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Scaling community-based aquaculture for enhanced nutrition and women's empowerment: lessons from Odisha, India

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Introduction: Aquatic foods, particularly fish, are essential for addressing malnutrition, especially in vulnerable populations like children and women. In India, traditional aquaculture practices centered around carp species often overlooked the production of nutrient-rich small fish. To address this, nutrition-sensitive aquaculture approaches advocate for integrating species like mola carplet (*Amblypharyngodon mola*) rich in micronutrients, into existing systems. In Odisha, India, where poverty and food insecurity are prevalent, the government initiated a program to empower women through aquaculture, focusing on nutrition-sensitive carp-mola polyculture in community ponds through Women Self-Help Groups (WSHGs).

Methods: This study evaluates the effectiveness of this government program in enhancing income, household nutrition, and women's empowerment. Data from field surveys conducted across all 30 districts of Odisha were analyzed to assess participation, capacity building, adoption of better management practices (BMPs), productivity of carp-mola polyculture, household fish consumption, and profitability.

Results and discussion: The study found widespread participation and adoption of BMPs among WSHGs, leading to increased productivity and income. Carp-mola polyculture systems showed higher productivity and consumption rates, contributing to improved nutrition among WSHGs and their communities. Despite challenges such as input costs and limited mola availability, WSHGs reported profitability from fish farming, with carp-mola polyculture systems yielding higher net income. Factors influencing productivity and profitability included water retention period, stocking density, feed application, and training. The program's impact extended beyond economic benefits, encompassing environmental improvement, women's empowerment, and enhanced nutrition outcomes.

The study highlights the success of the government program in promoting sustainable aquaculture practices and improving nutrition outcomes in Odisha. Continued support, capacity building, and collaboration among stakeholders are essential for scaling up nutrition-sensitive aquaculture interventions and ensuring long-term sustainability. Strengthening dissemination processes, addressing challenges, and further research on small indigenous fish production techniques are crucial for maximizing the program's impact on food security and rural development.

KEYWORDS

nutrition-sensitive aquaculture, carp-mola polyculture, women self-help groups, community ponds, Odisha

1 Introduction

Aquatic foods sourced from freshwater and marine ecosystems play a crucial role in global food systems, bolstering food security and nutrition by offering nutrient-rich options and livelihood support to vulnerable communities worldwide (Golden et al., 2021; Tigchelaar et al., 2022; FAO, 2024). Fish, celebrated as a superfood, are rich in protein, micronutrients, vitamins, and essential fatty acids, particularly omega-3 fatty acids, which are challenging to obtain from other dietary sources (Ahern et al., 2021). Consequently, fish play a critical role in addressing malnutrition, especially in regions where significant portions of the population, particularly children and women, suffer from inadequate nutrition (Béné et al., 2015).

In India, pond aquaculture[1] predominantly revolves around Indian major carp species (IMCs) combined with three exotic carps, collectively constituting over 70% of the country's freshwater production (DOF, 2020). Indigenous small fish species, abundant in calcium, iron, zinc, vitamin A, and vitamin B12, historically provided vital nutrients to rural households, often at a more affordable price than larger fish or terrestrial animal-source foods (Roos et al., 2003a; Bogard et al., 2017). However, their availability has dwindled due to habitat degradation and overexploitation of inland fisheries.

Nutrition-sensitive aquaculture advocates for a food-based approach to aquaculture development, emphasizing the production of nutrient-rich small fish alongside conventional carp polyculture to enhance nutritional outcomes (Thilsted et al., 2016; Shepon et al., 2020; Thorne-Lyman, 2020). This approach focuses on introducing mola carplet (*Amblypharyngodon mola*, hereafter referred to as "mola"), which is notably superior in micronutrient content compared to commonly farmed species like carps and tilapia. Mola is rich in calcium, iron, vitamin A, and vitamin B12, with 100 g of edible portion containing 2,503 μg Vitamin A (Bogard et al., 2015). Additionally, mola provides essential amino acids, omega-3 PUFAs, and lipids, with protein content similar to most carps (Bogard et al., 2015; Mustafa et al., 2015). Mola can be eaten in various forms such as fried, salted, semi-dried and mixed with vegetables. Its small size offers superior nutritional advantages as it is often consumed whole, utilizing all bio-available nutrients, including micronutrients particularly located in the head, bones and viscera (Ahern et al., 2021).

Efforts across South Asian countries have integrated mola into carp polyculture systems, enhancing micronutrient consumption without compromising carp yields (Wahab et al., 2003; Roos et al., 2003b, 2007; Milstein et al., 2009; Ali et al., 2016). Research indicates that incorporating mola increases its consumption among women and children, proving to be a cost-effective strategy to combat micronutrient deficiencies (Fiedler et al., 2016; Karim et al., 2016; Castine et al., 2017). Mola's spontaneous breeding in ponds eliminates the need for annual fingerling restocking, contributing to its sustainability within pond polyculture systems (Rajts and Shelley, 2020). Integrating small fish like mola with carp offers the potential to boost overall fish production for both consumption and income generation, with carp serving as a financial resource and mola meeting nutritional needs. Despite its benefits, widespread adoption of pond-based nutrition sensitive aquaculture remains limited in India.

1.1 The context of Odisha: aquatic and women resources

Situated in eastern India with a population of 46.6 million, Odisha faces daunting challenges rooted in poverty and food insecurity (PHDMA, 2020; NITI Aayog and UN, 2021). The latest National Family Health Survey (NFHS−5) paints a grim picture, revealing that 31.1% of children under five in Odisha suffer from stunted growth, while 29% are underweight (IIPS and ICF, 2021). Additionally, a concerning 64% of both young children and reproductive-age women struggle with anemia (IIPS and ICF, 2021), indicating widespread deficiencies in vital micronutrients due to inadequate dietary intake. Many households rely on subsistence farming, which is vulnerable to disruption by erratic weather patterns induced by climate change and natural disasters (Dubey et al., 2022). These challenges compound the existing issues of food insecurity and poverty, underscoring the urgent necessity for targeted interventions aimed at uplifting the economic and social fabric of Odisha's vulnerable communities.

Fish serves as a vital source of income and sustenance in Odisha, predominantly sourced from freshwater aquaculture. According to the latest estimate, during 2019–2021, over 90% of Odisha's population consumed fish (Padiyar et al., 2024). The primary aquaculture systems in Odisha cover 137,000 ha of ponds and earthen tanks, that are extensive to semi-intensive pond-based polyculture systems. Ponds in Odisha are typically classified as either privately owned or managed by

1 In India, pond aquaculture is dominated by carp species, including three species of Indian major carp, namely catla (*Labeo catla*), rohu (*Labeo rohita*), and mrigal (*Cirrhinus mrigala*), which are often cultured alongside three exotic carps (silver carp *Hypophthalmichthys molitrix*, grass carp *Ctenopharyngodon idella*, and common carp *Cyprinus carpio*) to form composite culture. In addition, minor carp species (Bata *Labeo bata/Labeo gonius*, Calbaus *Labeo calbasu*, silver barb *Barbonymus gonionotus*) and other exotic fish varieties such as striped catfish (*Pangasianodon hypophthalmus*), tilapia (*Oreochromis* spp.), and red-bellied pacu (*Piaractus brachypomus*) are also cultivated in the carp polyculture system, which diversifies the aquaculture production system.

government agencies. Odisha's rural landscape is dotted by numerous waterbodies that are under the common property regime and governed by the Gram Panchayats[2] (GP) under the aegis of the Panchayati Raj and Drinking Water Department (PR&DW). These ponds form the backbone of rural Odisha's water infrastructure. Over the past few years, numerous earthen ponds have been constructed through government initiatives and community efforts, primarily aimed at groundwater recharge and rainwater harvesting. These communal waterbodies, known as village community ponds or multi-utility GP tanks,[3] constitute over 60% of closed aquatic resources in rural areas, managed by local institutions or self-governing bodies for diverse uses (Radheyshyam et al., 2011, 2013). The PR&DW Department leases these GP tanks for community aquaculture purpose, with leases granted to Women Self-Help Groups (WSHGs), Men Self-Help Groups (MSHGs), registered cooperative societies, village communities, and others.

In India, WSHGs serve as vital social and financial pillars in rural communities, acting as catalysts for transformative change among the impoverished and marginalized, especially women. These groups provide avenues for skill development, employment, income generation, and poverty alleviation (Jakimow and Kilby, 2006; Deininger and Liu, 2009). Comprising 10 to 20 members residing in close proximity and sharing similar backgrounds, WSHGs convene regularly to contribute to a collective fund (Baland et al., 2019). Extensive research underscores the pivotal role of WSHGs in enhancing agricultural productivity, elevating women's status, facilitating decision-making, ensuring resource access, promoting behavioral changes, and improving health and nutrition outcomes (Kumar et al., 2018; Raghunathan et al., 2019; Kumar et al., 2021; Nichols, 2021). The role of women in aquaculture and fisheries has garnered recognition as a potent avenue for economic empowerment, social progress, and food security. Despite a favorable inclination toward aquaculture, gender disparities persist as significant barriers to women's active participation in the sector (St. Louis and Oliveira, 2020).

Odisha stands out as a torchbearer for the WSHG movement, with the 'Mission Shakti' program launched in 2001 by the state government under Women and Child Development Department (WCD). This pioneering initiative empowers women through WSHGs, providing support for socioeconomic activities, capacity enhancement, and market integration (DOMS, 2022). Currently, approximately 600,000 WSHGs, comprising roughly 7 million women members, operate in Odisha under the auspices of the Department of Mission Shakti[4] (DOMS, 2022).

1.1.1 The shift toward gender and nutrition-sensitive aquaculture policy

In 2018, a collaboration and inter-departmental convergence between three key government departments in Odisha - PR&DW, WCD and Mission Shakti Department and Fisheries and Animal Resources Development Department (FARD) marked the inception of a concerted effort toward gender and nutrition-sensitive aquaculture. This partnership, with technical support from WorldFish, aimed to harness the collective strengths of these departments by involving WSHGs in fish farming ventures within public waterbodies like GP tanks.

The PR&DW led the initiative by instituting a favorable policy in 2018–19, leasing out GP tanks to WSHGs on a long-term basis (3–5 years) across all 30 districts of the state. Building upon this foundation, FARD launched a gender-sensitive flagship program in the same year - the 'Scientific Fish Farming in Gram Panchayat Tanks by WSHGs', also known as the 'Input Assistance to WSHGs for Pisciculture in GP Tanks' program.[5]

This program was designed to provide comprehensive support to WSHGs in their fish farming endeavors, particularly emphasizing nutrition-sensitive carp-mola polyculture technology in a community farming approach, with women as primary stakeholders. The scheme's objectives are multifaceted, including increasing fish production and household income, empowering women, and enhancing nutritional outcomes through carp-mola polyculture. WSHGs underwent thorough training on better management practices (BMPs) and guidance throughout the fish farming process, ensuring sustainable and profitable operations through optimal utilization of public water bodies. Figure 1 portrays the design and implementation layout of the government program.

1.2 Research questions

The above narrative forms the foundation of the study. Overall, this research aims to evaluate the effectiveness of the government program in enhancing income, household nutrition, and women's economic empowerment, while also identifying areas for improvement and providing insights to support future policymaking and program sustainability efforts.

The study framed four research questions, which are:

1. What is the extent of participation and capacity building of WSHGs in scientific fish farming in GP tanks, and what is the adoption level of BMPs in aquaculture among these groups?
2. How productive are carp-mola polyculture systems under the program, and what is the impact on household fish consumption and nutrition among WSHGs?
3. What is the profitability of the government-supported, women-centric, nutrition-sensitive aquaculture program, and how does it vary between different polyculture systems?
4. What key factors contribute to overall productivity and income in fish farming in GP tanks under the program, and how can they inform future efforts in promoting carp-mola polyculture in public water bodies?

2 Gram Panchayat is a local self-government institution in rural areas of India. It aims to promote local self-governance, community development, and effective delivery of basic services to the people living in rural areas.

3 GP tank, village pond, community pond, public water bodies are synonymously used in this paper.

4 In 2021, Mission Shakti program appeared as separate ministry – Department of Mission Shakti and separated from Women and Child Development & Mission Shakti Department. "Shakti" is a powerful word that denotes the strength of the feminine.

5 The total operational cost of the scheme is INR 150,000 and government assistance is INR 90,000 with 60% subsidy to WSHGs. The subsidy to the eligible WSHG is given as Direct Benefit Transfer mode.

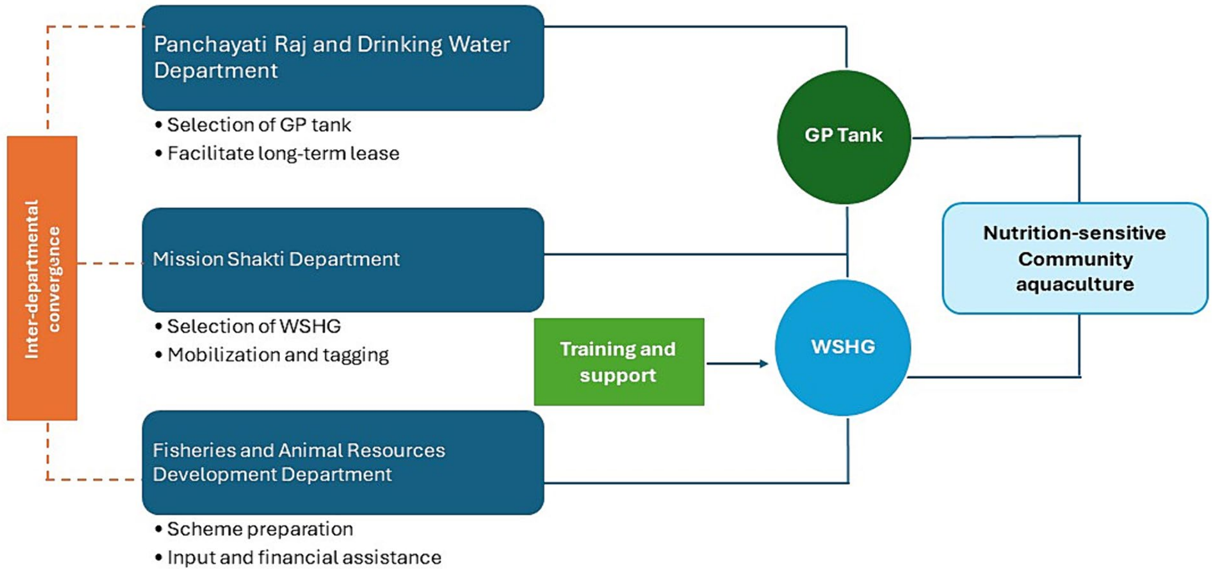

FIGURE 1
Design and implementation model of government-supported, women-centric, nutrition-sensitive aquaculture program in Odisha, India.

2 Methods

2.1 Data sources

Field survey datasets commissioned by the FARD, Government of Odisha, and other collaborative partners served as the primary data sources for this study. Specifically, we drew upon two published documents on the crop outcome survey report on scientific fish farming in GP tanks by WSHGs in Odisha (FARD, 2021; Padiyar et al., 2021). These surveys were conducted over the periods of 2018–2019 and 2019–2020, targeting WSHGs participating in the government scheme. The comprehensive survey spanned all 30 districts of Odisha and included 962 GP tanks managed by unique WSHGs. Information collected from WSHG during the field survey covered various facets of fish culture, including WSHG profiles, pond characteristics, BMP adoption, fish productivity, consumption patterns, and financial aspects of fish farming.

2.2 Data analysis and statistics

Survey data of 958 WSHGs from the years 2018 and 2019 were used for analysis in this study. Descriptive analyses were conducted to present socio-economic profiles, basic farm characteristics, input utilization, productivity levels, and fish consumption patterns.

To determine income and profitability from different production systems (i.e., carp polyculture, carp-mola polyculture, and overall), an economic analysis was undertaken. This involved assessing total costs (including variable costs such as seed, feed, fertilizer, lime, harvesting, and marketing, as well as fixed costs like lease expenses), gross income (calculated as total production multiplied by actual sales value), net income (derived from gross income minus total costs), benefit–cost ratio (BCR) (computed as net income divided by total costs), and return on investment (ROI) (expressed as net income divided by investment and multiplied by 100). One-way analysis of variance (ANOVA) was employed to compare different production systems, with a significance level set at 5% ($p < 0.05$) unless otherwise indicated. Additionally, the multiple comparison Tukey's Honest Significant Difference (HSD) test was used to identify significant differences.

To assess the factors influencing productivity and income across various production systems in GP tanks, multiple regression analyses were performed using the ordinary least squares method. Various explanatory variables were considered, including some social characteristics of WSHGs, characteristics of GP tanks, BMPs adopted and harvesting. District-level fixed effects were also incorporated into the analysis. STATA version 18.0 (SataCorp. College station, Texas) was utilized for this analytical process.

In this paper, we have presented important descriptive data in tabular format such as fish productivity, fish consumption and income (Tables 1–5). The rest of the data is presented in Supplementary file.

2.3 Description of basic data

2.3.1 Profile of WSHGs

The average age of WSHGs who are involved in fish farming through the govt. supported program is 9 years, with the majority (40%) having been formed within the past 1–5 years. Across all WSHGs, the number of women involved ranged from 9 to 22, with an average of 11 members per group. Considering social stratification,[6] the surveyed members of WSHGs were mixed caste

6 India's caste system is among the world's oldest forms of surviving social stratification. The Scheduled Castes (SCs) and Scheduled Tribes (STs) are officially designated groups of people and among the most disadvantaged socio-economic groups in India. The terms are recognized in the Constitution of India and the groups are designated in one or other of the categories. The

TABLE 1 Fish productivity of GP tanks managed by WSHGs.

Items	Value
Total fish production (kg/ha)	1868.79 ± 1253.02
Carp production (kg/ha)	1771.09 ± 1222.05
Mola production (kg/ha)	155.50 ± 166.80
Other fish production (kg/ha)	162.73 ± 196.80

The data are presented as Mean ± SD. Total fish production considers fish sold and consumed and the aggregate of carp, mola and other fish. Other fish included murrels, catfishes and other naturally occurring fish species.

TABLE 2 Comparison of productivity of carp polyculture and carp-mola polyculture at Odisha.

Items	Carp polyculture	Carp and mola (mola broods introduced)	Carp and mola (mola produced naturally)	Carp-mola polyculture (mola brood stocked + naturally produced) *
Total fish production (kg/ha)	1797.82 ± 1333.52a (11.74–11046.82)	2221.26 ± 1307.72b (166.38–9636.90)	1851.85 ± 1143.21 ac (91.43–9266.25)	1945.36 ± 1197.28c (91.43–9636.90)
	% Increase (compared to carp polyculture)	24%	3%	8%
Carp production (kg/ha)	1765.82 ± 1317.28a (11.74–11046.82)	2102.98 ± 1284.83b (158.14–9575.13)	1668.73 ± 1062.34a (24.71–8648.50)	1775.61 ± 1135.43a (24.71–9575.13)
	% Increase (compared to carp polyculture)	19%	-5%	0.5%
Mola production (kg/ha)		120.17 ± 104.67a (4.41–646.58)	166.85 ± 180.98b (5.66–1976.80)	155.50 ± 166.80b (4.41–1976.80)
	% Increase (compared to mola brood stocking)		39%	

The data are presented as Mean ± SD. Mean values followed by different superscript letters in a row indicate significant differences ($p < 0.05$) based on ANOVA.
*Here, the carp-mola polyculture system was taken into account in terms of mola production, including both locations where mola was produced with and without stocking.

groups and predominantly were General Caste (57%) and then the Scheduled Tribes (ST) (24%). Among the WSHGs surveyed, 17% were predominantly Adivasi communities (tribal groups) having ST membership of 10 or more. About half of the WSHGs were engaged in diverse and gainful self-employment activities in addition to the fish farming program to boost their group and household income. Among them, agriculture, mushroom farming and livestock rearing, and small business were common (Supplementary Table S1).

2.3.2 Characteristics of GP tank

Well over 95% of GP tanks in the village were located within 0.5–1 km from the houses of WSHG members. The average lease period of a GP tank to WSHG for fish farming activity was 3 years in the case of 77% WSHGs while 19% WSHGs have 5 years of lease arrangements. The GP tanks assigned to the WSHGs had a wide range of water areas, ranging from 0.10 to 32.38 ha with an average size of 0.93 ha (Supplementary Figure S1).

Almost all GP Tanks depended fully on rainwater as the primary source of water storage for fish cultivation and the remainder relied on the canal, groundwater recharge and borewell to supplement rainwater. The water depth of the GP tanks ranged from 1 to 6 m throughout the year with an average water depth of 2 m which is quite congenial for fish farming. Most of the GP tanks hold water year-round with a minimum water retention of 5 months.

Interestingly, only 13% of the GP tanks were exclusively used for fish farming by WSHGs. The vast majority of the GP tanks leased out (87%) were used for a variety of community uses in addition to fish farming, including irrigation, bathing, washing, daily household tasks, animal bathing, drinking, as well as religious rituals (Supplementary Table S2).

SC and ST comprise about 16.6 and 8.6%, respectively, of India's population (according to the 2011 census).

3 Results and discussion

3.1 Enhancing knowledge source and capacity building of WSHGs

Effective agricultural extension services play a pivotal role in enhancing productivity, facilitating access to information, and encouraging the adoption of diverse crops and cultivation methods (Raghunathan et al., 2019). However, more than 75% of WSHGs lacked prior experience in fish farming. Therefore, sub-district (block) level training sessions focused on carp-mola polyculture and BMPs for fish farming and harvesting methods were deemed essential for all participating WSHGs.

TABLE 3 Average fish production and use by WSHGs.

Fish use pattern	Carp			Mola			Other fish			Total		
	WSHG (%)	Kg/WSHG	% Contribution	WSHG (%)	Kg/WSHG	% Contribution	WSHG (%)	Kg/WSHG	% Contribution	WSHG (%)	Kg/WSHG	% Contribution
Sold	100% (958)	1440.46 ± 2170.22	97%	42% (402)	41.84 ± 105.79	70%	7% (68)	13.71 ± 95.04	81%	100% (958)	1494.52 ± 2228.95	96%
Consumed and gifted	77% (735)	47.48 ± 111.19	3%	47% (453)	18.28 ± 45.03	30%	6% (63)	3.14 ± 21.56	19%	87% (833)	68.90 ± 137.36	4%
Total produced	100% (958)	1486.44 ± 2205.86	100%	54% (515)	60.14 ± 125.75	100%	9% (84)	16.84 ± 108.09	100%	100% (958)	1563.42 ± 2275.49	100%

The data are presented as Mean ± SD. Average fish production and use were calculated by taking account of all samples. In other words, for example, among the mola-producing WSHGs, the mean annual production of mola was 112.09 ± 153.83/WSHG. Figures within parentheses indicate the actual sample size.

These training sessions were collaboratively organized by the FARD and Mission Shakti department across the state, ensuring widespread participation. Nearly all WSHGs sent representatives to attend the training sessions. On average, three members from each WSHG were present, with many of them having received training during the post-stocking phase of their farming operations. Improving knowledge and capacity building for at least key members of WSHG is extremely important as the trained members can further share the knowledge and train other group members, which can influence overall economic return. Ideally, training should be provided at the beginning of fish farming to ensure a comprehensive understanding; however, the training dates varied across sub-districts, leading to a mismatch with the farming calendar (Supplementary Table S3).

Additionally, almost all WSHGs reported receiving farmgate technical services and guidance from officials and staff associated with the program. These officials made approximately six visits to the GP tanks of the WSHGs during the crop period, providing valuable support and assistance.

3.2 Women's adoption of better management practices for aquaculture

3.2.1 Adoption of improved pond management techniques and monitoring

The uptake of BMPs among WSHGs in aquaculture has demonstrated significant improvement compared to prior studies conducted in Odisha (Radheyshyam et al., 2013; De et al., 2016). Following training sessions, a substantial majority of surveyed WSHGs have embraced fundamental BMPs for fish farming, including dike repair, aquatic weed removal, predatory fish control, pond preparation, lime and fertilizer application, among others (Supplementary Table S4). Almost unanimously, 96% of WSHGs have employed lime treatment (averaging 330 kg ha^{-1}) to regulate pH levels before stocking fish fingerlings, indicative of BMP adoption and enhanced resource accessibility facilitated by governmental initiatives. Moreover, 54% of WSHGs have utilized fertilizers to stimulate natural food production within the ponds. Nearly all WSHGs have integrated supplementary feeding practices to optimize fish growth.

Roughly two-thirds of WSHGs have implemented water quality monitoring alongside monthly fish sampling to assess growth and health, as prescribed by BMPs. A majority of WSHGs have independently assessed water quality parameters such as pH and transparency using field test kits. In cases where assistance was required, department officials (including WorldFish project staff) supported WSHGs in conducting water quality tests. Additionally, a significant proportion of WSHGs diligently maintain daily records of fish farming-related activities in record-keeping notebooks.

3.2.2 Improved fish seed stocking practices and species composition

Following the eradication of aquatic weeds and the application of lime and fertilizer, WSHGs proceeded to stock fish seeds in GP tanks. A majority of WSHGs (60%) opted for an annual fish seed stocking regimen, while others undertook multiple stockings. Among those practicing multiple stockings, over 80% stocked fish seed twice annually.

TABLE 4 Fish consumption pattern by WSHG households in carp polyculture and carp–mola polyculture system.

Species	Carp polyculture			Carp mola polyculture		
	% WSHG	Kg/WSHG/year	Contribution to total consumption (%)	% WSHG	Kg/WSHG/Year	Contribution to total consumption (%)
Carps	100% (331)	60.56 ± 73.63	93%	81% (409)	50.68 ± 139.14	57%
Mola	–	–	–	90% (453)	34.88 ± 57.38	39%
Other fish	9% (30)	4.41 ± 29.43	7%	7% (33)	3.08 ± 17.72	4%
Total	100% (331)	64.98 ± 80.27	100%	100% (502)	88.64 ± 173.82	100%

The data are presented as Mean ± SD. Average fish production and use were calculated by taking into account all consumption samples. Figures within parentheses indicate the actual sample size.

TABLE 5 Comparative economic analyses of production costs and income of carp polyculture and carp–mola polyculture system in GP tanks.

Cost and returns (INR/ha/year) *	Production systems (Mean ± SD)			Average (Mean ± SD) *N* = 958
	Carp polyculture *N* = 442	Carp-mola (stocked) *N* = 127	Carp-Mola polyculture *N* = 515	
Variable cost (VC)				
Seed	41630.10 ± 25047.66a	42220.63 ± 14831.76a	43939.58 ± 20173.98a	42874.04 ± 22571.06a
Feed	60299.51 ± 35089.48a	67387.02 ± 37102.50b	57039.07 ± 34961.07a	58601.66 ± 35041.44a
Fertilizer	2559.20 ± 9483.19a	1585.63 ± 2054.90a	1350.91 ± 3225.31a	1970.37 ± 7172.44a
Lime	3629.52 ± 2743.63a	4418.51 ± 2968.29b	3031.59 ± 2847.37c	3301.73 ± 2815.25c
Harvesting and marketing	10204.73 ± 12191.89a	15489.88 ± 20988.47b	13623.69 ± 20518.55b	12016.10 ± 17191.65a
Fixed cost (FC)				
Lease	10644.09 ± 11958.36a	8961.67 ± 9826.23a	11042.26 ± 13877.53a	10858.55 ± 13022.11a
Total cost (TC=VC + FC)	126943.43 ± 60029.11a	138905.10 ± 61374.22a	123980.30 ± 60036.22a	125347.42 ± 60019.76a
Operational cost (OC)	116302.69 ± 56818.88a	129943.43 ± 56419.37b	112968.11 ± 55598.90a	114506.61 ± 56160.25a
Gross income (GI)	254016.00 ± 190448.72a	301620.22 ± 180647.81b	271675.82 ± 165126.98a	263648.63 ± 177208.66a
Gross margin (GI-OC)	130816.94 ± 170426.02a	171676.79 ± 160617.03b	158707.72 ± 144327.94c	145839.53 ± 157440.96a
Net income (NI = GI-TC)	120176.21 ± 170880.00a	162715.12 ± 160346.64b	147730.00 ± 143389.16b	135017.29 ± 157191.15a
Benefit cost ratio (BCR)	1.98 ± 1.20a	2.24 ± 1.19bc	2.35 ± 1.28b	2.18 ± 1.25c
Return of investment (ROI)	0.98 ± 1.20a	1.24 ± 1.19bc	1.35 ± 1.28b	1.18 ± 1.25c

The data are presented as Mean ± SD. Mean values followed by different superscript letters in a row indicate a significant difference ($p < 0.05$) based on ANOVA.
* As of December 2019, 1 USD = 71.61245 INR (Source: The European Commission's InforEuro).

The species composition in GP tank fish farming primarily comprises IMCs alongside other exotic carp varieties. Rohu, catla, and mrigal are the predominant species, followed by exotic carps like grass carp and common carp. Approximately two-thirds of WSHGs (63%) exclusively stocked IMC fingerlings, while the remainder engaged in composite fish farming, combining IMCs with exotic carp fingerlings or including mola alongside carps.

Majority of WSHGs procured fish fingerlings from private hatcheries and local seed traders, while a smaller proportion (30%) obtained seeds from government fish seed hatcheries. Mola broods were introduced in only 13% of the surveyed GP tanks. Mola broodstocks were sourced from natural habitats such as nearby village ponds and reservoirs. The rationale behind stocking mola broods in GP tanks lies in their rapid multiplication after introduction, owing to mola's ability to breed freely in open water bodies and its short reproductive cycle. However, the limited adoption of mola brood stocking by WSHGs can be attributed to the scarcity of mola broods and the absence of suitable technology for their wild harvest and transportation. It is important to note that, collecting mola from wild sources may have negative ecological consequences. Additionally, during the scheme's implementation phase, no technology was available for the artificial reproduction of mola under hatchery conditions.

The scheme advocates for stocking advanced sized carp fingerlings weighing 50 g to 100 g to enhance survival rates and expedite the cropping cycle. Despite recommendations, the reported average fingerling size remained at 46 g, with a range spanning from 2 g to 250 g. More than half of the surveyed WSHGs stocked advanced fingerlings (50–100 g), followed by fingerlings between 10 and 50 g.

While the scheme suggests stocking advanced carp fingerlings at a rate of 2,700 numbers ha^{-1} and mola broodstock at a rate of 25 kg[7] ha^{-1}, WSHGs reported varied stocking densities, with an average carp stocking density of 6,546 numbers ha^{-1}. Over two-third of WSHGs preferred stocking densities up to 5,000 numbers ha^{-1}. Mola stocking densities in GP tanks also exhibited wide variations depending on broodstock availability, averaging 24 kg ha^{-1}. Among WSHGs stocking mola, 80% stocked at a rate of 20–30 kg ha^{-1} (Supplementary Table S5).

The stocking of carp fry and fingerlings in village community ponds often occurs in improper ratios (Radheyshyam et al., 2013). Currently, low stocking density in GP tanks is due to the adoption of large-size fish fingerlings. However, it appears that GP tanks are currently understocking and could benefit from an increased stocking density for optimum utilization of resources.

3.2.3 Augmentation of natural food and adoption of supplementary feeding

Fertilization serves as a catalyst for fostering an environment conducive to the proliferation of various plankton, algae and smaller crustaceans, collectively referred to as natural food, crucial for sustaining a healthy pond ecosystem and promoting fish growth (Horváth et al., 2002). Throughout the cultivation period, only half of WSHGs (54%) applied fertilizers to their ponds to stimulate the production of natural food, encompassing phytoplankton and zooplankton. Among those embracing fertilization practices, 60% opted for organic fertilizers, 31% for inorganic fertilizers, while the remainder utilized a combination of both (Supplementary Table S4). Notably, organic fertilizers such as raw cattle dung, rice bran, mustard oil cake, and poultry manure were preferred by WSHGs, whereas inorganic options included urea, diammonium phosphate, and single superphosphate. On average, the rate of organic fertilization was 2,343 kg ha^{-1} while the inorganic fertilization rate was 123 kg ha^{-1}.

A substantial portion of WSHGs abstained from fertilizer usage due to restrictions imposed by villagers and other water users, resulting in over 40% of GP tanks in the study remaining unfertilized. This finding resonates with observations by Radheyshyam et al. (2011), indicating a common trend, especially in GP tanks, where water resources are utilized for community purposes with various users.

One of the successful practices adopted in this scheme is supplementary feeding with commercial fish feed. In the carp-mola polyculture system, feeding is crucial to supplement natural food production and promote better fish growth. WSHGs employed three types of supplementary fish feed in GP tanks: floating pellets, sinking pellets, and homemade feed. Floating pellets dominated the feed choices, accounting for 76% of WSHGs' preferences. Homemade feeds, comprising traditional unformulated mixtures primarily composed of rice bran and other agricultural byproducts like groundnut oil cake and boiled rice, were also utilized. The quantity of fish feed used by WSHGs varied greatly, with an average of 1,662 kg ha^{-1}. About 68% of WSHGs used supplementary feed up to 2000 kg ha^{-1}. Most participants in the scheme relied on nearby retail grocery stores or fish feed vendors for commercial feed.

7 Taking the average 2.5–3g mola weight, it can be 8,000–10,000 individuals.

3.3 Improved productivity and consumption of fish

3.3.1 Harvesting and fish production

Within the framework of this scheme, the targeted total fish production aimed at reaching 2,500 kg ha^{-1} $year^{-1}$, encompassing carps and other species like mola. Since the majority of the GP tanks were perennial, WSHGs preferred to harvest periodically by hiring a harvesting team for sale or consumption as well as both. An overwhelming majority of WSHGs (87%) conducted multiple fish harvests from their GP tanks annually, with over 60% opting for 2–3 harvests per year. Carps were the primary species harvested from GP tanks across all 30 districts of Odisha. Mola, along with carps, was produced in 28 districts, including 14 districts where mola broods were introduced into GP tanks.

The aggregate fish production from GP tanks managed by WSHGs, encompassing all species, averaged at 1869 kg ha^{-1} $year^{-1}$ (Table 1). Production varied significantly, with 52% of WSHGs achieving yields up to 1,000 kg ha^{-1}, while 24% reported yields ranging between 1,000 to 2000 kg ha^{-1} (Supplementary Figure S2). The average annual carp production stood at 1771 kg kg ha^{-1}, with 42% of tanks yielding carp in the range of 1,000 to 2000 kg ha^{-1}.

Carps were harvested at an average weight of 807.51 ± 238.42 g, with the majority ranging between 800 and 1,200 g (Supplementary Figure S3). As the harvested carps presented an opportunity for income generation, all WSHGs preferred to sell most of them rather than consume them in their own households. Over 40% of WSHGs sold carps at local retail fish markets and farm gates, with some also selling to wholesale traders (19%). On the other hand, the majority of harvested mola were sold directly to pond-side villagers (58%), while the remaining fish were sold at local retail fish markets (32%), to wholesale traders (6%), and occasionally to WSHG members (4%).

This productivity trend aligns with findings from carp-small fish polyculture in homestead ponds in Bangladesh (Jahan et al., 2015). In comparison to earlier studies on community ponds in Odisha (Panda et al., 2011; De et al., 2012a,b; Radheyshyam et al., 2013), the productivity of GP tanks managed by WSHGs is notably higher. However, it is pertinent to acknowledge that further improvements in the overall productivity of GP tanks (beyond 3,500 kg ha^{-1} $year^{-1}$) can be achieved with more efficient management of community ponds (De et al., 2016; Sahoo et al., 2017; Mohapatra and Barik, 2018).

Mola productions were realized from 54% of the tanks, with only 13% stocked with mola brooders (Supplementary Figure S4). The remaining 41% produced mola naturally through self-recruitment, likely due to connectivity with nearby rice fields or canals, facilitating water exchange during monsoons. On average, annual mola production from GP tanks reached 155 kg ha^{-1}, with only half of the tanks yielding up to 100 kg ha^{-1}.

Comparative productivity analyses of different production systems managed by WSHGs indicate that the carp-mola polyculture system, especially when stocked with mola broods, yields significantly higher annual total fish and carp production compared to carp-only polyculture systems (Table 2). This observation aligns with findings by Kohinoor et al. (2005) and Karim et al. (2016). When mola broods were introduced in the carp-mola polyculture system, total fish and carp production increased by 24 and 19%, respectively, compared to carp-only polyculture systems. Conversely, mola yield was significantly higher ($p < 0.05$), in systems where endemic presence of mola broods that populate through natural breeding.

Contrasting reports from carp-mola polyculture systems in Asia have indicated varying productivity levels of mola (maximum up to 700 kg ha^{-1}) based on stocking densities and pond management practices (Dubey et al., 2024). In small-scale settings, an average mola production of 150–300 kg ha^{-1} from carp-mola polyculture homestead pond system can typically be attained (Dubey et al., 2024). The current mola productivity in GP tanks appears comparatively low. The primary reasons for this lower productivity include the absence of mola brooders and broodstock ponds at the village level, leading to a substantial number of GP tanks being empty. Additionally, large pond size, challenges in partial harvesting, and the lack of fertilizer application have contributed to the reduced mola production from GP tanks.

However, the introduction of mola and other small fish into carp polyculture systems can potentially create interspecific competition, as they feed in the same niche. In a well-managed system, regular fertilization and supplementary feeding can maintain steady plankton production and provide sufficient food for all fish, thereby reducing competition between species. Nonetheless, further research is needed to understand the complex interactions between different trophic levels in ponds (surface, column, and bottom), pond ecology, and the inter- and intraspecific competition between species.

3.3.2 Consumption of nutrient-rich fish

It is interesting to note that 87% of WSHGs have consumed and distributed fish from their harvested lot to their relatives, friends etc. on a complimentary basis. Thirty-eight percent of WSHGs preferred to eat carp and mola together, and each WSHG consumed 69 kg of fish on average per year (Table 3 and Supplementary Figure S5). Carp, mola, and other fish made up 69, 26 and 5%, respectively, of the total amount of fish consumed by WSHGs annually. Out of the total quantity of mola harvested, on average, 30% of them were consumed, amounting to 18 kg mola per WSHG per year. Therefore, given that there are typically 11 members in a WSHG, each woman member's household consumed 6 kg of total fish (carps, mola, and other fish) annually with 1.6 kg of exclusively mola.

Table 4 presents a comparison of fish consumption patterns between two different polyculture systems, carp polyculture and carp-mola polyculture. The data reveals that each WSHG in the carp-mola polyculture system consumed a greater quantity of fish per year (89 kg) compared to the carp polyculture system (65 kg). This finding is consistent with the study by Karim et al. (2016), which demonstrated higher total fish consumption in households who adopted carp-mola polyculture in Bangladesh.

WSHGs who have adopted carp-mola polyculture, 90% of them consumed nutrient-rich mola. Furthermore, an average of 35 kg of mola was consumed by WSHGs over a 12-month production period in the carp-mola polyculture system, which accounted for approximately 39% of the total fish consumption. Large fish such as carps contributed 57% of total fish consumption in carp–mola polyculture. In light of this, each woman member's household consumed a total of 8 kg of fish including 3 kg mola annually from the carp-mola polyculture system, taking average of 11 members in a group.

The fish consumption pattern in India and especially Odisha depends on several factors such as location, accessibility, income, season, social issues and gender (Padiyar et al., 2024). In Bangladesh's carp-mola polyculture system, Karim et al. (2016) found that households consumed an average of 6.74 kg of mola during a 12-month production season, accounting for about 18% of the total household fish consumption, whereas large fish still made up the majority of total fish consumption, accounting for 74% of consumption in this system. Castine et al. (2017) reported that mola could provide 98, 56, and 35% of the recommended daily intake of vitamin A, iron, and zinc, respectively. If consumed within the household, mola could contribute half of the vitamin A and a quarter of the iron intake recommended for a family of four annually (Castine et al., 2017).

3.4 Income and profit sharing

On average, the WSHGs spent INR[8] 125,347 ha^{-1} year^{-1} toward the operational cost of fish production in GP tanks (the average size of pond WSHG operated was 0.93 ha). The annual cost of fish production did not differ significantly ($p > 0.05$) between carp polyculture and carp-mola polyculture systems, however, remained marginally higher in the carp-mola polyculture system (INR 138,905 ha^{-1}) (Table 5). The earnings from fish sale are equally distributed to all the women members of group with some percentage directly goes to group's bank account for future savings.

The cost of feed and seed dominated the variable costs and remained higher in the carp-mola polyculture system. Similarly, because mola were frequently harvested for both consumption and sale, harvesting cost was substantially higher in carp-mola polyculture ($p < 0.05$). Expenses toward feed, fertilizer, lime, and harvesting were higher in the carp-mola polyculture system. Roy et al. (2003) mentioned that because indigenous small fish brood stock is relatively expensive and increased input costs in the first year of stocking indigenous small fish. It is likely that in perennial ponds, mola would reproduce at least three times a year, ensuring input costs would be reduced in subsequent years.

Under this flagship scheme, 87% of WSHGs have realized a gross profit from fish farming in GP tanks with financial subsidies from the government. The average net income was INR 135,017 ha^{-1} while each WSHG earned INR 106,031 from fish farming. WSHGs who practiced carp–mola polyculture, obtained significantly higher gross and net incomes compared to carp polyculture ($p < 0.05$). The average annual gross income from fish sales was INR 263,649 ha^{-1}. It was significantly higher ($p < 0.05$) in carp-mola polyculture (INR 171,676 ha^{-1}) than in carp polyculture tanks (INR 130,817 ha^{-1}), reflecting differences in productivity. The average benefit–cost ratio (BCR) was 2.18 and it was significantly higher ($p < 0.05$) in carp–mola polyculture tanks (2.24) compared to carp polyculture ponds (1.98).

The cultivation of carp in polyculture with mola has been found to yield a higher net profit compared to carp polyculture without

8 As of December 2019, 1 USD=71.61245 INR (Source: The European Commission's InforEuro).

mola, according to several studies (Roy et al., 2002, 2003; Milstein et al., 2009; Jahan et al., 2015; Karim et al., 2016). It is worth noting that some GP tanks used a high level of inputs with a low surface area, resulting in high annual costs per unit area. Conversely, some farms utilized smaller quantities of inputs in ponds with larger surface areas, leading to a wide range of total annual costs per unit for fish culture. Despite this variation, the profit margin observed in the present study was considerably higher than that reported in previous studies on community tanks in Odisha, such as Radheyshyam et al. (2013) and De et al. (2016). However, it is important to note that with scientific monitoring and community capacity building, a higher benefit–cost ratio of 2.5–3.0 could be achieved from community ponds in Odisha, as demonstrated in studies by De et al. (2016) and Sahoo et al. (2017).

3.5 Factors influencing productivity and profitability

The development of community aquaculture is the result of a complex interplay of ecological, technological, sociological and institutional factors. Community-based aquaculture management is a multifaceted process, with several limiting and stimulating factors that work together in an ununiform manner.

The study has identified 21 explanatory variables that are hypothesized to influence (some positively and some negatively) the total fish and mola productivity in GP tanks operated by WSHGs. These were age of the group, total membership, water area, lease duration, water depth, retention period, attendance at training sessions, record-keeping practices, pond preparation techniques, management of predatory fishes and aquatic weeds, application of lime, fertilizer, and supplementary feed, stocking parameters, sampling frequency, harvesting practices, and average harvest size. Ordinary least square (OLS) regression models, controlling for district fixed effects, were used with different explanatory variables to determine which variables had a significant association with total fish production in GP tanks. The results showed that variables such as water retention period, size of carp fingerlings, monthly sampling and harvesting frequency had a positive and statistically significant ($p < 0.05$) association with total fish production in GP tanks. Variables such as carp stocking density, lime application, and quantity of home-made and pellet feed applied are significantly associated with total fish production, as well as carp production in GP tanks at 1% level, indicating that these are the powerful explanatory variables for bringing changes in total fish production. The average quantity of fish sold, profit margin, and BCR were significantly associated with the size of carps at harvest ($p < 0.01$). These findings corroborated with the findings from other studies (Radheyshyam et al., 2013; Ali et al., 2016; Karim et al., 2016).

Training and capacity building has been shown to have a positive and significant association with mola production from GP tanks ($p < 0.05$). One way to improve productivity and maximize nutritional benefits from the carp-mola polyculture system is through training and capacity building of the community and finding is resonating with Castine et al. (2017). Under this scheme, members of WSHGs have already received training at the block level and farm-gate extension services. This provides them with an opportunity to augment mola production in the GP tanks.

Other critical factors related to an increase in overall mola production from GP tanks include stocking a higher quantity of mola brood and harvesting more frequently ($p < 0.01$). The removal of aquatic weeds in the carp-mola polyculture system in GP tanks has also been found to have a significant positive influence on total mola production ($p < 0.1$). However, certain management practices, such as removing predatory fishes, have been shown to have a negative and statistically significant ($p < 0.1$) association with mola production in carp-mola polyculture. One of the most effective strategies for improving mola production and household consumption from ponds or rice fields is partial harvesting at multiple intervals (Thilsted and Wahab, 2014). Known to be prolific breeders, mola could attain sexual maturity within 3 months of age and can spawn 3–5 times in a year in natural or semi-natural conditions (Rajts and Shelley, 2020). Therefore, frequent partial harvesting can reduce anticipated competition between mola and carps and help maintain a sustainable population of mola in the pond, as well as increase the chances of consumption and income for households. Partial harvesting after 3 months allows for the capture of parent or large-sized mola while retaining juveniles in the pond to continue breeding. The quantities of small fish harvested may seem small; however, these are significant in countries like Bangladesh, where weekly consumption of 250 g of mola or punti can supply essential nutrients to a 5–6-member household (Wahab et al., 2003).

3.6 Overcoming challenges in fish farming

With the introduction of the program, WSHGs widely perceive fish farming as an appealing venture due to its low investment requirement and potential for higher profits compared to agriculture. While more than half report no major obstacles, others face challenges including fish theft, poisoning, inadequate support from villagers, high harvesting costs, credit difficulties, and a lack of quality inputs. Additional issues such as high input costs, labor shortages, natural disasters, limited collective action, and family support, as well as diseases, are also noted but less prevalent. Local opposition to fertilizer use is seen as hindering fish yields in GP tanks. Other challenges mentioned include aquatic weed infestations, larger water areas, and marketing issues.

Despite these hurdles, only a minority of WSHGs employ adaptive strategies, such as seeking government intervention, enhancing teamwork, or acting as watchwomen against poaching. Some WSHGs consult government field officers for guidance, while others focus on reducing operational costs, securing credit, and utilizing homemade feed. Monitoring fish health, employing preventative measures, and adapting to climate change through water management and dike elevation are also observed practices. Partial harvesting during summer is adopted by some to mitigate crop losses.

To mitigate major challenges, WSHGs should be encouraged to adopt adaptive strategies through capacity building and awareness activities. Institutional strengthening and awareness at the village level can help reduce various social issues faced by WSHGs. Regarding high input costs, the government may increase financial incentives through convergence program until the WSHGs are fully empowered and self-sufficient. The availability of mola seed and brood is a significant challenge that hinders the expansion of nutrition-sensitive carp-mola polyculture in GP tanks. The low adoption of stocking mola broods by WSHGs can be attributed to the unavailability of broods and inadequate techniques to harvest and transport them from the wild.

Recently, hatchery-based protocol for the mass production of mola seed has been developed in Odisha (Rajts et al., 2023). Therefore, establishing mola hatchery at the sub-district level can ensure a steady supply of hatchery-reared mola hatchlings to the GP tanks. Additionally, establishing village-level broodstock ponds for mola can help address the gap in supply, where mola hatcheries are unavailable. This local approach can enhance the availability of mola seed, supporting the broader adoption of carp-mola polyculture and improving nutrition outcomes for participating WSHGs.

4 Overall impact of the women-centric government program

The women-centric government program in Odisha has had a profound impact, owing to the concerted efforts of various governmental departments and the proactive bureaucracy. A significant stride in this initiative is the government's long-term leasing policy of GP ponds to WSHGs, coupled with financial and technical support, which has fostered the acceptance of community-based aquaculture at the grassroots level. This acceptance owes much to comprehensive training, doorstep assistance, and the adoption of BMPs such as pond preparation, feeding regimes, and water quality monitoring. These measures have augmented the capacity of WSHGs, leading to sustainable production and multifaceted improvements in economic, environmental, and food security realms.

Moreover, the scheme has been instrumental in fostering economic empowerment of women at the village level, as depicted in Figure 2, which illustrates the overall impact of the program linked with Sustainable Development Goals (SDGs). The program contributed the SDGs 1, 2, 5 directly and SDGs 3, 13, 16 and 17 indirectly.

- **Resource utilization:** By promoting nutrition-sensitive carp-mola polyculture managed by women-led community institutions, it showcases a sustainable approach to public waterbody utilization. GP tanks, once neglected, have transformed into vital community assets, providing not only economic opportunities but also environmental and aesthetic benefits through the removal of aquatic weeds and restoration of pond dikes.
- **Economic empowerment:** In terms of direct income, the scheme has significantly empowered women economically, with each WSHG earning an annual income of INR 1,06,031 from fish farming in GP tanks. Research indicates that women's active involvement in small-scale aquaculture enhances income and food security, thereby improving overall welfare outcomes.
- **Improved fish production:** The initiative's focus on low-input modified-extensive polyculture has not only increased total fish production but also enhanced the productivity of community ponds across Odisha. This, in turn, has bolstered income and improved access to nutrient-rich fish, with carp-mola polyculture showing superior production, income, and consumption rates compared to carp polyculture.
- **Improved nutrition:** Nutritional enrichment is another crucial facet of the program. By ensuring regular availability of live and fresh fish at affordable prices, it has increased fish consumption among local communities. WSHGs distributed and consumed an average of 69 kg of fish per year per group, contributing to

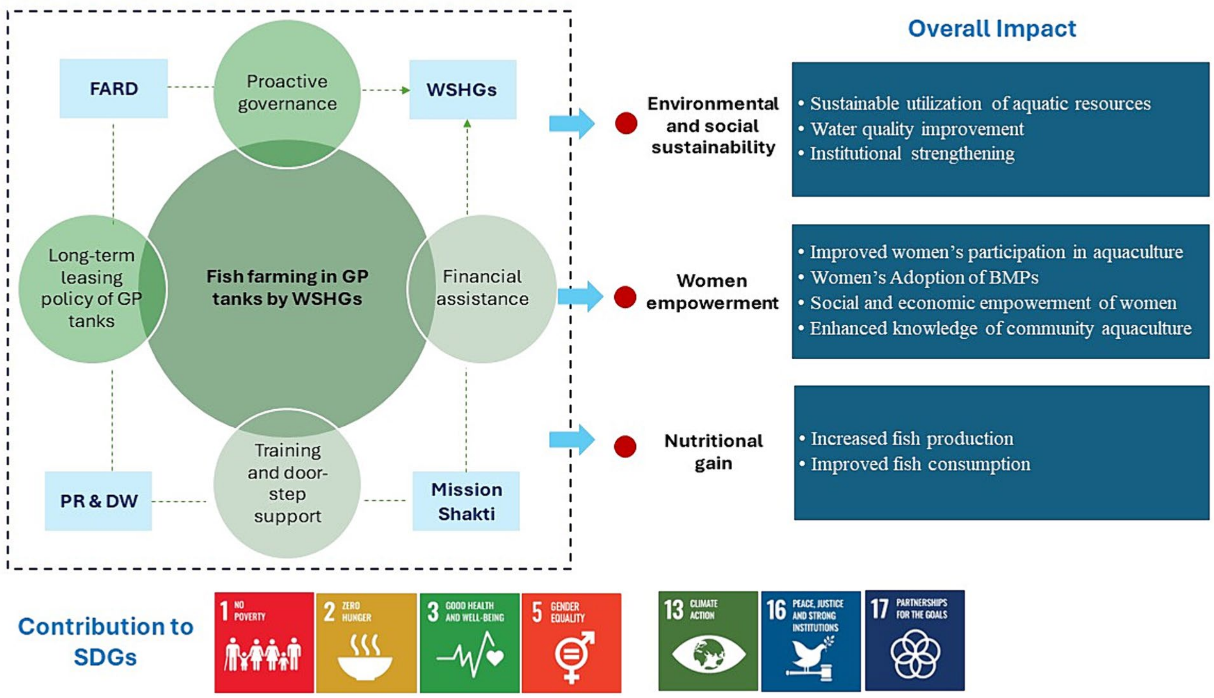

FIGURE 2
Overall impact of the program and contributions to the different SDGs.

improved nutrition and combating malnutrition in the state. Additionally, the adoption of carp-mola polyculture further enhances the nutritional quality of fish production from GP tanks.

- **Climate resiliency:** The scheme promotes resiliency by introducing climate-smart practices like advance-sized carp fingerling stocking. Greater pond depth in GP tanks mitigates water stress during prolonged summers, ensuring the sustainability of the initiative amidst fluctuating environmental conditions.

Women's empowerment in aquaculture and fisheries has profound implications for food security and nutrition, particularly in low-income and marginalized communities. Women are often the primary caregivers in households, responsible for ensuring their families' nutritional needs are met. By engaging in fish farming and fish processing activities, women contribute to the availability of nutritious food sources, thus improving household diets and overall nutritional outcomes. Additionally, the income generated from aquaculture can be invested in healthcare, education, and other essential services, further enhancing the well-being of families and communities.

5 Conclusion

In conclusion, this study evaluates the impact of a government program in Odisha aimed at promoting community-based fish farming in public waterbodies, with a particular focus on enhancing women's participation and empowerment. The findings demonstrate the technical feasibility, economic viability, and social acceptability of community-based aquaculture, especially in the context of nutrition-sensitive carp-mola polyculture. The program emphasized training and capacity building for WSHGs in fish farming techniques, facilitated by government departments, which led to widespread participation and the adoption of BMPs. Significant improvements were observed in pond management, water quality monitoring, and supplementary feeding practices. The adoption of nutrition-sensitive practices like carp-mola polyculture contributed to increased productivity, household fish consumption, and income. Key factors such as water retention period, stocking density, feed and fertilizer application, and training significantly influenced fish production and income. The introduction of mola broods underscored the importance of access to brood mola or hatchery-reared mola seed. The program profoundly impacted resource utilization, economic and social empowerment of women, fish availability, household nutrition, and climate resiliency, exemplifying the potential of community-based aquaculture initiatives in achieving SDGs.

To fully harness the potential of carp-mola polyculture, several recommendations are essential: continuing awareness campaigns and training sessions to educate farmers about the nutritional benefits and management practices of carp-mola polyculture; strengthening capacity-building efforts to enhance the skills of farmers, especially women, in managing ponds and harvesting fish; promoting small fish consumption for health benefits through collaboration between various government departments; advocating for supportive policies at the state and national levels to incentivize and scale up nutrition-sensitive aquaculture initiatives; encouraging collaboration between government departments, non-governmental organizations, research institutions, and private sector actors to create an enabling environment for carp-mola polyculture; extending nutrition-sensitive aquaculture programs to more regions and communities, particularly those with high rates of undernutrition and poverty; utilizing extension services to provide technical assistance, access to inputs, and market linkages to small-scale farmers; allocating resources for research and innovation in hatchery-based mass seed production of mola to ensure the availability of quality seed stock for farmers; exploring innovative technologies and practices to optimize pond management, feeding regimes, and disease control in carp-mola polyculture systems; strengthening value chains, improving infrastructure, and promoting market linkages for small-scale farmers to facilitate access to markets for mola and other fish products; providing support for processing, storage, and marketing initiatives to enhance the value proposition of carp-mola polyculture; and establishing monitoring and evaluation mechanisms to track the impact of nutrition-sensitive aquaculture interventions on nutrition outcomes, livelihoods, and environmental sustainability. By implementing these recommendations, the full potential of nutrition-sensitive aquaculture can be realized, contributing to sustainable development and improved livelihoods for communities in Odisha and beyond.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author/s.

Ethics statement

Ethical review and approval were not applicable for the study as the study was analyzed and interpreted based on the data collected from the Government of Odisha (FARD) allowing WorldFish to document the key findings.

Author contributions

SD: Conceptualization, Data curation, Formal analysis, Writing – original draft, Writing – review & editing. AP: Conceptualization, Funding acquisition, Resources, Supervision, Writing – review & editing. VC: Supervision, Writing – review & editing. NS: Data curation, Formal analysis, Writing – review & editing. AG: Writing – review & editing. BR: Writing – review & editing. BB: Conceptualization, Methodology, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2024.1412686/full#supplementary-material

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