CRITICAL REVIEW OF FISH DOMESTICATION IN AQUACULTURE: DETERMINANTS, PROCESSES, AND IMPACTS

Sébastien KPOSSOU *, *Simon AHOUANSOU MONTCHO* *,**,
Idossou Ayodédji Clovis HOUNTCHEME * and *Hyppolite AGADJIHOUEDE* *,**

* Research Unit in Aquaculture and Fisheries Management (URAGeP), Laboratory of Animal and Fisheries Sciences (LaSAH), National University of Agriculture (UNA), P.O. 5, Porto-Novo, Benin, sebastienkpossou@gmail.com, ORCID: 0009-0007-5899-553X, hountchemeclovis@yahoo.fr, ORCID: 000-0002-6644-1904.
** Laboratory of Hydrobiology and Aquaculture (LHA), Faculty of Agronomic Sciences (FSA), University of Abomey-Calavi (UAC), P.O. Box 526 Cotonou 01, Benin, s.ahouansoumontcho@gmail.com, ORCID: 0000-0002-2776-1964, agadjihouede@gmail.com, ORCID: 0000-0001-6074-2469.

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ABSTRACT

Domestication in aquaculture is recent and limited to a few species. This study, conducted through a literature review from indexed databases (Scopus, Web of Science) and other relevant sources, is based on a rigorous methodological screening. The analysis defines domestication, addresses its determinism, and discusses the domestication syndrome in relation to genetics, epigenetics, and environmental factors. The effects on fish behavior, reproduction, and life cycle are examined, along with challenges related to farming practices. Finally, the study highlights the impacts of domestication on resilience and ecological interactions.

RÉSUMÉ: Examen critique de la domestication des poissons en aquaculture: déterminants, processus et impacts.

La domestication en aquaculture est récente et limitée à peu d’espèces. Cette étude, à travers une revue de littérature issue de bases indexées (Scopus, Web of Science) et autres sources pertinentes, est basée sur un criblage méthodologique rigoureux. L’analyse définit la domestication, aborde son déterminisme et discute du syndrome de domestication en lien avec la génétique, l’épigénétique et l’environnement. Les effets sur le comportement, la reproduction et le cycle de vie des poissons sont examinés, ainsi que les défis liés à l’élevage. L’étude souligne enfin les impacts sur la résilience et les interactions écologiques.

REZUMAT: Revizuire critică a domesticirii peștilor în acvacultură: factori determinanți, procese și impacturi.

Domesticirea în acvacultură este recentă și limitată la puține specii. Studiul, realizat printr-o revizuire a literaturii din baze indexate (Scopus, Web of Science) și alte surse relevante, se bazează pe un proces riguros de filtrare metodologică. Analiza definește domesticirea, abordează determinismul și discută sindromul de domesticire în legătură cu genetica, epigenetica și mediul. Sunt examinate efectele asupra comportamentului, reproducerii și ciclului de viață al peștilor, precum și provocările legate de creștere. În final, studiul evidențiază impacturile domesticirii asupra rezilienței și interacțiunilor ecologice.

INTRODUCTION

In the evolution of human societies, domestication has been a central process that facilitated the transition from hunter-gatherer societies to sedentary agricultural societies. This process allowed for more stable management of food resources and laid the foundation for structured agriculture, which was essential for the development of civilizations (Zeder, 2012; Diamond, 1997). It also enabled human societies to control and increase food resources, playing a crucial role in human population growth and sedentarization, two foundational elements of modern societies (Smith, 2011; Harlan, 1992).

In aquaculture, domestication is considered relatively recent, and only a few aquatic species have been domesticated till now. It involves adapting fish species to captive farming conditions to optimize certain genetic, and behavioral traits of individuals. According to Gjedrem et al. (2012), the genetic improvement of aquatic species is essential to ensuring the future sustainability of aquaculture. This process goes beyond mere genetic selection, integrating ecological and behavioral dimensions as well (Teletchea and Fontaine, 2014). Domestication has already shown promising results in some species, improving productivity and meeting the growing demand for aquatic products (Gjedrem et al., 2012). One of the main challenges of domestication in aquaculture lies in balancing the genetic improvement of species while maintaining their well-being and adaptability to natural conditions (Teletchea and Fontaine, 2014). The effects of domestication on living organisms and their environment improvement remain a central issue, particularly regarding the risks of crossbreeding between domesticated fish and wild populations (Lorenzen et al., 2012). Recent research has also highlighted the behavioral implications of domestication, such as changes in social interactions, reproduction, and stress management in fish raised in captivity (Huntingford et al., 2006).

Therefore, it is crucial to better understand the key factors of domestication in aquaculture to ensure sustainable and responsible practices, minimizing ecological risks while optimizing benefits for the industry (Klinger and Naylor, 2012). This multidimensional approach to domestication in aquaculture underscores the need to integrate ecological, behavioral, and genetic considerations to develop more sustainable long-term strategies (Teletchea and Fontaine, 2014; Gjedrem et al., 2012). The underlying mechanisms of fish domestication, particularly in modern aquaculture systems, are still poorly understood and require further exploration to fully grasp their long-term impacts. The domestication process of fish is complex, as it involves interactions between genetic, environmental, and physiological factors that affect reproduction, growth, and behavior. Huntingford et al. (2006) demonstrated how these interactions influence the reproductive cycles and growth strategies of domesticated fish, which can have consequences for ecosystems if these fish are reintroduced into the wild (Lorenzen et al., 2012). Thus, understanding the determinants of domestication in aquaculture is fundamental, not only to improve management practices but also to anticipate the ecological and ethical repercussions of this practice. In this perspective, this study aims to explore the genetic, behavioral, and environmental determinants of fish domestication in aquaculture.

The primary objective of this research is to analyze the effects of domestication on the morphological, behavioral, and reproductive traits of fish, relying on the available scientific specific literature. This study primarily utilizes data from databases such as Web of Science and Scopus, as well as relevant online scientific documents, and applies a structured methodology, notably the PIC framework (Population, Intervention, Comparator), as recommended by Klinger and Naylor (2012), to deepen research questions in biology and ecology.

MATERIAL AND METHODS

This scientific study was conducted using the Scopus and Web of Science databases. It is a critical literature review of articles published up to June 2024. The research process incorporated thematic organization, synonyms with Boolean operators, and wildcard characters (*) to account for word variations and plurals. The following keywords were used: “fish”; “domestication”; “determinism”; “process” and “impact”. The searches were conducted in the article title, abstract, and keywords. Table 1 presents the research terms within the PIC framework, linking inclusion and exclusion criteria of articles based on Population (P), Intervention (I), and Comparators (C).

Table 1: Inclusion criteria of articles related to research questions using the PIC framework.

Key elements	Eligibility criteria
Population (P)	Fish species (freshwater, brackish water, and marine) includes data on marine, brackish, and freshwater fish species in controlled environments, as well as data from natural environments with individuals in captivity.
Intervention (I)	Identification/comparison or determination of differences between domesticated and wild individuals includes data from comparative studies of wild and domesticated individuals of the same species, identification of the origins of differences between domesticated and non-domesticated individuals, and characteristics distinguishing domesticated from wild individuals.
Comparators (C)	Genetic, climatic, environmental, behavioural, dietary, and reproductive markers includes identification of genetic and behavioural determinants, and selection differences between domesticated and wild individuals of the same species. The same applies to environmental and reproductive determinants for individuals in farming systems or captivity.

The research was conducted using keywords in titles and abstracts without considering grey literature (theses, reports) and conference proceedings. Two databases (Scopus and Web of Science) were compiled and then merged. Using EndNote, duplicates were removed.

The new database was screened based on the inclusion and exclusion criteria established in table 1, applied to the title and abstract reading of each article using the “Sysrev” platform. Articles deemed relevant for this literature review were downloaded for in-depth reading. The different steps of the screening process (PRISMA diagram) are presented in figure 1.

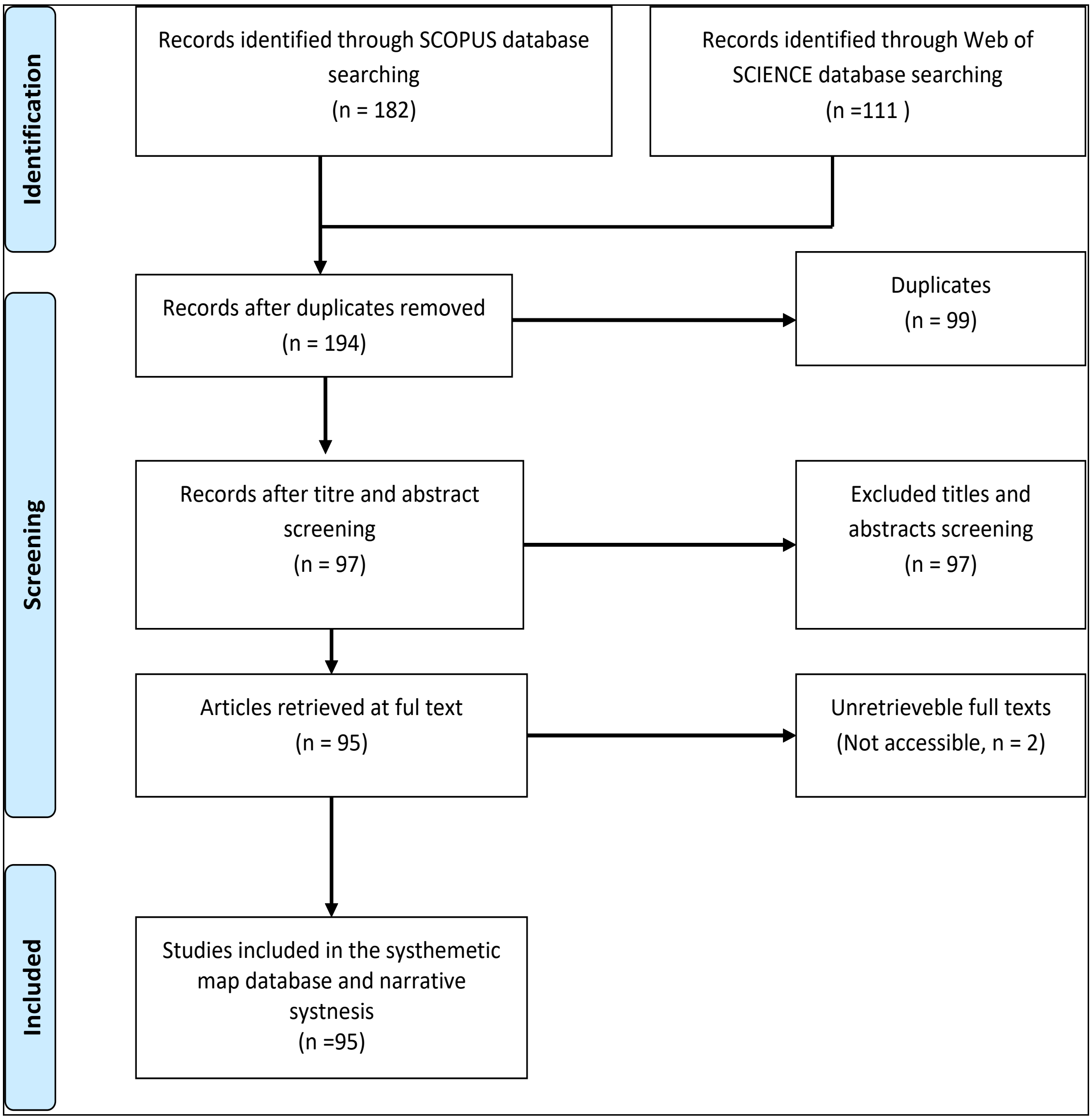

Figure 1: Screening process (PRISMA diagram).

RESULTS AND DISCUSSION

Definition of the concept of domestication

Domestication is the process by which an animal or plant adapts to the conditions and requirements of the human environment (Milla et al., 2020). It is defined as a process that leads to animals or plants becoming adapted to controlled environments and human interaction after generations (De Almeida et al., 2019). This approach involves humans modifying the physical and behavioral traits of a group of individuals from a species in a controlled environment (Triplet, 2015). This adaptation, under human control, requires the transition of organisms from their wild environment to a controlled one, with the goal of meeting needs related to food, labor, companionship, or other uses. Indeed, domestication primarily aims to satisfy human needs. Animals are domesticated to produce food for human consumption, provide labor, offer companionship, or supply products (Zeder, 2012). Plants are domesticated for food production, medicinal purposes, material supply, or aesthetic uses (Larson et al., 2014). The underlying idea behind this concept relates to accessibility, control over the production mechanism, and availability, often referred to as the “domesticatory system” (Digard, 2009). From a more in-depth perspective, domestication is a long and ongoing process that originates from genetic modifications (Anastasiadi et al., 2019). In social anthropology, the concept often encompasses all aspects of human-plant and human-animal relationships, as well as the socialized techniques and actions related to them. It involves both animals or plants and humans. As a result, some researchers describe this relationship as mutualism (Zeder, 2012). This perspective leads biologists to use the term “domestication” when referring to ants or termites that raise aphids or cultivate fungi, based on the idea of mutualism, as one species benefits from the other. However, unlike what is observed in humans, this strong ecological interaction between two species does not involve the invention and refinement of tools or techniques, nor profound cultural modifications comparable to those of the Neolithic “revolution” (Vigne, 2015). Thus, depending on the author, domestication seems to take on multiple meanings, varying according to different schools of thought.

Specificities and challenges of domestication in aquatic environments

In aquaculture, domestication has specific characteristics. Vandeputte and Prunet (2002) described it as the development of breeding methods and an understanding of the biological needs of aquatic species. It is a succession of stages aimed at acquiring individuals of an aquatic species from their natural habitat and acclimating them to production infrastructures. In other words, it involves mastering farming in a controlled environment (growth, reproduction) and understanding life cycles (Zulfadhli et al., 2023) in a flexible approach where the behavior of individuals is first managed before refining the complete production cycle (Liao and Huang, 2000). In some cases, it is necessary to collect juveniles from the wild to initiate farming in a controlled environment. In this regard, Shen et al. (2021) pointed out that limited research efforts hinder the development of aquatic domestication. The unique characteristics of aquatic environments explain why domestication in aquaculture is more recent compared to terrestrial animal domestication. Domestication is an evolutionary and flexible process in which humans adapt plant or animal species to controlled conditions, thereby meeting specific needs while modifying their genetic and behavioral traits over generations. This process has distinct particularities depending on the species and its application context, such as in aquaculture.

Determinism of domestication

One of the fundamental questions is by what alchemy will humans predict the success of a species’ domestication? This raises the issue of determinism and pre-determinism. In other words, to what extent do the innate characteristics of a species determine its success in domestication, and to what extent can human intervention predict or influence this outcome? Indeed, these questions involve several key elements of domestication. According to Triplet (2015), the notion of determinism, in general, is based on the idea that certain events, phenomena, decisions, or actions are unavoidable because they result from a set of pre-existing conditions that have caused them. Determinism relies on present states to explain future events. For example, genetic differences between domesticated and wild fish populations are influenced by maternal genes contained in unfertilized eggs (Żarski et al., 2020). Unlike determinism, pre-determinism assumes that all events are fixed in advance, following a plan or an omniscient and omnipotent force (Triplet, 2015). In this view, the future is already "written", independent of the current causal chain. In fact, predicting the success of species domestication relies on a complex balance between genetics, environment, behavior, and human interactions an "alchemy" difficult to anticipate. These elements are interconnected, making the domestication process both fascinating and complex (Teletchea and Fontaine, 2014; Zeder, 2012; Gjedrem et al., 2012; Gjedrem et al., 2012; Huntingford et al., 2006).

Genetic selection is one of the major factors in the domestication process, significantly influencing its success. By selecting individuals with favorable traits, such as docility or the ability to reproduce in captivity, humans guide the domestication process. However, this selection cannot be separated from the pre-existing genetic variability within the species. Genetic improvement is essential in aquaculture to ensure the sustainability and performance of domesticated species (Gjedrem et al., 2012). Genetic determinism in fish domestication refers to the direct influence of genes on behavioral, physiological, and morphological traits of domesticated fish. According to Maroso et al. (2021), initiating the domestication process can induce anatomical, physiological, and molecular modifications, impacting biological functions in fish. These changes manifest through various effects, including genetic transcription processes in fish embryos, gradually altering species traits over generations (De Almeida et al., 2019). These elements show that domestication is a complex phenomenon that goes beyond simply selecting superficial characteristics and involves deep genetic transformations, influencing the evolutionary trajectories of domesticated fish populations.

Animal behavior plays a main role in domestication. Species most likely to succeed in captivity are those with behaviors facilitating human management, such as sociability or tolerance to humans. According to Huntingford et al. (2006), behavioral modifications in domesticated fish are critical for their survival in captivity, allowing predictions of their success in controlled environments. The human-animal relationship is a main factor. Domestication involves constant species management, but also moral and ethical choices regarding animal living conditions. This dynamic shows how humans influence not only the genetic traits but also the behaviors of animals, based on the needs of agriculture or aquaculture (Zeder, 2012). The domestication of fish depends not only on genetic factors but also on environmental conditions, which play a main role in its success. The adaptation of a species to captivity, to a vastly different habitat, is vital for domestication. In aquatic environments, domestication is not limited to genetic selection but also incorporates ecological and behavioral factors that influence species adaptability to controlled environments (Teletchea and Fontaine, 2014). Environmental interactions are particularly critical for reproduction under domestication. For example, factors such as temperature and photoperiod, which are artificially controlled in captivity, strongly influence the reproductive cycles of domesticated fish. These conditions can accelerate sexual maturation but also alter natural reproduction patterns (Wilson et al., 2014). Such changes can reduce the ability of domesticated fish to engage in natural reproductive behaviors, such as mate selection or territorial defense, impacting their reproductive success in the wild (Chen et al., 2020).

Additionally, hormonal modifications due to captivity influence hormonal regulation, mostly pituitary hormones like LH and FSH, which are essential for reproduction (Khendek et al., 2018). These hormonal adjustments result from the complex interaction between genetics and the environment, affecting both internal biological processes and the reproductive behaviors of domesticated fish. Sometimes, domestication may lead to chromosomal disruptions, affecting sexual determination and reproduction (Wilson et al., 2014). Thus, the environment plays a central role not only in controlling the living conditions of fish but also in modifying their reproductive traits, directly influencing domestication success.

The success of domestication lies in the interaction of these various factors, which often combine in unpredictable ways. The domestication process does not follow a linear trajectory but results from a complex entanglement of natural and human forces, leading to varied outcomes (Smith, 2011). It is an evolutionary phenomenon whose predictions remain uncertain, influenced by historical contexts and human choices.

Epigenetic effects

Epigenetic effects in aquaculture refer to modifications in gene expression in response to environmental and management factors, without altering the DNA sequence. These modifications can influence key traits for farming, such as growth, disease resistance, behavior, and reproduction. For example, factors like water quality, temperature, population density, or nutrition can induce epigenetic changes affecting gene expression in fish, modifying their performance and adaptation to aquaculture environments (Gjedrem et al., 2012; He et al., 2021). Epigenetic modifications can optimize the genetic traits of farmed species, improving their adaptation to specific captivity conditions found in fish farms.

According to Chen et al. (2020), exposure to stress, such as overcrowding or poor water quality, induce changes in DNA methylation, affecting fish growth and behavior. These epigenetic effects can, over time, enhance aquaculture sustainability, enabling fish to better adapt to environmental conditions and minimizing negative effects on health and welfare.

Still, epigenetic modifications can be inherited, creating lineages of fish adapted to farming. This could impact genetic selection practices in aquaculture (Zhang et al., 2016). However, more study is needed to fully understand how these changes can be integrated into breeding programs to improve performance and sustainability in fish farming (He et al., 2021).

Dynamic DNA methylation and the domestication syndrome

The domestication of fish induces significant epigenetic changes, including dynamic DNA methylation modifications at the gene level. These changes influence the development and behavioral characteristics of fish in captivity (Anastasiadi et al., 2019).

To understand the impact of domestication on fish, it is essential to examine associated behavioral and physiological effects. Thus, the "Darwinian Domestication Syndrome" becomes relevant, highlighting the genetic and behavioral changes induced by captivity. Among vertebrates, the domestication process is associated with this syndrome, characterized by epimutations. Indeed, epimutations emerge early in domestication, representing complex interactions between the captive environment and genetic modifications in fish (Xu et al., 2012; Baesjou and Wellenreuther, 2021). According to these authors, such changes begin as soon as individuals are placed in captivity for domestication purposes. The success of fish domestication relies on a delicate balance between genetic, environmental, and behavioral factors, where epigenetic effects, such as DNA methylation modifications, play a crucial role. They influence fish development and adaptability, while also highlighting Darwin's domestication syndrome, which reflects the profound transformations induced by captivity.

Fish domestication process

Species selection for aquaculture domestication

The domestication process begins with the selection of the species (Marsden et al., 2013). This need in aquaculture worldwide, mostly in less developed countries, is driven by the growing demand for animal protein and the diversification of strains or species to be domesticated. However, aquaculture production must consider species features and consumer preferences. Therefore, certain important characteristics must be taken into account when selecting the species. Additionally, growth, hardiness, feed acceptance, and the possibility of reproduction in a controlled environment are parameters linked to the species that must be considered. Furthermore, the market value of individuals of the species is determined by organoleptic characteristics, whose appreciation is related to consumers' dietary habits.

Domestication strategy

The domestication process has three facets depending on the context. According to (McDermid et al., 2010), these include negative selection that opposes individuals adapted to the natural environment, positive selection for individuals that develop tolerance to the controlled environment, and finally, individuals that do not adapt (relaxation of selection pressure). Thus, the strategy (process) of domestication begins with the adaptation of individuals to be domesticated to the production environment. Reproduction under controlled conditions, juvenile production, and maintenance are secondary stages of domestication. Several authors, including Toth et al. (2022) and Palińska-Żarska et al. (2020), agree that this is a long process that can sometimes take decades.

Isolation or controlled conditioning

The domestication process begins when a small number of animals are isolated from the wild species. This population may then undergo a phenomenon of microevolution, adapting to farming conditions and due to human selection (Kucharczyk et al., 2023). This adaptation, consisting of environmental and genetic determinism during the domestication process, in one way or another, allows for the creation of new types of individuals from wild individuals (Palińska-Żarska et al., 2020). Therefore, great attention must be paid to farming conditions to ensure survival, growth, and the development of reproductive characteristics (Alit et al., 2023).

Reproduction

In the domestication process, mastering reproduction in a controlled environment and managing juveniles or their growth are stages that can be developed simultaneously (Kucharczyk et al., 2023). According to this author, selection is a theme or means to achieve domestication. Thus, once placed in a controlled environment, individuals exhibiting characteristics sought by the breeder, following phenotypic and genetic modifications at maturity, can enter reproduction (Priyadi et al., 2024).

Growth

Regarding fattening and larval rearing, some features of wild individuals are diminished or lost in favor of new emerged ones. For certain species, domesticated individuals tend to forage in the upper water column. They also have a relatively higher growth rate as they do not expend energy or time searching for food. Individuals in the domestication process exhibit intermediate characteristics regarding these traits (Palińska-Żarska et al., 2020). According to Alit et al. (2023), feed training, can be achieved through dietary treatments. The fish which relies on species selection based on criteria such as growth, resilience, and reproduction in controlled conditions, involves extensive genetic and behavioral adaptation to specific habitats. The goal is to meet the growing demand for animal protein.

Impacts of domestication

Environmental impact

The environmental impacts of fish domestication are complex. The influence of environmental factors on domesticated phenotypes is significant. The interactions among genetic determinants and environmental factors play a key role in the development of traits in domesticated fish. For Teleosts, phenotypic, molecular, and morphological modifications are strongly influenced by factors such as temperature, light, and farming conditions (Etchegaray et al., 2022*)*. These elements can alter the biological features of fish, sometimes making them less suited to uncontrolled natural environments. The effects of farming conditions on the ecological behaviors of domesticated fish are also notable. Fish raised in captivity, subjected to artificial conditions, develop modified ecological behaviors. For example, they are generally less sensitive to natural dangers, such as predation, and show difficulties in adapting to wild environments, which can hinder their survival if these individuals are released into the wild (Álvarez and Nicieza, 2003). This loss of responsiveness and adaptability can have serious consequences, particularly in reintroduction or population reinforcement programs.

Moreover, domesticated populations can disrupt natural ecosystems. When individuals bred in captivity are introduced into the wild to strengthen natural populations, their ecological role may differ from that of natural populations. This can lead to imbalances, particularly in local trophic networks, where their behavior and interaction with other species can disrupt existing ecological dynamics (Jiang et al., 2014). Finally, domestication tends to reduce fish resilience to environmental changes. Domesticated fish, more dependent on controlled conditions in captivity, are often less able to adapt to sudden changes in their natural environment. This loss of resilience can limit their survival and integration into natural habitats if unforeseen environmental changes occur. Thus, while fish domestication has optimized aquaculture production, it also raises significant environmental challenges, particularly in terms of adaptability and integration into natural ecosystems.

It is essential to regulate cage farming in bodies and waterways and to take necessary measures concerning the quality of nets for natural environment farming, as well as the size of fish at stocking, to prevent certain individuals from escaping. Likewise, farming zones must be clearly defined and located between fishing areas. These measures create a management framework that can help regulate farming and protect aquatic ecosystems.

The baz1d locus occupies a pivotal position in the expression of domestication-specific phenotypic traits, contributing to the emergence of distinctive characteristics in fish individuals raised in captivity conditions compared to wild fish. However, phenotypic modifications are not solely the result of genetic selection but also stem from the interaction between genetic and environmental factors. Etchegaray et al. (2022) highlighted that phenotypic changes vary among species and are influenced by complex interactions between genetic determinants, such as sexual determination, and environmental conditions. These factors work together to induce significant molecular and morphological modifications, making domesticated fish different from their wild counterparts not only externally but also at the cellular and genetic levels.

Finally, the ecological effects of phenotypic changes in captivity can have consequences on fish behavior and survival in the wild. Captive-reared fish exhibit changes that alter their vigilance against predators, their ability to forage in nature, and their aggression, negatively impacting their adaptation to wild conditions. These behavioral deficits make domesticated fish less capable of surviving and reproducing in natural environments, which can have significant ecological repercussions, particularly if these fish are released into the wild to strengthen wild populations (Álvarez and Nicieza, 2003; Jiang et al., 2014).

In summary, fish domestication induces profound phenotypic modifications that affect their physiology, behavior, and interactions with the environment. While these changes can enhance aquaculture productivity, they raise concerns about the survival and integration of domesticated fish into natural ecosystems.

Genetic aspects

Fish domestication impacts their genetic variability, chiefly in terms of growth and reproduction. According to Weber and Lee (2013), two key elements to consider when discussing fish domestication are the high growth rate and the induction of reproduction in captivity. In controlled habitats, domesticated fish, subjected to selection and environmental conditions, exhibit superior growth compared to their wild counterparts (Ahammad et al., 2022; Wringe et al., 2010). These growth differences between domesticated and wild populations are mainly attributed to genetic foundations, confirming the idea that domestication alters fish developmental trajectories (Cheng et al., 2023; Konstantinidis et al., 2020).

The impacts of domestication are not limited to growth but also affect fish reproduction. Controlling the genetic factors regulating sex in fish is a major challenge in aquaculture, helping improve farm management and optimize fish productivity (Wilson et al., 2014). In controlled environments, rearing conditions such as diet, temperature control, and light exposure can influence fish reproductive cycles. These conditions can sometimes accelerate the sexual maturation process, reducing the time required for fish to reach full reproductive maturity. Domestication itself also induces genetic and phenotypic changes related to reproduction. For example, it affects the transcription of genes involved in regulating pituitary hormones, such as LH (luteinizing hormone) and FSH (follicle-stimulating hormone), which vary depending on the age and size of domesticated fish (Khendek et al., 2017; Cheng et al., 2005). These modifications can impact reproductive cycles and the ability of fish to reproduce efficiently in captivity.

Finally, some domesticated fish species exhibit chromosomal disturbances related to sexual determination, affecting reproduction. These alterations can lead to imbalances in sex ratios, disrupting natural reproduction and having effects on aquaculture management (Wilson et al., 2014). Thus, while fish domestication can improve certain aspects of growth and reproduction, it also introduces changes that require precise management to avoid undesirable effects.

Behavioral aspects

At the behavioral level, it was observed that the different phenotypes of domesticated fish are based on genetic determinism. According to Devlin et al. (2020), the behavioral characteristics of domesticated fish have a genetic basis, explaining the variability observed among these individuals. Regarding the adaptation of domesticated fish, significant changes occur early in the ontogenetic process, affecting their digestive capacity. These changes result in low enzymatic activity and reduced expression of genes responsible for enzyme production (Palińska-Żarska et al., 2020), reflecting the specific adjustments required for domestication in a controlled environment. In terms of behavioral transformation induced by artificial feeding, transitioning from natural to artificial feed during the domestication process has been observed to cause genetic modifications in captive individuals. These changes manifest through the inhibition of certain genes and the transcription of new DNA fragments (He et al., 2021), demonstrating the impact of diet on the biology of domesticated fish. The feeding and growth behaviors of domesticated fish also evolve under domestication pressure.

These fish are more attracted to artificial feed and tend to feed more at the water surface. Additionally, they exhibit better growth performance compared to their wild counterparts. This behavioral evolution is gradual and depends on the intensity of the domestication process (He et al., 2021).

However, fish domestication also induces some behavioral changes, such as docility, reduced stress responsiveness, altered body proportions, decreased locomotor ability, and increased growth are frequent consequences of this process (Palińska-Żarska et al., 2020; Horreo et al., 2017; Christensen et al., 2014). These changes pose challenges for managing domesticated fish in captivity. It is also possible to see undesirable behavioral effects linked to domestication. For example Douxfils et al. (2014, 2011) reported a loss of immunity in domesticated fish, making them vulnerable to pathogens. In domesticated shrimp, modifications in reproductive behaviors have also been observed. According to Marsden et al. (2013), females lost their ability to produce pheromones, and males became less vigorous, negatively impacting reproductive success. These alterations result from rearing conditions and the specific objectives associated with domestication (Devlin et al., 2020). Thus, fish domestication induces complex transformations, affecting not only their genetic traits but also their behaviors and ecology. These changes present significant challenges for managing captive populations and their reintroduction into natural environments.

Critical evaluation of sources

The complexity of domestication are key factors influencing studies on this subject. As a result, a variety of methods have been used in the different scientific articles reviewed. Most studies on genetic improvement or selection are conducted on a limited number of individuals in controlled environments (Gjedrem et al., 2012). This raises concerns about the applicability of findings in real-world settings and their long-term effects. The studies by Teletchea and Fontaine (2014) highlighted the ecological and behavioral dimensions of fish domestication. However, species differences and the duration of experimentation can introduce unexpected changes in the domestication process. Other researchers argue that selection and isolation of individuals for domestication often overlook environmental factors (Lorenzen et al., 2012). Few studies assess the long-term consequences of genetic modifications on aquatic biodiversity. Furthermore, research on the epigenetic impacts of domestication (Anastasiadi et al., 2019) remains limited and requires further empirical validation.

Identification of literature gaps

Many studies on domestication and selection focus on genetic, behavioral, environmental, and sometimes ecological traits under controlled natural conditions. However, none of these studies take a comprehensive and holistic approach over time. Few researchers have examined how social behaviors influence the success of domestication (Huntingford et al., 2006). Most studies are based on short-term experiments and do not track population evolution over multiple generations (Liao and Huang, 2000). Additionally, the effects of domestication vary across species, but few studies have compared different species in the domestication process (Shen et al., 2021).

Perspectives and implications

Domestication presents both advantages and disadvantages for aquaculture production. From an environmental perspective, interbreeding between domesticated and wild fish populations can lead to genetic homogenization and reduce the adaptability of natural populations (Wilson et al., 2014). Regarding fish welfare, few studies have investigated the impact of domestication on stress levels (Douxfils et al., 2014). It is crucial to develop precise indicators to assess these effects. Moreover, the use of “gentle domestication” techniques combining genetic improvement with optimized environmental conditions could be a more sustainable approach (Khendek et al., 2017).

CONCLUSIONS

This study provides an in-depth literature review on fish domestication in aquaculture, highlighting its genetic, behavioral, environmental, and physiological dimensions. Domestication involves not only genetic selection aimed at improving traits such as growth, controlled reproduction, or disease resistance but also significant changes through complex interactions between environmental factors (rearing conditions, climate, and farming methods) and genetics. Unintentional modifications create new types of individuals that resemble their wild counterparts but differ in key ways. The adaptation of species to controlled environments can be beneficial or detrimental to humans.

The duration of fish domestication can range from a few years to several generations, depending on various factors. These include reproductive behavior and adaptability (for instance, fish that reproduce quickly can be domesticated more rapidly), as well as rearing conditions and the goals of domestication. If the objective is simply to raise fish in captivity, it may be achieved more quickly than if the aim is to modify specific traits.

Furthermore, the study emphasizes that fish domestication occurs in three major stages, with flexible succession over time. The process begins when a group of individuals from a species is isolated and maintained under controlled conditions for farming purposes. However, a more critical approach reveals that several aspects remain underexplored, and long-term consequences need to be better anticipated. Therefore, it is essential to develop sustainable domestication strategies that balance economic performance, environmental conservation, and animal welfare.

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