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Cannibalism and its importance in Aquaculture: A review

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SUMMARY

Intracohort cannibalism may lead to significant losses during the early life stages of farmed fish. The mechanisms driving cannibalism dynamics are common across many fish species and are closely linked to the factors that influence growth variation within a population. This genetically encoded behaviour allows the individual to eliminate competitors in the competition for resources and increases the chances of survival and reproduction. Many fish species display aggression towards individuals of the same species, which can often lead to cannibalistic behavior. This foraging strategy is also present in intensive aquaculture systems, and its economical, ecological and phylogenetic implications have been debated by many researchers. Many fish species can be produced economically in recirculation aquaculture (RAS) systems, but the efficiency of larval and juvenile rearing remains a bottleneck for most species. The success of initial rearing depends on many factors. In addition to genetic factors, the level of cannibalism is mainly influenced by the applied production and feeding technology. Literature suggests that mortality during larval rearing can be as high as 50%, largely due to aggression. In the case of predatory fish species, the presence or absence of certain husbandry conditions can lead to even higher levels of cannibalism, which significantly reduces production yields by causing mortality and secondary injuries, thus further decreasing the survival rate. This review therefore aims to identify and quantify the effects of biotic and abiotic factors that influence cannibalism.

Keywords: *cannibalism; aquaculture; larval and juvenile rearing of fish; survival; size heterogeneity*

INTRODUCTION

Intensive aquaculture systems (RAS) are playing an increasingly important role in fish (*Pisces*) production in Europe and Hungary. Many fish species can be produced economically in RAS systems; however, the efficiency of larval and juvenile rearing remains an unsolved problem for most species. The success of initial rearing depends on the homogeneity of fish stocks and cannibalism, what can lead to size heterogeneity.

Based on literature sources cannibalism and the resulting yield losses vary between species, and it is a significant problem in intensive fish production. Especially with the increased interest for *Siluridae* families in global aquaculture. Many taxa of fish being produced, including more than 30 species of catfish worldwide, and almost every continent has its most abundant and preferred catfish family. For example, the Striped catfish (*Pangasianodon hypophthalmus*) and the Broadhead catfish (*Clarias microcephalus*) in Asia, the African catfish (*Clarias gariepinus*) in Africa and Europe, the Channel catfish (*Ictalurus punctatus*) in North America and species from the *genus* of *Pseudoplatystoma* in South America (Gisbert et al., 2021; Quyến et al., 2025). According to FAO aquaculture statistics, in 2018 the worldwide catfish production was 5.781.235 tons (FAO, 2018). These data also show that predatory fish species, including catfish, play an important role in world aquaculture production, and that cannibalism can result in significant yield losses in larval and fry rearing.

In the book Fishes of the World by Joseph S. Nelson and colleagues, cannibalism has been reported in 36 different fish families (Pisces) (Nelson et al., 1984). For recent days this list has expanded to include 104 families and 390 species (*Table 1*), with 150 of these based solely on reports from captive fish (Pereira et al., 2017).

Table 1. **Main farmed fish species, in which cannibalism has been documented**

Family	Species	Source
Clariidae	*Clarias gariepinus*	Hecht and Appelbaum, 1988
Centropornidae	*Lates calcalifer*	Shafland and Kochl, 1980
Salmonidae	*Oncorhynchus mykiss*	Shirahata, 1964
Percidae	*Sander vitreus*	Mitchill, 1818
Cichlidae	*Oreochromis mossambicus*	Uchida and King, 1962
Percichthyidae	*Morone saxatilis*	Katavic et al., 1989
Sciaenidae	*Cynoscion nebulosus*	Tucker, 1988
Scornbridae	*Scomber japonicus*	Hunter and Kimbrell, 1980
Gadidae	*Gadus morhua*	Oiestad, 1985
Anguillidae	*Anguilla anguilla*	Degani and Levanon, 1983
Cyprinidae	*Cyprinus carpio*	van Damme et al., 1989
Esocidae	*Esox lucius*	Bry and Gillet, 1980
Serranidae	*Epinephelus malabaricus*	Chua and Teng, 1980
Carangidae	*Seriola quinqueradiata*	Fujiya, 1976
Coryphaenidae	*Coryphaena hippurus*	S. Kraul, Hawaii 1999

Source: Hecht and Pienaar, 1993

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The prevalence of cannibalism is judged differently by researchers. Some literature suggests that the absence of cannibalism in fish populations is unusual, while other sources claim that the consumption of conspecifics is rare in a given habitat and within a population, even for predatory fish species.

This shows that there are many contradictions in the literature on this subject (Domney and Blumer, 1984; Davis, 1985; Hecht and Pienaar, 1993). Some researchers associate cannibalism only with predatory fishes, while other authors mention that larvae of most species typically exhibit predatory behavior during the early stages of development. This may also imply that these species show a tendency to consume conspecifics as adults under certain environmental conditions and in absence of nutrient sources (Hunter and Kimbrell, 1980; Polis, 1981).

Research on cannibalism in cultured fish has primarily been goal-oriented, focusing mainly on species with frequent or intense cannibalistic behaviors. However, studying species that rarely exhibit cannibalism under culture conditions, such as *Pangasius djambal*, can also provide valuable insights, particularly when compared to other closely related species that show more frequent or intense cannibalism (Lazard et al., 2009). Most species that exhibit high rates of cannibalism in captive environments show little to no cannibalism in their natural habitats (Fuentes and Quiroga, 2012). The risk of cannibalism in species that have been recently domesticated or are potential candidates for aquaculture diversification is difficult to predict, except possibly through the analysis of morphological factors, which are generally reliable indicators of cannibalism (Baras et al., 2010).

In light of these findings, it is crucial to assess the occurrence of cannibalism and the loss it causes during the early stages of fish development, particularly during the larval and juvenile rearing phases of the economically important fish species (Polis and Myers, 1985; Smith and Reay, 1991; Hecht and Pienaar, 1993; Krasteva and Yankova, 2021).

TYPES OF CANNIBALISM

In the ecosystem, several forms of cannibalism are distinguished and their classification was developed by Carl Smith, Peter Reay, and Anthony Pienaar in the early 1990s (Hecht and Pienaar, 1993). The act of killing and consuming individuals of the same species is a form of cannibalism that can occur both within a cohort (same age group) and between cohorts (different age groups), known as intra-cohort and inter-cohort sibling cannibalism, respectively. It should be noted that intra-cohort cannibalism is very frequent within aquaculture rearing (Krasteva and Yankova, 2021). Intra-cohort cannibalism can also be influenced by sex, particularly in species that exhibit sexual growth dimorphism during early development (Naumowicz et al., 2017)

Many fish species practice cannibalism during the early developmental stages, targeting larvae and juveniles (Pereira et al., 2017). In case of an individual only bites or kills its sibling but does not consume it falls into category of agonistic behavior, which is a consequence of aggression (Hecht and Pienaar, 1993). This latter ethological phenomenon is also an important aspect of the unsuccessful aquaculture rearing.

International research has led to the categorization of cannibalism according to three criteria, which allow the full spectrum of cannibalism in the current ecosystem to be covered. The first criteria is the developmental stage of the prey, i.e. the pre-hatching or egg stage, and the post-hatching life stages (larva, fry, adult). The second criterion defines the genetic relationship between the cannibal and the prey. A distinction must be made between cannibalism by a parent on its own offspring (filial cannibalism), cannibalism between siblings (sibling cannibalism) and cannibalism by non-kin (Pereira et al., 2017). In many cases, especially in field studies, the genetic relationship of individuals cannot be determined and it must be assumed that the predator and prey are not related. Finally, the third aspect is age categorization. In the case of intra-cohort cannibalism, the predator and prey are the same age, while in inter-cohort cannibalism the cannibal individual is older than the conspecific. On these three criteria, cannibalism can be categorized into seven classes (Smith and Reay, 1991).

The classification below (*Table 2*) illustrates that cannibalism in fish is not without pattern:

Table 2. **Classification of Cannibalism**

Categorization of fish cannibalism	
Criterion	Life stage
Prey developmental stage	pre-hatch cannibalism post-hatching cannibalism (larva, fry, adult)
The genetic relationship between predator and prey	parent-offspring sibling-sibling non kin
Age relationship between predator and prey	within-cohort-same age inter-cohort-different age

Source: Smith and Reay, 1991

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From these seven categories the sibling-sibling cannibalism can reduce the most volume of the larvae and juveniles in aquaculture rearing.

As shown in *Table 2.* cannibalism can manifest in different forms across fish species, occurring in both natural and artificial environments. It should be noted that most reports of cannibalism in nature have been based on diet analysis, without providing details on behavior. Direct observations of cannibalism have been gathered from aquaculture research, field studies on reproductive behavior, and laboratory studies with captive fish. Studies investigating cannibalism in nature seem to be rare, with most field reports of cannibalism being linked to studies of community trophic ecology rather than directly focusing on cannibalism itself. Additionally, most species that exhibit high rates of cannibalism in captive settings show little to no cannibalism in their natural habitats (Fuentes and Quiroga, 2012; Pereira et al., 2017).

CARNIVORE OR NON-CARNIVORE

Eating of own kind is most common among piscivore fish. It is important to note because to date the promising candidates for use in aquaculture due to rapid growth and high protein content are carnivoure species. Especially those with diets consisting of varying proportions of aquatic insects, crustaceans, mollusks, and fish (Baras et al., 2010). However, there are cases where omnivorous fish, such as common carp, may prey on conspecific individuals when stocking densities are high in aquaculture production (Smith and Reay, 1991). Many freshwater fish that primarily feed on benthic invertebrates also exhibit cannibalism at frequencies nearly as high as those reported for piscivores (Pereira et al., 2017). Certain carnivorous fish alternate between feeding on fish and invertebrate prey based on the availability of each. Cannibalism can arise when there is a high density of conspecifics coupled with low prey diversity and abundance (Svenning and Borgstrøm, 2005; Venturelli and Tonn, 2006; Yag˘ci et al., 2014). Cannibalism in non-carnivorous species, such as those that feed on algae, plants, and/or detritus, is rarely reported in nature. However, three cases of partial filial cannibalism have been documented in two herbivorous pomacentrid species, for instance the *Stegastes rectifraenum*, what feed primarily on zooplankton (Copepod) (Petersen, 1990). Cannibalism is typically observed in piscivores, as members of this group possess enhanced abilities to detect and capture fish prey. Most piscivorous fish are invertivorous during their early life stages, with few reports of cannibalism occurring among their larvae (Prado et al., 2006). In contrast, some herbivorous species, such as *Brycon spp*. (*Bryconidae*) and *Colossoma spp*. (*Serrasalmidae*), which primarily feed on fruits, have carnivorous larvae that typically consume small invertebrates but may occasionally exhibit cannibalism in aquaculture settings (Liao et al., 2001). These observations suggest that cannibalism is a species-specific trait, rather than a general behavioral strategy influenced by specific environmental conditions, and should be considered in the aquacultural fish production also.

FORMS OF CANNIBALISM

According to literature, there are two types of cannibalism: type I and type II cannibalism (Kestemont et al., 2003; Krasteva and Yankova, 2021). In the case of type I, one individual bites and attacks another (aggressive, agonistic behavior), but does not consume it. Incomplete (type I) cannibalism typically offers cannibals a growth advantage, enhances size variation, and aids in the transition to complete (type II) cannibalism (Babiak et al., 2004). The occurrence of type I called "tail end" cannibalism does not depend on the larvae size homogeneity. However, the emergence of type II cannibalism in larvae and juvenile production is due to size heterogeneity. Type II cannibalism is also characterized by complete prey ingestion and limitations based on gape size (Hecht and Appelbaum, 1988; Smith and Reay, 1991; Folkvord and Ottera, 1993, Król et al., 2014). That is one of many aspects why cannibalism is regarded as an asymmetric interaction, where larger individuals typically consume smaller ones (Polis, 1981; Pereira et al., 2017). These two forms of cannibalism can lead to losses ranging from 15–90% in larvae and fry production, making it a significant issue in aquaculture.

FACTORS DETERMINING THE ONSET AND EXTENT OF CANNIBALISM

Cannibalism poses a complex challenge in the intensive commercial production of various fish species and cannot be effectively managed without understanding the factors that influence its occurrence and severity. Each instance of cannibalism must be evaluated in relation to the biology and specific characteristics of the species involved (Pereira et al., 2017; Król et al., 2014; Baras et al., 2010). Various endogenous and exogenous factors influence fish cannibalism (Svenning and Borgstrøm, 2005) and numerous studies have explored the impact of food, light, and shelter availability in an effort to find ways to reduce cannibalism in aquaculture settings (Gisbert, et al., 2021). Nevertheless in most instances, cannibalism serves as an alternative feeding strategy, primarily influenced by environmental factors rather than any genetic component.

Genetic and environmental factors (*Table 3*) that contribute to the basis of cannibalism (Hecht and Appelbaum, 1988; Pienaar, 1990).

Despite the available literature, it remains unclear whether cannibalism is a genetically predetermined behavior, a random occurrence, or a learned process. However, it can be concluded that both genetic and environmental factors play a significant role in the emergence of cannibalism. Furthermore, a reduction in cannibalistic behavior does not always correlate with the best production outcomes, so it is important to carefully select the appropriate parameters

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(Naumowicz et al., 2017; Krasteva and Yankova, 2021).

Table 3. **Influencing factors**

Basics of cannibalism	
Population factors:	**Environmental factors:**
Genetics	Feed quality-quantity
Sex	Illumination
Breeding season, spawning	Temperature
Larvae size	Color and shape of the rearing area
Population density	Technological conditions
Degree of domestication	Shelter/refuge

Source: Naumowicz et al, 2017

Genetic factors

In certain tested species, cannibalism seems to be influenced by genetic factors. Cannibalism among larvae is influenced by size, however, exceptions occur in some species, such as *Dorada*, where larvae can consume conspecifics of equal size or even slightly larger than themselves (Baras and Fortune´ d'Almeida, 2001; Baras et al., 2000). In fish reproduction, it is important to consider that smaller-bodied females produce smaller and fewer eggs. Smaller spawn leads to smaller larvae, while larger eggs result in larger larvae. Therefore, eggs from female fish of different body sizes should not be mixed during fertilization, as this creates the potential for cannibalism among the larvae. The risk of early mortality and cannibalism among cultured fish species with similar ontogenetic paths may be largely influenced by egg size. This comparison of closely related species from a cannibalistic viewpoint supports the broader notion that the viability of fish larvae is enhanced by larger egg size (Kamler, 2005). Eggs in the developmental stage are most commonly subject to cannibalism, a behavior observed across various feeding guilds. Parents may consume the entire clutch (total filial cannibalism) or just a few eggs (partial filial cannibalism). The former is considered an investment in future reproduction, while the latter affects both current and future reproductive success (Sargent, 1992).

Larvae that hatch earlier than their siblings will have an advantage in gaining bodyweight and may consume their smaller counterparts due to that (Pine et al., 2000). These factors are especially important in the farming of species such as Atlantic cod (*Gadus morhua*), African catfish (*Clarias gariepinus*), Rainbow trout (*Oncorhynchus mykiss*), Brown trout (*Salmo trutta*), Walleye (*Sander vitreus*), and European seabass (*Dicentrarchus labrax*). Deformed or diseased fish should be removed from the rearing tanks, as they can contribute to the deterioration of the group (Król and Zielinski, 2015).

During larval rearing, both larval density and size are positively correlated with the onset of cannibalism-related behaviors. In the case of Type I cannibalism, it is important to note that conspecifics provide more nutrients and digestible energy compared to planktonic animals. Once a larva begins consuming its sibling, it tends to prefer this form of feeding over other natural (planktonic) or artificial (mixed) feeds. This gives an advantage to the cannibals, allowing them to quickly progress to stage II, further exacerbating the differences in body size. (Baras and Jobling, 2002; Król and Zielinski, 2015).

The mortality rate resulting from the two type of cannibalism vary across different fish species. In Type I, mortality is measured within the larvae population. (Naumowicz et al., 2017):

- European perch (*Perca fluviatilis*) larvae: 1.5–12%
- Pikeperch (*Sander lucioperca*) larvae: 10–17%
- Dorada (*Brycon morei*) larvae: above 40%

In contrast to these examples, Type II cannibalism can lead to significantly higher mortality in aquaculture, primarily due to factors such as population density and variations in body parameters (Folkword, 1997; Vallon et al., 2016; Yang et al., 2015).

From a production standpoint, indirect selection for cannibalism can also occur in the intensive farming of carnivorous fish, as the traits sought by fish farmers (phenotype) – such as large size, rapid growth, and robustness – are commonly found in cannibalistic individuals. To minimize growth discrepancies and losses caused by cannibalism in the intensive farming of carnivorous fish (also omnivore and herbivore fish), farmers can manage food availability and employ feeding strategies. Furthermore, they can sort fish by size (Potongkam and Miller, 2006), and lastly adjusting stock density appropriately (Kubitza and Lovshin, 1999).

Hormones

According to Hecht and Appelbaum (1988), cannibalism may also be influenced by modulators of the neuroendocrine system. The use of certain hormones may reduce the level of aggression:

- Serotonin: reduce aggressive behavior
- Glucocorticoids: reduce aggressive behavior
- CRH-Corticotrophin-releasing hormone: reduce aggressive behavior and motor activity

Intraspecific predation in fish farming can be linked to aggressive behavior, with testosterone being one of the hormones responsible for driving the aggression (Heltonika, et al., 2022). It has been stated that the increase in testosterone concentration in Asian catfish (*Clarias batrachus*) is associated with gonad maturation and the process of vitellogenesis. This phenomenon was also demonstrated in *Clarias gariepinus* by regularly injecting catfish broodstock with 17α-methyltestosterone (Rahmadiah et al., 2019). Under these conditions, testosterone accumulates in the eggs and is transferred to the larval stage. The presence of this innate testosterone in the parents triggers aggressive behavior, which can result in cannibalism (Zairin et al., 2002).

The impact of intrinsic factors, including maternal or paternal effects, on growth heterogeneity has been demonstrated in several species during larval or

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juvenile stages. Within a given population, cannibalism may also be taxa-specific in species where cannibalism occurs early in the phylogeny of the individual, such as the Vundu catfish (*Heterobranchus longifilis*). Research has also found that maternal genome has a much greater effect on interbreeding cannibalism than paternal gene pool (Baras, 1999; Mousseau, 1998; Yang et al., 2015). Hybridization between cannibalistic species and a non-cannibalistic species, such as *Silurus meridionalis* and *S. asotus*, resulted cannibalism rate intermediate in the hybrids than in the pure-blooded parental gene-pool (Yang et al., 2015; Pereira et al., 2017)

In most cases cannibalism occurs when larger sibling prey on smaller sibling. Cannibals grow faster than the non-cannibals, often resulting in bimodal size distributions (Rudolf, 2006; Berg et al., 2010). This is a typical relationship in predator-prey interactions, and often influenced by the size of the predator's mouth opening. (Shirota, 1978). Hecht and Appelbaum (1988) found that the maximum prey size for the African catfish (*Clarias gariepinus*) is determined by the size of the mouth gape (phenotype) of the cannibal specimen. Shirahata (1964), Smith (1989), van Damme and colleagues (1989) found the same for Rainbow trout (*Oncorhynchus mykiss*), Nile tilapia (*Oreochromis niloticus*) and Common carp (*Cyprinus carpio*). An important exception to this rule is the larvae of Walleye (*Sander vitreus*), which actively attempt to cannibalize siblings larger than themselves (Cuff, 1980).

Finally, in terms of genetic factors, it's important to note, that stress can also contribute to cannibalism, which is linked to social hierarchy. In aquaculture system the stress can also be related to the aggressiveness of species, and varies not only with social hierarchy, but also with larvae and juvenile density in rearing tanks and the ontogenetic stage of the individuals (Martins et al., 2005).

Density

In aquaculture, population density can either increase or decrease cannibalism, depending on the species biology. For all fish species studied for cannibalism, a positive density-dependent correlation has been observed. This is demonstrated by the captive population studies of Degani and Levanon (1983), Tucker (1988), and Malhotra and Munshi (1984). The impact of different stocking density levels has been linked to different mortality rate, as observed in the larvae of Pike *(Esox Lucius*), Walleye (*Sander vitreus*), European perch (*Perca fluviatilis*), and African catfish (*Clarias gariepinus*) (Kucharczyk et al., 1998; Szkudlarek & Zakes, 2007; Baras et al., 2003, Solomon & Udoji, 2011). High stocking rate promotes cannibalism in Yellow perch (*Perca flavescens*) reared in intensive aquaculture (Malison and Held, 1992). In contrast, in African catfish, cannibalism and territorial behavior peak at 10.7 fish per liter and vanish at 17.9 fish per liter, suggesting that social dominance among fish may decrease at higher stocking densities (Hecht and Pienaar, 1993).

Size sorting

Bimodal distributions promote cannibal individual growth and survival, with the latter being highly dependent on size heterogeneity (Persson et al., 2000). Size sorting can be beneficial for some species and disadvantageous for others, but it does not reduce type I cannibalism once it has emerged in the population, as this behavior is entirely independent of size variation. Nevertheless, size grading remains an effective management practice to address differential growth among fish. This selection has been applied in the farming of Yellow perch (*Perca flavescens*) and Atlantic cod (*Gadus morhua*) to minimize losses caused by cannibalism (Nagel, 1976; Folkvord and Ottera, 1993; Brown et al., 2003).

In the case of European perch (*Perca fluviatilis*), sorting will cause stress and therefore mortality. To standardize the reared population by size, the smaller individuals should be removed, however not the larger ones, due to the established social hierarchy. Removing the larger siblings would trigger a new competition for resources, driven by territorial dominance. An important rule is that a 50% total length difference between individuals should not be allowed within a given breeding pool (Naumovicz et al., 2017; Sloman and Armstrong, 2002).

Rearing tanks

The design of the rearing tank or aquarium, including its color, shape, and size, can influence the rate of cannibalism. Stock behavior can vary depending on whether the tank is wide and flat or tall and narrow. Wide, flat tanks offer a larger water surface area and support better population distribution, providing more shelter and more even access to resources for the stocked individuals. In contrast, narrow, tall tanks create more competition for space and offer less time for rest. Additionally, the shape and size of the tank impact water flow, as it behaves differently on angled or curved surfaces. In smaller tanks, cannibals can detect prey more easily. (Smith and Reay, 1991; Britz and Pienaar, 1992; Kestemont et al., 2003; Baras et al., 2000; Folkvord and Ottera, 1993).

Shelter

In nature the availability of shelters is crucial for the survival of wild fish, as it helps them cope with challenging environmental conditions. Competition for shelters and their availability can greatly enhance fish survival (Harwood et al., 2002). In freshwater aquaculture, shelters usually consist of a mix of natural substrates covered in vegetation, which also serve as a food source, along with artificial structures. For nocturnal predatory fish (for instance *Lota lota*) the insufficient or absent shelter availability during the day can lead to elevated physiological stress, which in turn can cause reduced growth (Keshavanath et al., 2003; Wocher et al., 2011).

This is the same for intensive indoor rearing, shelters are commonly selected to reduce cannibalism, minimize energy use, promote the onset of exogenous feeding, support growth, and enhance survival and

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well-being. However, the increased competition for shelters in these systems, compared to natural environments, may lead to higher aggression levels and a subsequent rise in energy consumption (Slavík et al., 2012; Couliblay et al., 2007).

Illumination

Illumination is a crucial factor in aquaculture production. Light intensity, duration of light exposure, and water clarity all play a role in regulating the circadian rhythm and can influence the occurrence of cannibalism. Larvae of many fish species are visual predators, exhibiting positive phototaxis and myopia. These species can only see objects at a distance up to one-third of their body length, which impacts their feeding efficiency since they rely on sight to feed. For these species, feeding efficiency can be improved by adjusting light intensity and contrasting the color of the food with the color of the aquarium walls. For Northern pike (*Esox lucius*), European perch (*Perca fluviatilis*), and Pikeperch (*Sander lucioperca*), extending the duration of light exposure and ensuring proper light levels can enhance their production outcomes (Baras et al., 2000; Tamazouzt et al., 2000; Kestemont et al., 2003). For light-avoiding fish species, like the Qfrican catfish, which primarily relies on its chemoreceptors for feeding (Attema, 1980; Adams et al., 1988; Harada, 1989), lighting has a detrimental effect. For this species, it is recommended to maintain water turbidity, minimal light, and continuous darkness (Britz and Pienaar, 1992; Baras and Jobling, 2002).

There are also some studies from the past examining the impact of light and stocking density on the rearing efficiency of European catfish (*Silurus glanis*). It was found that cannibalism was more prevalent in illuminated tanks, with a rate of 53.7%, compared to 46.7% in dark tanks, and this difference was statistically significant. This can be attributed to light triggering aggressive behavior in the fish, causing them to gather at the bottom, near the walls, and in the corners of the tank. In contrast, fish reared in darkness are more evenly distributed throughout the water and do not exhibit crowding behavior, and they have better access for feed also (Kozłowski & Poczyczyński, 1999; Krasteva and Yankova, 2021).

Feeding

Cannibalism rates generally increase when food-sources are scarce and may decrease when these resources are abundant (Pereira, 2017). Aquaculture studies have shown that feeding frequency, food quantity, and food quality all affect the occurrence of cannibalism. The nutritional status of the larvae and juvenile biomass is also an important factor in the incidence of cannibalism (Luz and Portella, 2005; Manley et al., 2015). This correlation between cannibalism and nutritional level is commonly observed in fish (*Pisces*). This is supported by the fact that 62 species from 24 families show this behavior based on the above context. While cannibalism is often thought to be linked to the quantity of food, in many cases, poor food quality also plays a role in its occurrence (Smith, 1989). In some instances, diets deemed nutritionally complete were rejected, while nutritionally unbalanced diets were accepted with the same voracious appetite seen in other species. Starvation and nutrient deficiency are significant, though not always determining, factors in promoting cannibalism, as cannibalistic behavior can still occur even in fish that appear to be well-fed. (Li and Owings, 1978; Braid and Shell, 1981; Li and Mathias, 1982; Hoelzer, 1988).

For fish to survive and grow, they must be capable of capturing, ingesting, digesting food, and absorbing nutrients. The shift to exogenous feeding phase after the yolk sac is consumed is a key factor influencing the survival of newly hatched fish. Although fish larvae may have the morphological capability to capture various food items (such as zooplankton), their digestive system undergoes several developmental stages before becoming fully functional shortly after hatching. Understanding the ontogeny of the digestive system can help develop more effective larval feeding protocols for fish farmers. For instance, the morphology and functionality of the digestive system (including the activity of digestive enzymes) are often used to evaluate the nutritional condition of fish larvae reared under different condition (Rønnestad et al., 2013; Gisbert et al., 2021). The lack of certain digestive enzymes may limit the use of artificial feeds, which may contribute to cannibalism (Li and Mathias, 1982; Blaxter, 1988; Verga and Bohm, 1992; Walford and Lam, 1993).

For most fish, particularly carnivorous juveniles, zooplankton serves as the primary source of nutrients. (Takaoka et al., 1990; Kohbara et al., 1993). It is believed that the ingestion of live food stimulates the secretion of endogenous enzymes in the digestive tract of juvenile fish. This process supports digestive and absorption functions during the larval stage of development, enabling the efficient utilization of nutrients (Holm and Walther, 1988).

The exclusive use of artificial feed has been shown to increase cannibalism in larvae of Smallmouth bass (*Micropterus dolomieu*) and European seabass (*Dicentrarchus labrax*) compared to the use of live food (Folkvord, 1991). Additionally, a fish's ability to accept granulated feed in intensive culture may influence differential growth and cannibalism in carnivorous fish (Ehrlich et al., 1989). However, cannibalism in Largemouth bass (*Micropterus salmoides*) decreased after feeding training as fish learned to accept artificial feed (Snow, 1960; Kubitza, 1995). Nutrient quality, although important for normal growth, survival and overall health of the animal, is not a decisive factor in the acceptance of diets by carnivorous fish. In some instances, diets deemed to be nutritionally complete were rejected, while nutritionally unbalanced diets were accepted with the same voracious appetite seen in other species.

Global research indicates that food availability and its even distribution throughout the water column in intensive farming conditions are key factors influencing the differential growth rate of fish. Higher

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feeding rates have improved fish to easier access food, reducing size variations and cannibalism in intensively farmed Pikeperch (*Sander lucioperca*), Striped bass (*Morone saxatilis*) and European seabass (*Dicentrarchus labrax*) (Katavi, et al., 1989).

Cannibalism can also have an indirect impact on FCR. When larger individuals consume smaller ones, the overall biomass may decrease, allowing the remaining fish to convert feed more efficiently due to reduced competition. However, the precise effect on FCR can vary depending on factors such as species, size distribution, and environmental conditions.

Finally, Pienaar (1990) stated that feeding live feed (*Daphnia spp.*) can significantly reduce cannibalism and territorial behavior in the farming of African catfish (*Clarias gariepinus*) and Rainbow trout (*Oncorhynchus mykiss*). However, the effectiveness of live food in supporting positive digestive processes in farmed stocks depends on factors such as the nutritional status, age, species, and quality of the zooplankton and organisms used. Additionally, improved survival and growth rates in fish farming can be achieved with mixed feeding (a combination of feed and live food) rather than single feeding, which is also reflected in differences in protein-fat ratios (Akbary et al., 2010).

CONCLUSIONS

With the increasing focus on aquaculture to boost food supply, there is a clear need for research aimed at reducing cannibalism in fish kept at high densities in captivity. At the same time, the prevalence of cannibalism and its causes and effects on fish in the wild remain poorly understood. On the basis of the international literature discussed so far, it can be stated that cannibalism, this form of foraging and behavior, can only be reduced to a certain extent, but not completely eliminated, even with the right husbandry conditions. It has been observed that omnivorous and aggressive carnivorous species are more susceptible to cannibalism, which may vary by species. From an ethological perspective, cannibalism (type I and type II) appears to be a highly beneficial strategy for the predator, as it allows the transmission of its genes to the next generation and reduces competition with conspecifics for food resources. However, it is less advantageous from a production standpoint. In animal protein production, including aquaculture, cannibalism can lead to substantial yield losses, as its impact is more pronounced in artificial environments than in natural settings. One possible cause of this is the use of inappropriate population densities, feeding methods, or even unnatural environmental conditions.

Therefore, cannibalism rates can be reduced and mortality minimized by selecting breeding stock with a uniform and homogeneous body size. However, this requires additional cost, effort, and time from fish farmers. Given these factors, further research is necessary to reduce aquaculture costs and maximize output.

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