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The Role of *Catla catla*, *Labeo rohita*, and *Cirrihinus mrigala* in the Aquaculture Industry of Andhra Pradesh and Telangana

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Abstract

Major carps of India, *Catla catla* (Hamilton), *Labeo rohita* (Hamilton), and *Cirrihinus mrigala* (Hamilton) are the essential components of aquaculture in Andhra Pradesh and Telangana, being economically important for food security and employment opportunities. These species are a common subject of farming because the products obtained from them are valuable in the market and very nutritious. In this review, information on farming practices, challenges faced, economic importance, and environmental impact of these species for aquaculture is presented. The results presented stress the importance of their impact on the development of local economies, food security, and better living standards for farmers. Nevertheless, the sector has challenges such as disease outbreaks, pollution, and lack of infrastructure among others. Some of these problems have however been solved by developments in polyculture systems, selective breeding, and integrated farming. Thus, it is obvious that further enhancement of management practices, policy support, and Farming technology for sustainable growth is direly needed. Further studies should be directed to climate-proof systems, markets, and genetics for the improvement of aquaculture in the region.

Keywords: Aquaculture, Catla catla, Labeo rohita, Cirrihinus mrigala, sustainability, economic development, farming practices.

1. Introduction

Fish farming is one of the most promising sub-sectors within the field of fishery in India which is the third largest fish-producing country in the world. FAO estimated fish production in 2016 and placed India second in aquaculture production and the third largest producer of total fish in the world contributing approximately 6.3% of total world fish production. The country also become one of the major producers of inland fisheries which shows the potential place of the country in the development of aquaculture. Among the states in the southern region of India, AP and Telangana are two states that have dominated the aquaculture industry because of climatic conditions, availability of water sources, and most farmers' involvement (FAO 2016; Sugunan 1995).

These states are mainly concerned with freshwater aquaculture using reservoirs, ponds, and riverine stocks to provide breeding and rearing conditions for various species of fish (Marques *et al*., 2016). Among all the aquaculture sectors, Andhra Pradesh has been more prominent and has contributed about 65–70% of the total farmed freshwater fish production in India in 2016 (FAO, 2016; Zacharia *et al*., 2016). Even newly formed Telangana has made strides by using irrigation reservoirs and canals to extend its fish production sector (Union *et al*., 2013). These results bear testimony to the fact that aquaculture remains a key source of transformation and food security for the rural folks in these areas.

Indian Major Carps (IMC) includes Catla - *Catla catla*, Rohu - *Labeo rohita*, and Mrigal - *Cirrihinus mrigala* are the most widely cultured freshwater fish in Andhra Pradesh and Telangana. These species are culturally, ecologically, and economically valuable, and provide the basis for aquaculture in the region (Basavaraja, 2007). These fish are characterized by high growth rates, good feed conversion, and their ability to be cultured in polyculture systems that make utilization of resources and production more efficient (Bagchi & Jha, 2011).

There are cultural messages encoded in the various species that are associated with aquaculture practices. *Catla catla* is a surface feeder and is preferred for its high rate of growth and the size of the fish. *Labeo rohita*, the column feeder's most popular fish, is much preferred for its taste and nutritional value. *Cirrihinus mrigala* being a bottom feeder does not interfere with the feed provided to the upper strata fish and thus reduces feed wastage and provides a balance in the ecosystem of the polyculture systems (Goswami & Samajdar, 2011; Rakocy, 2012).

The combinational adaptability of these species in a polyculture system increases the production and utilization of resources, thus, it is very effective for small and commercial farmers (De Silva, 2016; Paul & Giri, 2015). The Indian Major Carps are an essential source of cheap protein food securing nutritional requirements of the local people (Ramakrishna *et al*., 2013).

The present review will help to understand the three species *Catla catla* (Hamilton), *Labeo rohita* (Hamilton), and *Cirrihinus mrigala* (Hamilton) about aquaculture in Andhra Pradesh and Telangana. It will review the biological and ecological factors that define their appropriateness for aquaculture, evaluate the current farming systems, and relate the difficulties encountered by fish farmholders in these areas. The study is underpinned by findings from the FAO 2016 report and other related studies to ensure that the understanding of freshwater aquaculture in these states is well captured.

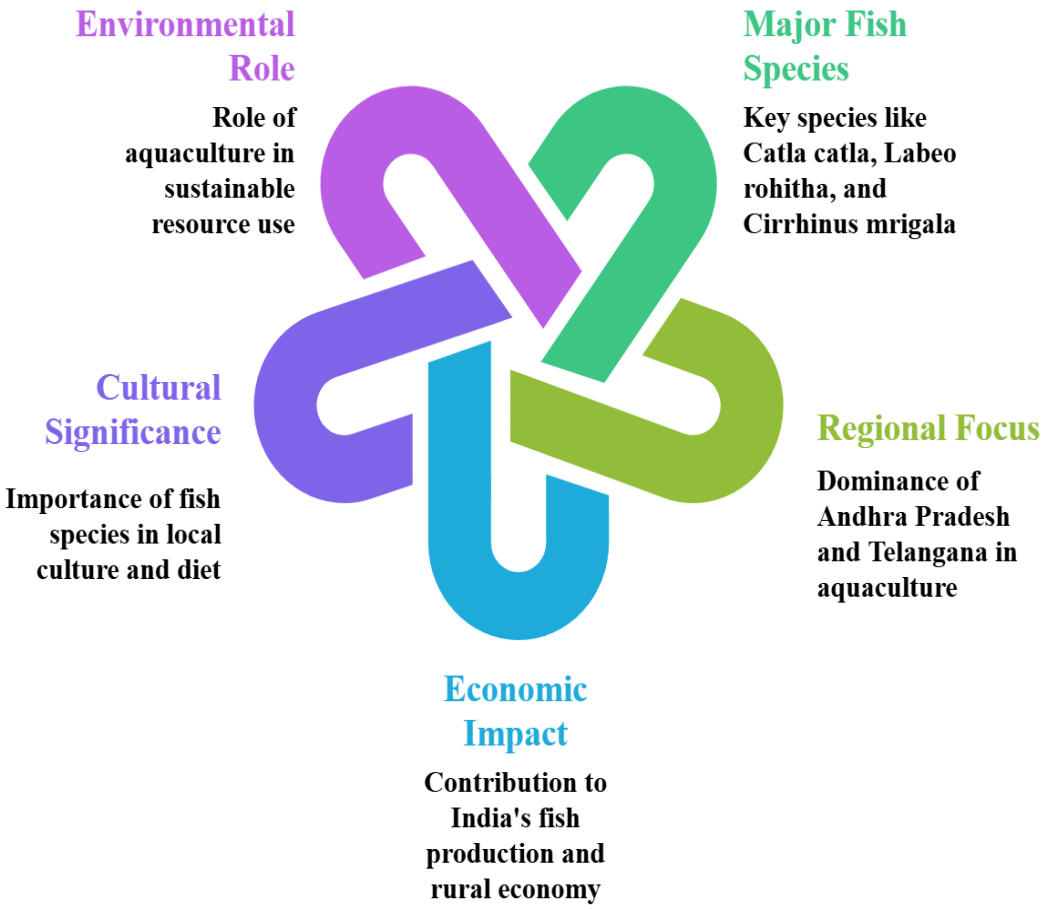

Fig.1. Aquaculture Dynamics in India

2. Biological and Ecological Characteristics of Indian Major Carps

2.1 *Catla catla* (Hamilton)

Catla catla or simply Catla, is a surface-feeding fish with a large head and body depth. It is identified by its slivery-white plates as well as its large mouth that is suitable for filter feeding (Deka & Gupta, 2013). Catla prefers freshwater habitats, both riverine and lacustrine, with moderate water currents and plankton production (Silva & Schiemer, 2000). It has a heat tolerant preference with an optimal range of temperature between 25°C and 32°C common to the aquaculture regions of Andhra Pradesh and Telangana (Jadhav, 2009). It mainly feeds on phytoplankton and zooplankton which make it a good species in the use of available resources in polyculture farming (Tina, 2008). Catla is a growing fish, the juveniles in many instances can reach marketable size within six months of farming. Due to its ability to breed under artificial conditions, this species plays an important role in Indian freshwater aquaculture (Pillai & Katiha, 2004).

2.2 *Labeo rohita* (Hamilton)

Labeo rohita, locally called Rohu, is one of the foremost fish species to be cultured in India because of its marketability and nutritional quality (Saravanan, 2016). Rohu has an elongated body, arched dorsal profile, and reddish fins, and it is a column feeder that inhabits freshwater environments with vegetation and plenty of plankton. It thrives in sluggish currents of water within a temperature range of 25 °C to 30 °C and the climate of Andhra Pradesh and Telangana suits this climate range (Lindqvist *et al*., 2012). Rohu is highly valuable in polyculture systems because it occupies the middle column of the water body without interplaying with surface feeders such as Catla or bottom feeders such as Mrigal (Desai & Radhakrishnan, 2003). Its composition features high protein, low fat, and satisfactory taste which makes it popular in regional diets. Further, the adaptability of Rohu in hatchery production has increased its availability for the expansion of aquaculture (Khan *et al*., 2011).

2.3 *Cirrihinus mrigala* (Hamilton)

Mrigal or *Cirrihinus mrigala* is a bottom feeder that is also considered an important complementary fish species in polyculture. Slim in body, silver in color, and slightly forked tail, Mrigal is well suited to freshwater environments especially lentic environments such as ponds and reservoirs (Wahab *et al*., 2002). The tolerance levels of this species to water quality parameters such as moderate turbidity and low Dissolved Oxygen (DO) make it suitable for aquaculture in Andhra Pradesh and Telangana, according to Reddy & Parameshwar (2015). Mrigal mainly consumes feed particles, remnants, and bottom-dwelling creatures, and this minimizes pollution and supports the original orderliness of the fish farming systems. Its slow but constant increase in production, coupled with the importance it brings to the improvement of water quality, has placed Mrigal as a critical species in the improvement of fish farming as shown in Table 1. Moreover, induced breeding technology has been developed to a stage that has made this fish consistently available for commercial production (Paul & Chanda, 2014).

Table 1. Biological and Ecological Characteristics of Indian Major Carps in Freshwater Aquaculture

Species	Common Name	Feeding Behavior	Habitat	Preferred Temperature Range (°C)	Diet	Aquaculture Role	Marketability	Breeding under Artificial Conditions
Catla catla	Catla	Surface feeder	Riverine, lacustrine, moderate current	25 - 32	Phytoplankton, Zooplankton	Essential in polyculture systems fast growth	High	Yes
Labeo rohita	Rohu	Column feeder	Freshwater, vegetated with plankton	25 - 30	Phytoplankton, Zooplankton	Valuable in polyculture, occupies the middle water column	High	Yes
Cirrihinus mrigala	Mrigal	Bottom feeder	Freshwater, lentic environments	-	Feed particles, bottom-dwelling creatures	Important for water quality, complementary in polyculture	Moderate	Yes
Catla catla	Catla	Surface feeder	Freshwater with plankton	25 - 32	Phytoplankton, Zooplankton	Plays a major role in Indian freshwater aquaculture	High	Yes
Labeo rohita	Rohu	Column feeder	Freshwater with vegetation	25 - 30	Phytoplankton, Zooplankton	Suitable for expansion in aquaculture due to hatchery adaptability	High	Yes
Cirrihinus mrigala	Mrigal	Bottom feeder	Ponds and reservoirs	-	Feed particles, bottom-dwelling creatures	Contributes to water quality improvement, slow but steady growth	Moderate	Yes
Catla catla	Catla	Surface feeder	Freshwater, moderate currents	25 - 32	Phytoplankton, Zooplankton	Used in polyculture farming for efficient resource use	High	Yes
Labeo rohita	Rohu	Column feeder	Freshwater with vegetation	25 - 30	Phytoplankton, Zooplankton	Important for its contribution to regional diets	High	Yes
Cirrihinus mrigala	Mrigal	Bottom feeder	Freshwater, ponds, and reservoirs	-	Feed particles, bottom-dwelling creatures	Helps in minimizing pollution and maintaining orderliness	Moderate	Yes

3. Aquaculture Practices in Andhra Pradesh and Telangana

3.1 Current Trends and Status of Carp Aquaculture

Andhra Pradesh and Telangana are the prominent states in India for aquaculture and contribute more than 30 % of India's freshwater fish production (Ponnusamy *et al*., 2016). Out of the major Indian carp *Catla catla, Labeo rohita, and Cirrihinus mrigala* have the highest production level because of their versatility to the various water bodies and high market preference (Ismat *et al*., 2013). These states have experienced fast growth of the aquaculture technologies, thus, raising the annual production to over 3 million tonnes in the recent past (Rajitha *et al*., 2010). The government has also set up programs like the Blue Revolution Scheme that aim at improving production by practicing sustainable culture. This growth has been complementary to the rising global fish consumption and has made Andhra Pradesh and Telangana key players in responsible aquaculture (Samal & Flaherty, 2010). The inclusion of these species in large-scale production systems has shifted to the focus on increasing production efficiency to feed the growing population and meet the nutritional and economic demands of the communities (Heywood, 2011).

3.2 Farming Techniques

These include the *Catla catla, Labeo rohita and Cirrihinus mrigala* in polyculture systems have brought a revolutionary change to aquaculture in Andhra Pradesh and Telangana. The use of resources is efficient in polyculture because Catla feeds on surface components, Rohu feeds on middle column components, and Mrigal feeds on bottom components (Marques *et al*., 2016). Some general conservation measures such as aeration control and regular pond observation to address Dissolved Oxygen (DO) levels have also been implemented the most in preventing high levels of ammonia (Boyd & Tucker, 2012). Also, the enhancement of feeding practices in combination with the production of high-quality floating pellets has enhanced feed conversion ratios and fish health (Yakupitiyage, 2013). Conventional monoculture systems are rare but are becoming popular among smallholder farmers targeting niche markets (Lithourgidis *et al*., 2011). There are also new farming techniques like the biofloc technology being adopted in the region showing the region's ability to adopt modern advances in aquaculture (Browdy *et al*., 2012).

3.3 Regional Challenges and Solutions

Some of the problems that carp aquaculture faces in both Andhra Pradesh and Telangana include water shortages and diseases. Ponding is especially influenced by seasonal changes where droughts cause low water levels affecting fish quality and water quality (Seshagiri *et al*., 2013). To overcome such problems measures such as rainwater harvesting and the utilization of the treated wastewater have been employed as shown in Fig 2. Epidemic illnesses, especially bacterial and parasitic, are some of the biggest threats to productivity (Paul, *et al*., 2016). Immunostimulants and probiotics as part of prevention strategies were found to improve overall fish resistance (Sahoo, 2007). This has been complemented by the promotion of good aquaculture practices and government-funded disease surveillance. For instance, farmers are using herbal-based fish medicines instead of chemicals, which has been made possible by several innovations (Hishe *et al*., 2016). Altogether, these have pointed to the fact that the aquaculture sector has been very much able to address regional issues (Njoroge, 2012).

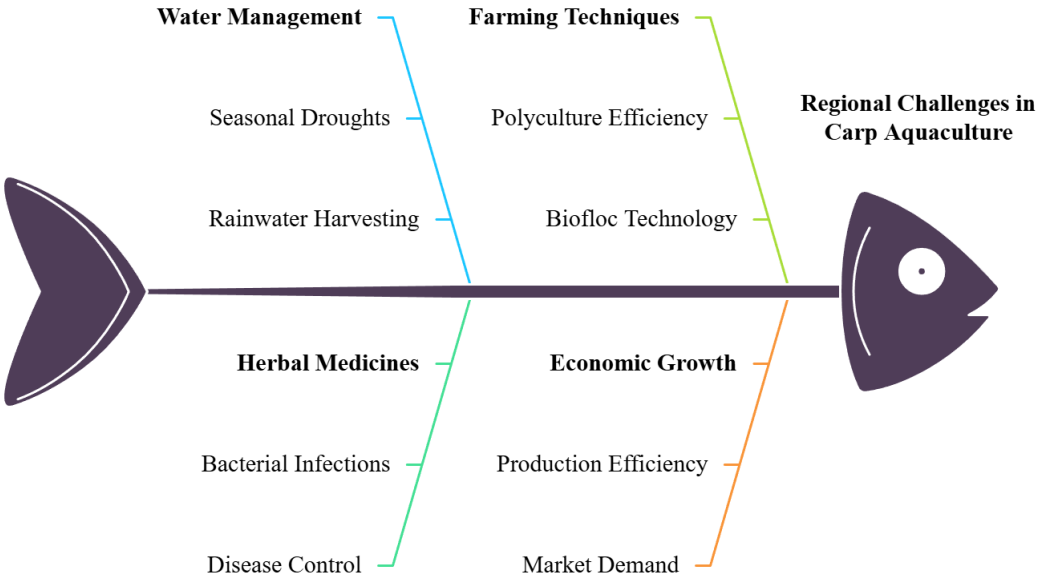

Fig.2. Challenges and Solutions in Carp Aquaculture

4. Economic Importance

4.1 Livelihoods and Employment

The farming of IMC is one of the most effective strategies for rural income in Andhra Pradesh and Telangana. In the case of fish farming, small-scale fish farmers participate in government policies such as Blue Revolution Scheme to obtain subsidies and cheap credit for developing aquaculture (Zajdband, 2011). Besides, the industry creates employment in all the value chain activities such as hatcheries and feed producers, processing, and marketers (Bjorndal *et al*., 2014). Women's involvement in aquaculture activities like fish processing and marketing is also an additional stream of income to the community-based income (Weeratunge *et al*., 2010).

4.2 Domestic and Export Markets

Domestic markets are preferred over export markets for Indian major carps especially *Catla catla* and *Labeo rohita* because of their taste and nutritional value. This has enhanced the incomes of India's aquaculture exports, particularly to Southeast Asia and the Middle East, where such species are in high demand (Zamarrud, 1994). Cold chain infrastructure has also been developed to increase the storage and transportation of processed fish and thereby increase export capacity (Kitinoja, 2013).

4.3 Contribution to GDP

Aquaculture forms an important segment of the economy of Andhra Pradesh and Telangana as it has a large contribution to the Gross Domestic Product (GDP) of the two states. Major carp dominate over 60% of the freshwater fish production in these states and have a business potential of billions of rupees per annum as shown in Table 2. Higher productivity and profitability levels have been realized through research and development investments in aquaculture, such as genetic improvement of carp (Ponnusamy *et al*., 2016).

Table 2. Economic Importance of Indian Major Carps in Aquaculture: Livelihoods, Markets, and Contribution to GDP

Economic Aspect	Focus Area	Key Activity	Region	Stakeholders Involved	Impact on Community	Market Preferences	Export Potential	Contribution to GDP
Livelihoods and Employment	Fish farming	Participation in PMMSY for subsidies	Andhra Pradesh, Telangana	Small-scale fish farmers, government	Rural income generation	Domestic markets preferred	High demand in Southeast Asia and the Middle East	Contributes to the rural economy
Livelihoods and Employment	Aquaculture value chain	Hatcheries, feed production, processing	Andhra Pradesh, Telangana	Hatchery workers, feed producers, marketers	Employment generation across the value chain	Domestic markets preferred	The development of cold chain infrastructure increases the export	Supports local livelihoods
Livelihoods and Employment	Women's involvement	Fish processing and marketing	Andhra Pradesh, Telangana	Women entrepreneurs in fish processing and marketing	Additional income stream for women	Domestic markets preferred	Increased export potential with improved cold chain infrastructure	Empowerment of women in the community
Domestic and Export Markets	Market demand	High demand for Catla and Rohu	Domestic, Southeast Asia, Middle East	Consumers, exporters	Increased income for local fish farmers	Domestic markets preferred	High export demand in Southeast Asia and the Middle East	Significant boost to national income
Domestic and Export Markets	Cold chain infrastructure	Development to enhance storage and transport	India, export regions	Infrastructure developers, fish farmers, exporters	Increased export capacity and efficiency	Domestic markets preferred	Expands export capacity, particularly to Southeast Asia and the Middle East	Strengthens economic infrastructure
Contribution to GDP	Freshwater fish production	Major carps in aquaculture	Andhra Pradesh, Telangana	Fish farmers, processors, government	A key contributor to regional economies	Domination of the domestic market	Limited export but growing potential	Contributes billions to GDP
Contribution to GDP	Research and development	Genetic improvement of carps	Andhra Pradesh, Telangana	Researchers, aquaculture professionals	Improved productivity and profitability	Domination of the domestic market	Export potential increases with higher productivity	Stronger economic growth
Contribution to GDP	Freshwater fish production	Aquaculture productivity and profitability	Andhra Pradesh, Telangana	Fish farmers, researchers, government	Increased income for farmers, economic growth	Domination of the domestic market	High export demand for quality fish	Key economic contributor
Contribution to GDP	Economic potential	Billions in business annually	Andhra Pradesh, Telangana	Government, farmers, export industry	Boosts overall regional economy	Domination of the domestic market	High export growth potential with infrastructure investment	Large contribution to state GDP

5. Contribution to Food Security

5.1 Nutritional Benefits

The major crops of India such as *Catla catla*, *Labeo rohita*, *and Cirrihinus mrigala* are good sources of protein, omega-3 fatty acids, and other essential nutrients like zinc and selenium. They help in combating malnutrition and enhancing the immune system more so among the most marginalized groups in society as noted by Mahanty *et al* (2014). Due to its low cost, it is thus a cheap source of protein especially for low-income earning families (Thilsted & Roos, 1999).

5.2 A Role in Public Health Programs

Extension of the Indian major carps in the school meal programs as well as in the Public Distribution System has also helped in the enhancement of the nutritional status of children and pregnant women (Bogard *et al*., 2015). For instance, fish products enriched from these species are used in areas affected by malnutrition to meet the required nutrient supplements (Thilsted *et al*., 2014). Such endeavors correlate with the country's strategic plans to meet food security and fight malnutrition (Banda-Nyirenda & Kaunda, 1985).

5.3 Enhancing Dietary Diversity

Due to their flexibility in the diets of many communities, *Catla catla*, *Labeo rohita*, and *Cirrihinus mrigala* can be prepared in many regional dishes. Consumption of these fish has been associated with a decreased chance of different chronic diseases including cardiovascular diseases, and type 2 diabetes meaning they help enhance human health (Kumari & Ahsan, 2011) as shown in Fig 3. Subsequently, awareness promotion campaigns have added to their adoption of daily meals in both urban and rural areas.

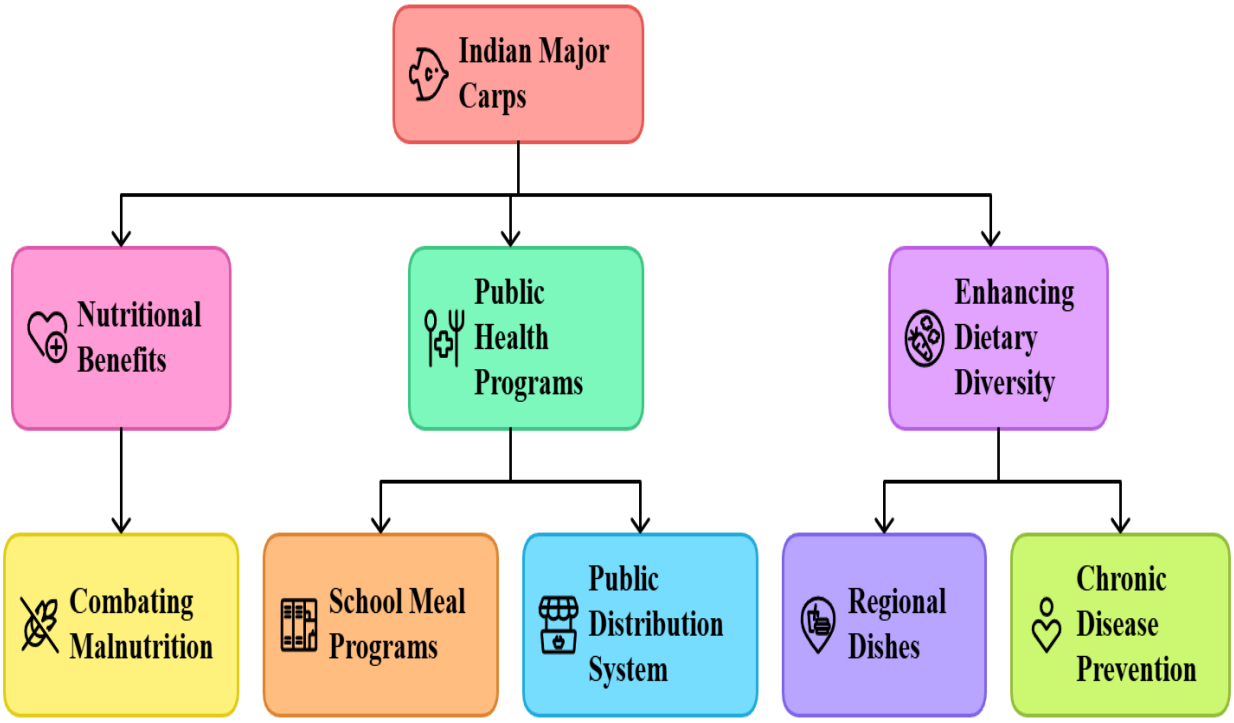

Fig.3. Enhancing Food Security Through Major Food Carps

6. Advances in Farming Practices

6.1 Polyculture Systems

Integrated fish farming has been effective in aquaculture, especially in polyculture farming of *Catla catla* (Hamilton), *Labeo rohita* (Hamilton), and *Cirrihinus mrigala* (Hamilton). These species are mutually complementary in their feeding habits and therefore the synergism improves resource use. For instance, *Catla catla* feeds on surface water, and *Labeo rohita* and *Cirrihinus mrigala* feed in mid and bottom water respectively (Milstein, 2005). This stratification minimizes competition that is usually observed in other developing systems and thus improves growth rates (Zajdband, 2011). Also, polyculture systems contribute to the improvement of bio-diversity hence, improving the stability of the polyculture systems to diseases (Thrupp, 2004). It also reduces the hazards related to the monoculture farming system that is dangerous for the environment (Frison, 2016). Therefore, polyculture practices are useful for the sustainable culture of fish and increase the total production of rural farming societies.

6.2 Genetic Improvements

The genetic enhancement of *Catla catla, Labeo rohita, and Cirrihinus mrigala* has recently exhibited better rates of growth, disease immunity, and better farming yield. Breeding strategies specifically targeting the growth of the species have improved the general productiveness of these species (Shyla, 2010). Furthermore, molecular breeding techniques such as marker-assisted selection (MAS) have been used in identifying genes controlling diseases to enhance resistance among these species to regular diseases (Chattopadhyay, 2016). Knowledge gained about genetic variation and population dynamics has also advanced breeding programs to support the sustainable production of aquaculture species (Nguyen, 2016). Therefore, farmers are getting better yields, and disease costs are coming down which are good signs for farmers. These genetic developments are also useful in the long-term viability of fish farming because of the improvement of stock quality and reduce the effects on the surroundings (Kitada *et al*., 2009).

6.3 Integrated Farming Systems

The Integrated farming systems (IFS) which refer to the combination of fish farming with crop and livestock farming have been adopted in India, especially for *Catla catla, Labeo rohita, and Cirrihinus mrigala*. IFS improves resource use productivity by recycling nutrients where fish outputs are used to fertilize crops and crop outputs to feed fish (Behera & France, 2016). This mutual interaction minimizes external inputs and hence improves the general farm profitability as pointed out by Rana & Chopra (2013). Furthermore, IFS practices are also effective in environmental pollution control by reducing waste generation which is a major issue in conventional monoculture aquaculture systems (Tacon *et al*., 1995). For instance, integrated rice-fish farming systems in Andhra Pradesh have gained improved yields in all crops as well as fish and reduced the use of synthetic fertilizers and pesticides as shown in Table 3. Such a system plays a central role in encouraging sustainable and eco-friendly farming systems for the economy and the natural environment.

Table 3. Advances in Farming Practices for Indian Major Carps: Polyculture, Genetic Improvements, and Integrated Farming Systems

Farming Practice	**Focus Area**	**Key Activity**	**Species Involved**	**Advancement**	**Impact on Farming**	**Environmental Impact**	**Economic Impact**	**Sustainability**
Polyculture Systems	Integrated fish farming	Combination of complementary species for efficient resource use	*Catla catla, Labeo rohita, Cirrhinus mrigala*	Synergistic feeding habits among species	Improved growth rates and reduced competition	Enhances biodiversity and disease stability	Increases total production in rural farming	Promotes sustainable fish culture
Polyculture Systems	Stratification of feeding habits	Surface, mid, and bottom feeders working together	*Catla catla, Labeo rohita, Cirrihinus mrigala*	Stratified feeding reduces competition	Improved growth rates and efficiency	Reduces environmental hazards of monoculture	Increased productivity of farming systems	Supports sustainable aquaculture systems
Polyculture Systems	Biodiversity improvement	Use of complementary species in polyculture	*Catla catla, Labeo rohita, Cirrihinus mrigala*	Better resource utilization	Enhances fish farming stability	Increases disease resistance and ecosystem balance	Improves overall farm yield and diversity	Boosts long-term sustainability
Genetic Improvements	Breeding strategies	Improved rates of growth, disease immunity, and yield	*Catla catla, Labeo rohita, Cirrihinus mrigala*	Genetic enhancement through breeding programs	Better growth and disease resistance	Reduces environmental impact of diseases	Lower disease costs and higher farm yields	Enhances sustainable long-term farming

Genetic Improvements	Marker-assisted selection	Identification of disease-resistant genes	*Catla catla*, *Labeo rohita*, *Cirrihinus mrigala*	Disease resistance improvement	Enhanced stock quality and disease control	Reduces the need for chemical treatments	Higher profits for farmers due to reduced disease costs	Strengthens sustainability of farming
Genetic Improvements	Molecular breeding techniques	Targeting genes for disease immunity and growth	*Catla catla*, *Labeo rohita*, *Cirrihinus mrigala*	Use of molecular breeding for selective traits	Better overall productivity	Minimizes the use of harmful chemicals in farming	Increases marketable yield and profitability	Supports sustainable aquaculture practices
Integrated Farming Systems	Resource recycling	Combining fish farming with crop and livestock	*Catla catla*, *Labeo rohita*, *Cirrihinus mrigala*	Nutrient recycling between fish, crops, and livestock	Increased farm productivity and profitability	Reduces external inputs and waste generation	Higher farm profitability and efficiency	Promotes eco-friendly farming practices
Integrated Farming Systems	Pollution control	Reduces waste generation through IFS	*Catla catla*, *Labeo rohita*, *Cirrihinus mrigala*	Reduced environmental pollution	Improved environmental health	Reduction in synthetic fertilizers and pesticides	Improved crop and fish yields with reduced costs	Fosters sustainable and eco-friendly farming
Integrated Farming Systems	Rice-fish farming systems	Combination of rice and fish farming in Andhra Pradesh	*Catla catl*, *Labeo rohita*, *Cirrihinus mrigala*	Reduced use of synthetic fertilizers and pesticides	Increased farm yields across crops and fish	Improved soil health and water quality	Boosts overall farm profitability	Promotes environmental sustainability

7. Challenges in Aquaculture

7.1 Disease Management

The disease is one of the major challenges facing aquaculture in India, especially in *Catla catla* (Hamilton), *Labeo rohita* (Hamilton), and *Cirrihinus mrigala* (Hamilton). Pests, diseases, and parasites are the major challenges to these fish species and lead to low production and loss of income (Monir *et al*., 2015). These are compounded by weak diagnostic tools and vaccines which make early diagnosis and containment hard (Waage & Mumford, 2008). In addition, through the use of antibiotics and chemicals to control diseases, diseases have become resistant to antimicrobial resistance making it even harder to treat diseases (Bartelt & Guerrant, 2012). Better surveillance mechanisms and the cultivation of species of fish that are disease-resistant and grown in an environmentally sustainable way are very important for increasing the sustainability of aquaculture (Hine *et al*., 2010). In addition, calls for research to improve the disease prediction models can help reduce disease risks in aquaculture significantly.

7.2 Environmental Concerns

The development of aquaculture in Andhra Pradesh and Telangana has impacted the environment for example through nutrient enrichment and loss of biological diversity. The artificial feeds and overstocking hence subject the water to rich nutrient content resulting in eutrophication of the adjacently located water bodies (Sarkar *et al*., 2015). Eutrophication causes water oxygen deficits, affecting the bio-system and decreasing species diversity (Khan & Mohammad, 2014). Also, poor water management leads to pollution of the groundwater and the surface water (Feeley *et al*., 2016). An integrated aquaculture agriculture production system is called for to help reduce the adverse effects on the environment ((Murshed-E-Jahan & Pemsl, 2011). Those issues can be solved using eco-friendly feed and better waste management in the aquaculture industry. Finally, the implementation of circular economy concepts in aquaculture can decrease pressure on the environment and improve the sustainable performance of other naturally occurring functions in ecological systems (Qian & Wang, 2016).

7.3 Market and Infrastructure Challenges

Another of the major challenges in the sector is market infrastructure which hurts potential fish farming. In Andhra Pradesh and Telangana, there is poor supply and processing infrastructure that restricts the ability to store and process farmed fish to enhance shelf-life and quality hence decreasing profitability (Seethalakshmi, 2010). Also, changes in the market price cause instabilities economically affecting farmers and their chances of planning for growth (Forster, 2014). The lack of good supply chains also results in post-harvest losses and market access for small-scale farmers (Akande & Diei-Ouadi, 2010). Thus, improvements in physical facilities, structures, and extension of cold chain logistics for fish, processing units, and market linkages are required to enhance the durability of fish and for a sustainable income for the producers as shown in Fig 4. In addition, proper formation of cooperative models will assist reduce market access barriers, and enable smallholder farmers to get better prices in the market (Entee, 2015).

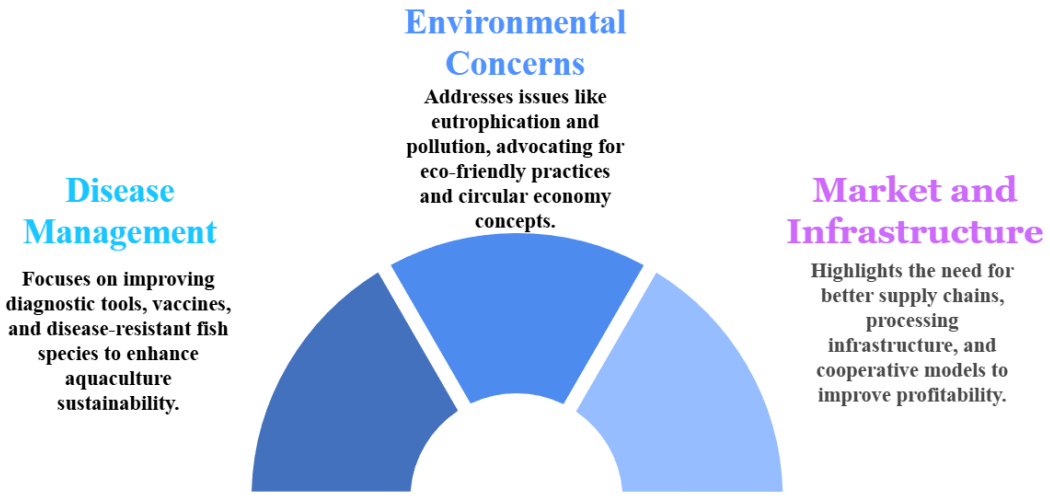

Fig.4. Overcoming Key Challenges for Sustainable Aquaculture Growth

8. Sustainability and Policy Support

8.1 Government-Sponsored Schemes for the Development of Aquaculture

The Indian government has initiated several measures on aquaculture development. Among them the Blue Revolution Scheme was launched in 2015 focusing on the modernization of fish farming practices and its infrastructure and improving the fish seed production (Mohan Joseph, 2007). Subsidized fish farming structures, fish seed production, and culture-based fishery through the National Fisheries Development Board (NFDB) were extended for aquaculture with a major concentration on small farmers (Pallapothu, 2012). Another important programme the National Mission on Protein Supplements (NMPS) launched to eat fish as an alternative source of protein targeting the rural population and also supporting the country's economy (Kumari, 2015). Altogether, these schemes were intended to increase the aquaculture output, increase employment opportunities in rural areas, and food adequacy.

8.2 BMPs for sustainability in management

It was established that the practice of Best Management Practices (BMPs) in aquaculture is crucial for sustainability. BMPs include measures that reduce environmental impacts, enhance water quality, and increase efficient use of resources. Over the years, BMPs have been gradually adopted in Andhra Pradesh and Telangana through enhancing filtration systems to prevent wastage of feed and nutrients as well as crop rotation to control nutrient loading in ponds. They asserted that the use of these practices in fish farming has been effective in easing the environmental impact of the fish farming practices including eutrophication and water conservation. BMPs also address ways of improving disease control so that fish health is maintained at the highest level and there is reduced use of toxic substances (Ozbay *et al*., 2014). More farmers in the region adopt BMPs thus improving the sustainability and longevity of aquaculture enterprises in the area (Engle & Wossink, 2008).

8.3 Compliance with International Standards for Sustainable Aquaculture

In light of the need to increase sustainability and upgrade market access, aquaculture needs to meet international standards. Such a standard helps to ensure that farmed fish is safe for human consumption and that the production of the fish is sustainable. India has also achieved a lot of progress toward the standardization of aquaculture production systems to the Aquaculture Stewardship Council (ASC) and Global Good Aquaculture Practices (G.A.P.) Regarding *Catla catla* (Hamilton), *Labeo rohita* (Hamilton), and *Cirrihinus mrigala* (Hamilton), certification guarantees that the species are bred under environmentally friendly practices, including water quality and feed issues. This adherence not only extends the sustainability of aquaculture but also assists the farmers in entering the global market since consumers across the globe are demanding responsibly produced fish stocks (Kaiser, 2012). Such certifications are becoming essential in the competitive global fish market to enhance both the environmental and economic sustainability of fish production.

8.4 Potential Course for Policy and Sustainability of Aquaculture

Thus, future policy interventions in Andhra Pradesh and Telangana should aim at increasing research grants, promoting Public-Private Partnerships (PPPs), and expanding the programs like development of environment-friendly feed and Integrated Multi-Trophic Aquaculture (IMTA) systems. Genetic selection for disease tolerance in some of the farmed fish species is also another way that needs to be invested in to increase sustainability. However, many policies to support water-saving technologies and less use of inputs, such as chemicals and fertilizers, help minimize the harms of aquaculture (Pingali & Rosegrant, 1995). Moreover, issues of market access will be well handled such as enhancing the cold storage and processing of the aquaculture products to ensure that the products that are being farmed sustainably are also able to meet market demands in domestic and international markets (Jennings *et al*., 2016). Thus, further cooperation between governmental agencies, farmers, and other stakeholders is needed to provide the proper conditions for the development of the aquaculture sector.

9. Future Perspectives

9.1 Scaling up Genetics for Improved Breeds

Relatively genetic work is significant in enhancing the growth and genetic quality of fish stock for production in aquaculture. Such species include *Catla catla* (Hamilton), *Labeo rohita* (Hamilton), and *Cirrihinus mrigala* (Hamilton) in which selective breeding has been established to improve growth rates, disease resistance, and overall health (Gjedrem, 2000). There is a need to increase the genetic improvement program for developing more robust strains that are capable of adapting to new environmental changes and diseases as a precondition

to the sustainability of aquaculture in Andhra Pradesh and Telangana (Tuteja *et al*., 2012). Molecular approaches like marker-assisted selection can enhance the capacity of developing improved stocks to enhance meat yield and are a key driver to the development of the economic stature of the region (Sosnicki & Newman, 2010). Further investment in genetics is important to sustain the competitive position in the global aquaculture market where high-quality fish is demanded.

9.2 Building Climate Resilient Aquaculture System

Climate change impacts the growth of aquaculture in that it reduces water temperature changes rainfall distribution and increases diseases (Rosa *et al*., 2012). It is thus important to establish climate-resilient types of aquaculture systems for the sustainable production of fish farming in Andhra Pradesh and Telangana (Handisyde *et al*., 2006). It established that measures that include enhancing water management, rising climate-adaptive species, and undertaking renewable energy for farmland operations can assist in putting off climate change. Also, the aquaculture systems must be able to address issues of climate change through technologies like integrated water quality control and feeding techniques (Martins *et al*., 2010). Such actions will not only support fish production sustainability but will also avoid climate change risks that threaten aquaculture, making farmers profitable even during the climate change period (De Young *et al*., 2012).

9.3 Market Access and Export Channels

The diversification of market connections and the availability of export channels are critical for improving the profitability of aquaculture in Andhra Pradesh and Telangana. As the global demand for quality fish continues to rise, there is a need to enhance the exportation of *Catla catla* (Hamilton), *Labeo rohita* (Hamilton), and *Cirrihinus mrigala* (Hamilton) to boost export revenue (Pallapothu, 2012). The Indian government has already attempted to enhance the cold chain infrastructure and export policies concerning seafood products. Despite these optimizations, challenges remain in areas of certification, traceability, and introduction to the world food safety standards. If India can overcome these hurdles, it can well become a competitive player in the international fish market (Umali-Deininger & Sur, 2007). The enhancement of market outlets and export channels will not only enhance the feasibility of aquaculture but also avert food insecurity and the growth of the fish farming business in the region.

Conclusion

The three important major carps of India, namely *Catla catla*, *Labeo rohita*, and *Cirrihinus mrigala* have a central role in the aquaculture system of Andhra Pradesh and Telangana and have significantly benefited the rural population and food security. The species indeed have complementary feeding habits and should therefore be suitable for polyculture systems, which optimizes the use of available resources thereby increasing the productivity of the farm. Hence *Catla catla* is a surface feeder, *Labeo rohita* is a mid-water feeder and *Cirrihinus mrigala* is a bottom feeder, there is very little competition for food resources and therefore, the overall farm production is high. These characteristics include fast growth, tolerance to environmental conditions, and reproduction in a controlled environment have placed them at the center of successful aquaculture in the region. Moreover, improvements in bin reeding technology, including genetic engineering and marker identification have enhanced disease tolerance, rate of growth, and farm yields. However, some constraints are still present for the sustainable development of the aquaculture industry. Some of the challenges include the management of water quality and issues to do with pollution from high levels of inputs. Moreover, achieving sustainable growth of meat production demands, resource investment in innovation, improving farming methods and composing suitable laws and regulations. Further studies should be directed to improving IFS and to studying such practices as Integrated Multi-Trophic Aquaculture (IMTA). Subsequently, there is a need for policy support for small-scale farmers in the form of subsidies and credit, as well as training in the best practices of intensive aquaculture. If more investment is made and the practice is made sustainable the aquaculture sector in Andhra Pradesh and Telangana can be a boon to the economy as well as the ecology.

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