supply of nauplii. The developmental lifecycle involves six naupliar phases and five copepodid stages prior to reaching adulthood. Depending on the specific species and environmental factors, this maturation process can take anywhere from seven days to an entire year (Michael *et al*., 2019) [15].

Calanoids

Calanoid copepods are primarily pelagic organisms, thriving across all water columns, though a subset of species is adapted to benthic or near-bottom habitats. While they generally subsist on tiny phytoplankton through filtration, some act as predators, consuming animal matter such as copepod eggs. Morphologically, they are identified by elongated antennules—often reaching the length of the body or exceeding it which feature as many as 27 segments. Their biramous antennae typically serve as supplementary tools for locomotion. Notable structural features include the modification of male antennules (Dussart and Defaye, 2001) [8] and a clear prosome–urosome junction situated between the fifth and sixth somites of the postcephalosome (Mauchline, 1998; Dussart and Defaye, 2001) [14,8].

In the context of hatchery production, several calanoid genera have gained prominence, including *Acartia, Pseudodiaptomus, Sinocalanus, Eurytemora, Centropages, Gladioferens, Parvocalanus, Bestiolina,* *Temora,* and *Labidocera*. Species such as *Acartia* are particularly valued for early-stage fish feeding, as their nauplii can be as tiny as 100 µm by 50–60 µm. Research into *Labidocera* has shown successful laboratory propagation, characterized by high egg production and consistent growth. Conversely, larger *Paracalanid* species serve as an ideal food source for more developed fish larvae. While *Acartia* copepods exhibit near-universal distribution, *Paracalanids* are predominantly found in coastal environments (Cheng, 2005) [5].

Harpacticoids

Harpacticoids represent more than half of all known copepod species. Predominantly marine and free-living, these organisms are typically found in benthic zones rather than the open ocean. They are categorized based on their habitat: interstitial species live among sand grains, burrowers reside within the sediment, and epibenthic varieties inhabit the surfaces of plants or the seafloor. Morphologically, they possess a compact, streamlined frame, biramous antennae, and antennules consisting of fewer than ten segments. As noted by Dussart and Defaye (2001) [8], the articulation between the prosome and urosome occurs behind the fourth post-cephalic segment. Typically, females carry a single egg sac, while males are generally smaller and feature modified antennules.

In aquaculture, harpacticoids are valued for their ability to achieve high population densities. While their preference for the benthos can make them challenging to retrieve for larval fish, certain species produce nauplii that are positively phototactic, allowing for efficient light-based harvesting. These copepods are highly productive, generally lack cannibalistic tendencies, and adapt well to artificial diets, permitting the co-culture of multiple species. In many cases, harpacticoids inadvertently appear as contaminants in calanoid copepod cultures alongside ciliates.

Species such as *Nitokra lacustris* offer a unique advantage: while their nauplii remain benthic, the subsequent copepodid stages measuring roughly 90 µm by 30–40 µm—frequently occupy the water column, making them suitable prey for fish larvae. Despite the general difficulty of separating nauplii from sediment (Cheng, 2005) [5], harpacticoids remain easier to mass-produce than their calanoid counterparts. Because they are nutritionally comparable to calanoids and many small epibenthic species can be harvested for larval feed, they are increasingly viable candidates for aquaculture. Furthermore, current semi-automated systems provide effective methods for feeding and harvesting, which significantly reduces the manual labor required for maintenance (Stottrup, 2006) [21].

Cyclopoids

Cyclopoid copepods exhibit a wide range of lifestyles, occupying habitats that vary from the open water column to the seafloor, and even include parasitic forms; notably, they are more prevalent in freshwater systems (Huys and Boxshall, 1991) [11]. Morphologically, they differ from calanoids by possessing shorter antennules, which typically consist of six to 17 segments and do not extend past the cephalothorax. Furthermore, cyclopoids are distinguished by their uniramous antennae, which are specialized for prey capture, a trait that sets them apart from calanoid and harpacticoid groups (Huys and Boxshall, 1991; Dussart and Defaye, 2001) [11,8]. As with harpacticoids, their body is divided into a prosome and urosome at the junction of the fourth and fifth postcephalosome segments (Dussart and Defaye, 2001) [8].

Within this group, *Oithona* and *Dioithona* are frequently utilized in aquaculture. Their nauplii, which often measure under 100 µm, exhibit negative phototaxis and are easily harvested using plankton nets. In Taiwan, the nauplii of *Apocyclops royi* serve as a critical initial food source for larval fish, with eggs hatching in just four to five days (Cheng, 2005) [5]. Research into the swarming behavior of *Dioithona oculata* indicates that this species is highly suitable for high-density production (Hernandez and Alvarez, 2003) [9].

In general, cyclopoids are easier to maintain in captivity than calanoids and can achieve significantly higher population densities. While they can consume a diverse diet, intensive systems typically rely on phytoplankton (Stottrup, 2006) [21]. For instance, *Oithona oculata* populations have reached concentrations of 13 individuals per milliliter in static, unaerated setups over a 15-day period (Hernandez and Alvarez, 2003) [9]. Additionally, Taiwanese aquaculture has explored the co-culture of non-feeding larval poecilostomatoid copepods with their host mussels to provide a live feed for fish larvae (Cheng *et al*., 2005) [5]. Similarly, *Pseudomyicola spinosus*, a member of the Myicolidae family that lives in symbiosis with bivalves, has been identified as a viable live feed for marine finfish; its first seven developmental stages are planktonic and can be harvested for such purposes (Ho, 2005) [10].

Conclusion

Researchers are actively refining cultivation techniques for various copepod species and exploring their integration into marine finfish aquaculture. While over 20 species have been utilized as larval feed predominantly in temperate regions the transition from experimental mass-culture protocols to industrial hatchery adoption remains incomplete. A comprehensive economic assessment of live prey must extend beyond production costs to incorporate the tangible advantages of using copepods, such as enhanced fish survival, accelerated growth, and improved resilience to environmental stressors.

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