Lambari

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Lambari is a group of small native fish from Brazil common in natural freshwater. They have gained visibility and good acceptance in very profitable market niches, such as human food and live bait for sport fishing.

Keywords: Astyanax ; IMTA ; integrated aquaculture ; baitfish ; aquaculture

1. Introduction

Worldwide aquaculture production surpassed 120 billion tons and USD 275 billion in 2019 [1]. This activity is one of the fastest-growing food-producing sectors, increasing about 6% yearly in the past three decades and employing more than 20 million people [2]. Aquaculture is essential to meet the increase in animal protein demand and provide food security [3]. Recently, animal aquaculture based on allochthone diets (fed aquaculture) surpassed unfed aquaculture [2]. Diet is the major operating cost in fed monoculture systems [4]. Moreover, it is the primary waste source in fish and shrimp monocultures [5][6][7]. This situation is because a single species is not able to assimilate most diet nutrients and energy. In monocultures, the farmed species assimilates only ~20% of the diet nutrients, while almost 80% are dispersed into the water as particulate matter or dissolved nutrients and transform into pollution [4].

Integrated systems are based on farming more than one species per pond, and then it is possible to occupy the three spatial dimensions and different ecological niches [4]. These systems promote synergistic interactions between farmed species. The available resources can be more efficiently used, shared, recycled, and converted into biomass of high commercial value, based on the economic circularity concept. These systems also promote animal welfare and reduce environmental impact [8][9]. The integrated multitrophic aquaculture (IMTA) system is based on the farming of species with different trophic levels and/or with complementary functions and economic potential. The IMTA systems generally combine fed species with extractive species. These species use food waste and residues from the production of the fed species to grow; thus, it is possible to recover nutrients and increase yield without increasing inputs [10]. Therefore, choosing suitable species that showed compatibility and complementarity is crucial to improving aquaculture sustainability [8][9].

The yellow tail lambari (*Astyanax lacustris*, former *A. bimaculatus*) [11] has opportunistic omnivorous feeding habits, high reproductive rate, short life cycle, and easy management, showing high qualities for aquaculture [12][13]. Despite the recent increase in production, reaching 1000 t in 2019 [14], and significant interest, there are no established standard raising systems and practices for farming this specie. Fonseca et al. [13] recommend the IMTA to improve the sustainability of the yellow tail lambari production in Brazil. Amazon river prawn, *Macrobrachium amazonicum*, is another species with great potential for aquaculture and described as an excellent alternative to composing IMTA systems. This species is a detritivore and omnivorous, ingesting macrozoobenthos, algae, dead plants, and other residues deposited on lakes and river bottoms [15], and has a benthic habit, which avoids competition with pelagic species. However, studies carried out previously showed that the nutrients accumulated on the pond bottom at the end of the integrated farming of pelagic fish and Amazon river prawn are still large, making it possible to include another bottom detritivorous species [16][17][18][19][20][21]. Therefore, the addition of a third detritivorous species should improve nutrient recovery in the integrated system composed of a fed pelagic fish and a benthic prawn.

Curimbatá, *Prochilodus lineatus*, is another indigenous species in Brazil also known as curimba or curimatã. This species is exploited by fisheries and aquaculture in different regions of South America [14][22][23][24][25][26]. This is an iliophagus fish that feeds predominantly on fine-particle organic matter and periphyton over the bottom of rivers and lakes [27][28]. Thus, curimbatá can be an excellent option for the IMTA system with yellow tail lambari and Amazon river prawn. Curimbatá was introduced in China and Vietnam, where it has been farmed in integrated culture [28].

Considering the above rationale, we aimed to evaluate if the introduction of benthic species with complementary niche trophic in the culture of a pelagic fish would recover lost nutrients and increase the yield, improving the utilization of the supplied diet. Yellow tail lambari, Amazon river prawn, and curimbatá are excellent models to test this hypothesis because they have complementary food habits and occupy different spaces inside ponds. Yellow tail lambari swims in the water column close to the surface, curimbatá close to the bottom, and the Amazon river prawn walks on the bottom. In addition, they have economic importance, and thus, results can be applied to develop farm technology.

2. Improving the Efficiency of Lambari Production and Diet Assimilation Using Integrated Aquaculture with Benthic Species

The integrated culture of yellow tail lambari, Amazon river prawn, and curimbatá was shown to be technically feasible, efficient, and productive. No adverse effect on the growth, survival, and yield of the yellow tail lambari was produced by the benthic species. Similarly, curimbatá did not affect the prawn's performance. All species developed well in stagnant earthen ponds using nutrient-rich water, corroborating previous results [29][30][31]. The total annual high-value biomass produced increased from 9 t ha^{-1} in lambari monoculture to 16 t ha^{-1} in integrated culture, using the same space, amount of freshwater, feed, and other resources indicating a tremendous increase in system efficiency. Annually, 7 t ha^{-1} of organic and mineral components were recovered from the environment and transformed into nutrient-rich human food and marketable product.

The yellow tail lambari is typically farmed in small earthen ponds (0.03–0.3 ha) for 3 to 4 months to attain 3 to 8 cm and are sold for USD 3.00/kg to processing plants or USD 50.00 per thousand individuals to bait-fish markets [14]. Generally, farmers have low control and records of the cultures [13]. A recent survey (not published yet) indicated that survival ranges at about 50–60%, productivity at ~2 t ha^{-1} cycle^{-1}, and FCR from 1.6 to 2.1 in commercial farms. Therefore, the results obtained in the present study conform to the actual commercial-farm performance. Nevertheless, in one experiment conducted in small net-cages (160 L) over 45 days, Vilela and Hayashi [32] obtained 100% survival. Henriques et al. [33] suggested that the Atlantic forest lambari (*Deuterodon iguape*) can attain 80 to 90% of survival raised in indoor recirculating tanks over 60 days. These data indicate the potential to increase the survival and yield of lambari culture by improving management practices. Mortality of yellow tail lambari in the present study and commercial farms may be caused by predation by birds and aquatic insects, susceptibility of the species to management, and the lack of a scientific-based farming protocol.

Herein, yellow tail lambari reached the commercial size in 60 days in monoculture or integrated culture. This time is relatively short when compared to what is usual in commercial farms, which is 3 to 4 months [14]. This difference may be due to the accelerated growth of yellow tail lambari in warm and rainy seasons, the high-quality diet, or more controlled management, as observed in the present study. Therefore, performing five production cycles annually, as we simulated, seems feasible after minor improvements in the technology used in commercial farms. Amazon river prawns stoked as post-larvae in growth-out ponds generally spent about 120 days to reach the commercial size [34]. Thus, at 2 months, juvenile prawn should be stocked in integrated culture with yellow tail lambari as a strategy to combine and coincide both species' cultivation periods. The curimbatá has a slow growth rate, but it should be traded as juveniles of different sizes to grow-out farms, as bait-fish for the sportive fisheries market, or to the environmental mitigation market [14][29]. Juveniles of different sizes produced in hatcheries are released annually into dam-impacted hydrological basins in Brazil, which support a massive artisanal fishery [14].

Herein corroborated that the Amazon river prawn can be raised with pelagic fishes in stagnant ponds filled with eutrophic or hypereutrophic water. Rodrigues et al. [31] demonstrated the feasibility of combining Amazon river prawn with Nile tilapia (*Oreochromis niloticus*), and Dantas et al. [30] demonstrated the same, combining the prawn with tambaqui (*Colossoma macropomum*). All these studies used nutrient-rich water in stagnant ponds. Nevertheless, the yield of the Amazon river prawn is about 0.5 t ha^{-1} cycle^{-1}, when eating only diet residues and wastes of a pelagic fish, which is half of that obtained when prawn is fed with a specific commercial diet in densities below 40 prawns m^{-2} [30][31][35]. In the present study, the use of inlet water rich in phosphorus and nitrogen led to suitable pond water quality during the entire experiment and consequently did not impact the yield. This result is according to the finds of Kimpara et al. [36], which demonstrated the feasibility of producing Amazon river prawn using nutrient-rich waters. This eutrophic or hypereutrophic inlet water may represent a source of unpaid nutrients, avoiding the use of fertilizers. Part of these nutrients can be recovered in integrated culture systems through assimilation by the farmed species.

Curimbatá may compete with prawns for space and food on the pond bottom. However, no effect on prawn growth, survival, or yield was observed. These results indicate that the competition may be low, and no agonistic behaviors negatively impacted the culture when stocking 25 juvenile prawns and 13 fingerling curimbatás by m^2. Probably, there is only a tiny overlap of trophic niches of both species. Curimbatá eats during the day [27], and Amazon river prawn eats during the day or at night alike [37]. Amazon river prawn eats mainly benthic organisms and large organic matter particles [15], while curimbatá ingest mud containing fine-particle organic matter, with most particles lower than 105 µm, and periphyton that grows over inorganic particles [27][38]. This periphyton is composed mainly of microbial biomasses [28] that extract carbon, nitrogen, phosphorous, and other nutrients from water and sediment, making them available for heterotrophic food webs.

The number and proportion of the unfed components of an integrated aquaculture system depends on the pelagic species' mass density because it provides residues and wastes. A co-stocking experiment that lasted 2 months showed that the yield of the Amazon river prawn stoked at 11 prawns m^{-2} together to 4 g tambaqui (the pelagic fed species), stocked at 1.4 m^{-2}, decreased by 25% when 5 curimbatás m^{-2} were added [29]. However, total species biomass increased 35%, and FCR decreased 30%, showing that the yield of curimbatá compensates for the decrease in the prawn yield and the recovery of lost nutrients and energy increased. The higher biomass of lambari in the present experiment than the biomass of tambaqui in the study of Franchini et al. [29] was enough to provide the necessary wastes to support the density of Amazon river prawn and curimbatá with no adverse effect on the prawn growth.

We observed that adding Amazon river prawn to yellow tail lambari culture increased the annual yield from 9 to 12 t ha^{-1} and reduced FCR from 2.5 to 1.8. The addition of curimbatá, a second benthic species, with iliophagus food habit, increased annual yield to 16 t ha^{-1} e and reduced FCR to 1.4. This remarkable increase in efficiency by adding species with complementary ecological functions represented an improvement in nutrient recovery of almost 80%. The present system is ranked as the maximum level of integration (level 5), according to the scale of Boyd et al. [4], which means that one cultivated species originates by-products, which are inputs for the others, and vice versa. Yellow tail lambari produces wastes that go down to the bottom, providing energy and nutrients for developing benthic communities. Amazon river prawn and curimbatá will feed on the aquatic biota or directly on the wastes, contributing to the mineralization of organic matter. Their bioturbation creates an upwelling of nutrient-rich water, which will fertilize the water column, boosting the development of phytoplankton, which will be eaten by the zooplankton that is nutrient-rich food for the yellow tail lambari. Therefore, the integrated system proposed creates a looping of nutrients, increasing recycling, assimilation, and the system's circularity. This scenario is provided by the compatibility of animals, which limits competition and agonistic behavior, and the complementarity exploited by the synergistic interaction between species, leading to biomitigation and production processes [9][39].

The proposed integrated system also contemplates some important sustainability principles claimed by Valenti et al. [40], such as production based on the circular economy concept, reduction in using natural resources, increasing efficiency in assimilation nutrients, and allowing the producer to conquer different markets offering different products. The three species are native to Brazil, which brings some advantages, such as avoiding risks to biodiversity and exploring consolidated local markets [26][41]. Furthermore, the experiment was performed in conditions equivalent to the commercial farms, and therefore, the results are directly applicable, requiring few management adaptations to the lambari monoculture farms. This technology was patented on the Brazilian patent basis # BR 10 2020 005641 7; 20 March 2020. Economic assessments of using this technology in different scenarios have been done, and preliminary results are positive. Thus, the adoption of this integrated system in the production sector is promising. Nevertheless, it depends on the extension services to spread this new conception and government policies to encourage farmers to move to a more sustainable way to produce fish and prawns.

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