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Climate-smart practices in freshwater aquaculture: Expert insights and empirical analysis

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Abstract

The vulnerability of inland aquaculture to climate-related changes and shocks is increasing steadily which necessitates the development, popularisation and adoption of climate-smart aquaculture strategies in the inland sector. Climate-Smart Aquaculture (CSAq) is built on three pillars, *i.e.*, sustainably increasing productivity and income, improving resilience and mitigating climate change. Successful application and adoption of CSAq strategies needs integration of expert knowledge and opinion based on evidence and acceptance. The present study throws light on the opinions of experts gathered through an online survey on selected freshwater aquaculture, harvest and post-harvest practices particularly suited for coastal flood-prone areas and their relation to the three pillars of CSAq, supported by research evidence. As per the expert opinion analysed using correspondence and cluster analysis, ten among the fourteen selected practices support increase in productivity, income and resilience/adaptation to climate change. The parameter estimates and significance using binary logistic regression showed that practices like modified extensive farming of Indian major carps (IMCs), use of farm-made aquafeed prepared with locally available ingredients, feeding management, use of passive harvesting gear like gillnets and use of solar dryers for drying of fish and vegetables can contribute to mitigation of climate change through reduction or elimination of greenhouse gas (GHG) emissions ($p<0.05$). The results showed that the productivity and adaptation pillar performed best with the selected CSAq practices. The findings of this study provide an important basis for recommendations to farmers and policymakers for the implementation and advancement of CSAq practices.

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Introduction

Fisheries, the sunrise sector of the Indian economy, contributes to nutrition, income and employment for millions of people in the country. In 2021-2022, India produced 16.2 million t of fish, with 12.1 million t and 4.2 million t from the inland and marine sectors, respectively. Inland freshwater fish landings alone accounted for 11 million t (DoF, 2022). Hence, aquaculture is an important contributor to the country's economy and the cheapest source of animal protein for millions of people. However, aquaculture like other production sectors, is also not safe from the adverse climate change effects (Ahmed and Diana, 2015). Although the climatic vulnerability of inland aquaculture is reportedly less than that of coastal aquaculture, the perilous effects of future climate change are predicted to severely impact inland fish production also (Islam *et al*., 2019). Consequently, the vulnerability to climate change of fisheries-based livelihoods is increasing over time (Islam *et al*., 2014). The Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2014) has pointed out some factors such as accelerated sea level rise, increase in frequency of extreme events like flooding in coastal areas, cyclones, and storm surges in the low-lying deltaic regions, as some of the deleterious impacts of climate change. Inland aquaculture is mainly affected by flooding, changes in temperature and precipitation. The physical changes caused by the increase in water temperature can result in variations in dissolved oxygen levels, resulting in the frequent occurrence of harmful algal blooms and an increased incidence of parasitic diseases (Karvonen *et al.*, 2010). Fluctuations in temperature can also affect the breeding cycle, fecundity and egg quality of freshwater aquaculture species. Sea level rise can result in the inundation of coastal freshwater ponds and can cause salinity intrusion. It can also result in flooding, thereby dislodging fishing settlements and infrastructure (Akankali and Jamabo, 2012), and reduce freshwater availability causing salinisation of ground water. Increased frequency and/or intensity of storm surges and cyclones may cause loss of and/or damage to aquaculture stock, gear and facilities (Islam *et al*., 2019). Small-scale fish farmers have comparatively low buffering capacity and are more susceptible to these climate-related shocks and variations. Hence the focus should be shifted to the popularisation and adoption of climate-smart aquaculture strategies to ensure livelihood security of fishers and to improve the nutritional security of the growing population. Climate-smart agriculture (CSA) is a strategy developed to address the challenges and risks posed by climate change on food security and development in a joint and collegial fashion (FAO, 2013; Aggarwal *et al*., 2018; Lipper and Zilberman, 2018). Aquaculture that sustainably enhances productivity (Pillar 1), strengthens resilience and adaptation (Pillar 2), reduces or mitigates greenhouse gas (GHG) emissions (Pillar 3) and supports food security and development goals can be termed as Climate Smart Aquaculture (CSAq) (Lundeba *et al*., 2023).

In general, strategies for developing or selecting climate-smart practices for aquaculture are broadly like those for agriculture and any other sector. But the failure to target the climate-smart practices according to the local needs reduces the efficiency and effectiveness of those practices to support the three pillars of CSAq. There is a paucity of research exploring expert perspectives on the climate smartness of aquaculture practices. Integrating expert knowledge and evidence-based opinions are crucial for making informed and robust decisions on implementing climate-smart practices, guiding policy and engaging general public (Preston *et al.,* 2011, Qasemi *et al*., 2023). The present study throws light on the opinions of experts and the inferences there of on selected freshwater aquaculture, harvest and post-harvest practices, that can be popularised as climate-smart practices among fish farmers in the coastal flood-prone areas of the country, so as to improve productivity, resilience, and mitigation for achieving food security and sustainable developmental goals.

Materials and methods

This study was primarily based on the expert elicitation on the climate-smartness of selected freshwater aquaculture, harvest and post-harvest practices that can be popularised in flood prone coastal areas of the country with an abundance of homestead pond resources. The study employed a qualitative survey methodology using Google Form as the primary research equipment. The survey was conducted online from March to July 2022. The questionnaire covered 14 activities distributed across 3 dimensions of Climate-Smart Aquaculture (CSAq), *i.e.,* sustainably increasing production and farm income (Pillar 1 of CSAq), helping in adapting and building resilience to climate change risks and shocks (Pillar 2 of CSAq), and directly or indirectly reducing emissions of GHGs (Pillar 3 of CSAq). A total of 30 experts from across the country participated in the survey. The study did not relate to seniority in profession, age, or number of years in the profession. We searched for respondents on the internet and from contacts known or recommended to us and emailed them the survey links. The email invitation also requested that the survey be forwarded to others in the field, thereby initiating a respondent-driven snowball sampling (Johnson, 2014). The respondents had expertise in fisheries resource management, aquaculture, fish nutrition and disease management, post-harvest fisheries, participatory aquaculture research with farmers and gender in fisheries. Among them, 73.3% were researchers, 13.33% were academicians and 13.33% were KVK scientists. The survey was kept open-ended to welcome suggestions from the experts on additional approaches that could be adopted by farmers to cushion against the climate change-related shocks. The fourteen practices upon which responses were collected were finalised through a literature review. In order to identify the relevant CSAq practices, a desktop search involving online information was done. Additionally, we gathered information from published literature by selected international institutions, including CGIAR organisations, that are directly and indirectly involved in climate-smart agriculture. The practices thus identified were narrowed down to 14 practices based on their feasibility of application and adoption by rural farmers of coastal flood-prone areas characterized by an abundance of small (0.01-0.1 ha) homestead pond resources. The attempt is to classify them as climate-smart based on their capacity to support the three pillars of CSAq. The respondents were asked to mark their response according to the potential of the respective aquaculture practice to support the three pillars of climate-smart aquaculture. The climate-smart aquaculture practices that were included in the survey and the corresponding references are depicted in Table 1. Data obtained through the survey was further analysed using correspondence analysis (PROC CORRESP), cluster analysis (PROC CLUSTER) and parameter estimates and significance using Binary Logistic Regression analysis (PROC LOGISTIC) using SAS 9.3 software. Correspondence analysis, a statistical technique that shows how categorical variables relate to each other was used to understand the association or closeness of the 14 CSAq practices with the 3 pillars of CSA and hierarchical cluster analysis using average distance was performed for data driven grouping of 14 CSAq practices. Hierarchical cluster analysis is a clustering method that creates a dendrogram (hierarchical tree) of the practices to be clustered/grouped. The dendogram represents the hierarchical relationships between the practices and shows how similar practices are clustered at different distances. Binary logistic regression analysis for binary responses (yes/no) was done for better understanding the relationship and to identify the practices significantly contributing to each pillar of climate-smart aquaculture.

Results and discussion

Relationship of pillars of CSAq and selected practices based on expert opinion

Correspondence analysis (Fig. 1) provides preliminary understanding of association between rows and columns and in the present study it showed that practices 1 to 9 and 12 (Table 1) are closely related to pillar 1 (sustainably increasing production and farm income) and 2 (helping in adapting and building resilience to climate change, risks and shocks) and practices 10, 11 and 14 (Table 1) are closely related to pillar 3 (directly or indirectly reducing emission of GHGs) (Fig. 1) of CSAq. Practice 13 is away from all the three pillars. This

Table 1. Expert opinion on the climate smartness of freshwater aquaculture, harvest and post-harvest practices

Practices	References	Expert opinion (%) (N=30)		
		Supports CSAq Pillar 1	Supports CSAq Pillar 2	Supports CSAq Pillar 3
Utilisation of homestead pond for integrated aqua-horticulture	Belton and Azad (2012); Ahmed *et al.* (2016); Newaj *et al.* (2016); Barange *et al.* (2018); Mulokozi (2021)	93.3	70	40
Participation of women in integrated homestead aqua-horticulture	Nandeesha *et al.* (1994); Choudhary *et al.* (2017); *Colgan et al.* (2019); Parrao *et al.* (2021); Hossain *et al*. (2024);	86.67	46.67	20
Formation of women farmer interest groups at village level	Starkloff and Pant (2011); Thaker (2012); Mishra and Gadeberg (2022)	86.67	56.67	16.67
Modified extensive farming of Indian major carps in homestead ponds	Ghoshal *et al.* (2019); Macleod *et al.* (2020); Abhisha *et al.* (2022); Rossingoli *et al.* (2023).	83.33	53.33	46.67
Polyculture of IMC with small indigenous species, minor carps and medium carps	Rai *et al*. (2014); Das and Mishra (2016); Karim *et al*. (2017); Das *et al.* (2018); Yengkokpam *et al.* (2022)	83.33	63.33	30
Production of stunted juveniles of IMC at village level for replenishment of stocks during grow out culture	Nandeesha *et al.* (1994); Dubey *et al.* (2017); Mishra (2020); Mishra *et al.* (2020);	90	60	33.33
Fencing of ponds with nets to prevent loss of crops during flood	Dubey *et al.* (2017); Adhikary *et al.* (2018); Mishra (2020); Chand *et al.* (2022)	80	66.67	20
Late stocking of homestead ponds with stunted juveniles/advanced fingerlings in flood prone areas	Ramakrishna *et al.* (2013); Belton *et al.* (2017); Hossain *et al.* (2021); Oyebola *et al*. (2021)	76.67	70	20
Culture of short-term species like Tipalia or minor carps in seasonal ponds	Gupta (1990); Gupta and Rab (1994); Felsing *et al*. (2003); Gupta (2019)	86.67	67.33	33.33
Feeding management (for *e. g.* Intermittent feeding)	Nandeesha *et al.* (1993, 1995, 2002); Lin and Yi (2003); Ali *et al.* (2005); Rodjaroen (2020); Bjornevik *et al.* (2021)	73.33	50	70
Preparation of farm made aquafeeds using locally available raw materials	Ramakrishna *et al.* (2012); Sarder (2013); Shipton and Hasan (2013); Barange *et al.* (2018)	66.67	36.67	63.33
Multiple stocking and multiple harvesting practices	Jena *et al.* (2002); Das *et al.* (2018)	96.67	60	33.33
Use of passive harvesting gear like gill net	Bhoopendranath and Hameed (2009); Vivekanandan *et al.* (2013); Thomas (2019)	30	6.67	43.33
Use of solar dryers in post-harvest drying of fish and vegetables for use in lean season	Arata *et al*. (1993); Aravindh and Sreekumar (2016); Rajarajeswari and Sreekumar (2016); El Hage *et al.* (2018); Rajaraeshwari *et al.* (2018); Singh and Gaur (2021)	50	46.67	76.67

*CSAq Pillar1- Sustainably increasing productivity and income
CSAq pillar 2- Adapting and enhancing resilience to climate change
CSAq Pillar 3- Reducing and/or removing GHG emissions

is because not more than 30% and 43% of the experts had the opinion that the practice can support pillar 1 and 3, respectively and only 6% of the experts opined the practice can help in improving resilience/adaptation to climate change and shocks. Responses for three pillars were further analysed using hierarchical cluster analysis for grouping of 14 CSAq practices and depicted in the form of dendrogram (Fig. 2). Grouping observed in the dendrogram were found similar to grouping observed in correspondence analysis. Further, data was subjected to binary logistic regression analysis for better understanding of the relationship and to identify the practices contributing to each pillar of climate smart aquaculture. Practices 14, 13 and 3 were used as reference level for computation of estimates and probability values for pillar 1, 2 and 3 respectively and the results are given in Table 2. It was observed that all practices were significantly contributing to pillar 1, except practices 10, 11, 13 and 14 at 5% level of significance while all practices were significantly contributing to pillar 2 except practice no. 13. For pillar 3, practices 4, 10, 11, 13 and 14 were found to be significant. Similar observation can also be seen in percentage values as per expert opinion depicted in Table 1.

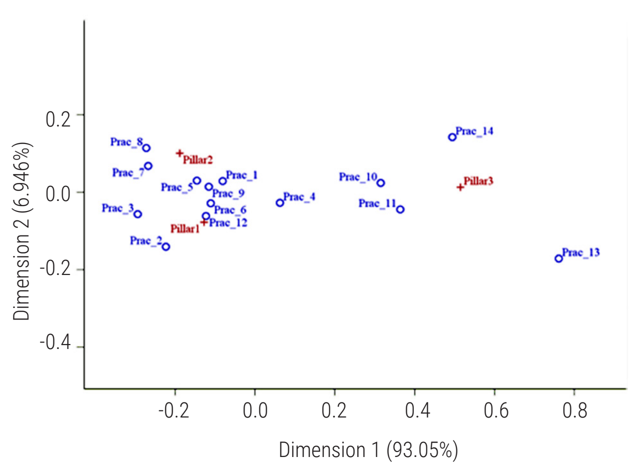

Fig. 1. Correspondence analysis of data on experts opinion on climate smartness of freshwater aquaculture, harvest and post-harvest practices

Table 2. Parameter estimates and significance using Logistic Regression

Parameter	Pillar1		Pillar2		Pillar3	
	Estimate	Pr > ChiSq	Estimate	Pr > ChiSq	Estimate	Pr > ChiSq
Intercept	1.86E-16	1.0000	-2.6388	0.0003	-1.6094	0.0010
Practice 1	2.6391	0.0013	3.4861	<0.0001	1.2039	0.0505
Practice 2	1.8718	0.0040	2.5053	0.0022	0.2231	0.7390
Practice 3	1.8718	0.0040	2.9071	0.0004	-	-
Practice 4	1.6094	0.0084	2.7723	0.0007	1.4758	0.0158
Practice 5	1.6094	0.0084	3.1854	0.0001	0.7621	0.2275
Practice 6	2.1972	0.0020	3.0443	0.0002	0.9162	0.1423
Practice 7	1.3863	0.0177	3.3320	<0.0001	0.2231	0.7390
Practice 8	1.1896	0.0354	3.4861	<0.0001	0.2231	0.7390
Practice 9	1.8718	0.0040	3.1854	0.0001	0.9162	0.1423
Practice 10	1.0116	0.0665	2.6388	0.0013	2.4567	0.0001
Practice 11	0.6931	0.1928	2.0923	0.0111	2.1559	0.0005
Practice 12	3.3661	0.0018	3.0443	0.0002	0.9162	0.1423
Practice 13	-0.8473	0.1169	-	-	1.3411	0.0287
Practice 14	-	-	2.5053	0.0022	2.7989	<0.0001
AIC	451.091		582.099		563.927	
SC	455.131		586.139		567.967	
-2 Log L	449.091		580.099		561.927	
Likelihood Ratio Chi-Square	67.5258	<0.0001	47.8499	<0.0001	62.0287	<0.0001
Wald Chi-Square	55.5079	<0.0001	30.0852	0.0046	53.2952	<0.0001
Percent Concordant	70.7		61.5		65.9	

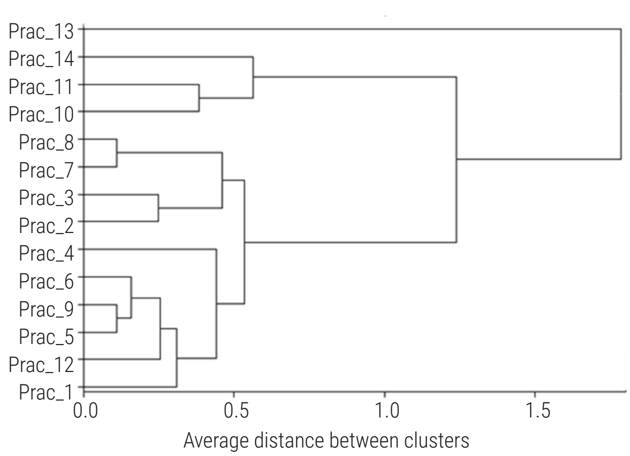

Fig 2. Cluster analysis by dendrogram of data on experts opinion on climate smartness of freshwater aquaculture, harvest and post-harvest practices

Utilisation of homestead pond for integrated aqua-horticulture

Majority (93%) of the experts found utilisation of homestead ponds for integrated aqua-horticulture to support the first pillar of CSAq, *i.e.*, sustainable increase in productivity and income. Farming households that invest in aquaculture have been proven to increase their food and nutrition security by enhancing incomes, diversifying their crops and consuming more fish (Kaminski *et al.*, 2024). For example, in Bangladesh, homestead fish farming accounts for 3 to 15% of total household income and 25% to 50% of all fish production (Belton and Azad, 2012). Mulokozi (2021) reported that the fish yield and income from the integrated aquaculture agriculture (IAA) ponds were 60 and 175% higher compared to non-IAA ponds, respectively, because of a more frequent use of on-farm resources and better management. Seventy percent of the experts were of the opinion that integrated homestead aquaculture will help in adapting and building resilience to climate change. Analysis using correspondence analysis, cluster analysis and parameter estimates and significance using binary logistic regression also denotes the close relation of the practice to pillar 2 of CSAq. The small ponds in farmers homestead offers resilience to climate shocks by not only serving as a source of subsidiary income through aquaculture but will also help them to conserve water for irrigation purposes during droughts (Rahman, 2018). The practice also supports the pillar 3 because of the minimal impact it has on the environment. Reports say that emissions from aquaculture and fisheries represent only 10% of total agriculture emissions, or about 0.58 GtCO2-eq y^{-1} (Barange *et al.*, 2018). Furthermore, Ahmed *et al.* (2016) have reported that conversion of 25% of total aquaculture area to integrated aquaculture-agriculture ponds has the potential to sequester 95.4 million t of carbon per year. Hence, integrated aquaculture helps to generate diversified crop yield in the face of climate change, help the system to adapt to climatic changes and minimise GHG emissions by improving nutrient flow in the system (Newaj *et al.*, 2016).

Participation of women in integrated homestead aquaculture

Women's vulnerability to climate changes are comparatively higher because of their increased dependence on natural resources. The multiple roles played by them combined with power inequalities results in limited coping and adaptive capacity among women (Salgueiro-Otero *et al*., 2022). But given a chance, women are comparatively more receptive to adoption of climate resilient strategies and practices. Expert opinion indicated (87%) that participation of women in integrated homestead aquaculture will help in sustainably increasing aquaculture productivity and income ($p<0.05$) (Table 2). Women's access to productive agrifood resources is critical in improving their climate resilience. The proximity of ponds to their homes will enable women to participate in aquaculture and improve household income without having to venture out (Hossain *et al.,* 2024). Findings suggest that homestead aquaculture by women contributes to positive outcomes in terms of participation of women in decision-making around consumption and provision of nutritious food to self and family; equitable power relations within households; improvement in women's access and control over resource use and incomes; and increased awareness of women about their rights (Parrao *et al*., 2021). The parameter estimates and significance using binary logistic regression of the data on expert's opinion show that women's involvement in homestead integrated aquaculture can significantly improve their adaptability to climate related shocks and risks (Table 2). Colgan *et al.* (2019) have said that women's participation in aquaculture can not only help communities to adapt to the changing climate by providing alternative livelihoods and income sources but also can contribute to the conservation of natural resources.

Formation of women farmer interest groups at village level

Logistic regression of the data on experts opinion shows a significant contribution of the practice ($p<0.05$) in supporting the pillars 1 and 2 of CSAq (Table 2). In the survey, 87% of the experts (Table 1) opined that the formation of women collectives like interest groups will sustainably increase production and farm income. Omeje *et al*. (2021) and Olagunju *et al*. (2021) stated that group membership positively influences women's income and participation in fish farming and has the potential to empower women resulting in economic and social upliftment of their families. More than 50% of the experts (Table 1) were of the opinion that collective action will help women as well as the community to adapt and build resilience to climate related shocks, which corroborates with the report by Thaker (2012). Working with women's groups and collectives can be effective in identifying their needs and constraints in adopting climate-smart practices and for tailoring capacity-building activities based on these needs and constraints. The women collectives can act as the platforms where women would be able to exercise their agency and decisions in adopting and putting in practice the climate adaptation/climate smart strategies. Access to and sharing of information, resources, and economic opportunities needed to respond to climate change are more effective within collectives and groups. Working in unison through collectives has made women farmers of India aware of and adopt new practices and climate information services, as reported by Mishra and Gadeberg (2022). The success of the project 'Women in Aquaculture in Nepal' both at national and international levels was attributed to the empowerment of women members through forming co-operatives (Starkloff and Pant, 2011).

Modified extensive farming of Indian major carps (IMCs) in homestead ponds

Adoption of modified extensive farming of IMCs in homestead ponds will help in sustainably increasing productivity and income as suggested by the experts ($p<0.05$) (Table 2). Correspondence analysis and cluster analysis (Fig. 1 and 2) also showed a greater relation of the practice to pillar 1. Sustainable aquaculture is an eco-friendly practice with the objective of obtaining optimum production without any adverse environmental impact in the long run. In India, carp culture is majorly based on extensive or modified extensive farming techniques. The modified extensive carp aquaculture system is a highly efficient sustainable food production system where low-trophic species such as carps convert feed into body mass in highly efficient and climate-resilient ways (Abhisha *et al*., 2022). More than 50% of the experts believed that adoption of the practice will reduce the financial loss to farmers in areas vulnerable to climate-related shocks, thereby improving their adaptability and resilience. This is because extensive or modified extensive aquaculture requires three to four times less capital investment than semi-intensive/intensive aquaculture (Ghoshal *et al.,* 2019). Modified extensive farming of carps will also help in mitigation of climate change, as opined by the experts (43%), mainly because of the lower stocking density and minimal water exchange required. Whereas in the case of intensive farming practices, total water uptake will increase with the increased stocking density, as ponds with higher density require more water exchange to maintain the water quality, which will result in increased energy use. A study on the quantification of GHG emissions from global aquaculture shows that the GHG emission in terms of thousand metric CO_2e is much lower in the case of IMC farming when compared to other cultured species (MacLeod *et al*., 2020). Because of the lower stocking density and feeding level in extensively managed ponds, the pond effluents will contain lesser nutrients, thereby posing minimal threat to water and the environment. Small-scale carp aquaculture has become increasingly relevant to meet local fish demand and food and nutrition security needs in Bangladesh (Rossignoli *et al*., 2023). Since the coastal rural areas of India are also blessed with similar ecosystems, adoption of modified extensive farming of IMCs in homestead ponds will help farmers not only to have sustainable production, income and nutrition ($p<0.05$) but also will help them to absorb the shocks of climate change in terms of adaptation ($p<0.05$) and mitigation ($p<0.05$) as could be deduced from the parameter estimates and significance using binary logistic regression (Table 2).

Polyculture of IMCs with small indigenous species, minor or medium carps

Strengthening of climate-smart aquaculture can be achieved through diversification of the production through varieties that are good candidates for aquaculture. Polyculture adds more value to ecosystem with several ecological services such as taxa co-habitation, diversified production, improved income and consumer acceptance (Karim *et al.*, 2017). Majority of the experts (83%) in the survey agreed that polyculture of IMCs with minor or medium carps will help in sustainably increasing productivity and income (pillar 1) (Figs. 1, 2 and Table 2) thereby meeting the criteria of being considered a climate-smart practice. Medium and minor carps are best suited for polyculture with IMCs. As minor carps are considered local fish by the consumers, they command 20-30% higher market prices than IMCs depending on the regional demand. Das *et al*. (2018) have reported 21% higher yield and moderate FCR (2.06) in the polyculture of IMCs with minor carps, which can be attributed to the effective use of the available natural productivity for multispecies farming without compromising the biomass yield. Das and Mishra (2016) have reported 28.8% higher yield with 10.4% lower FCR through multispecies farming of major and minor carps compared to composite culture of IMCs alone. Yengkokpam *et al.* (2022) reported that the polyculture of carps with small indigenous fishes (SIF) in pens proves to be an effective climate-resilient system that could enhance the income and livelihood of the fishers besides providing nutritional security in developing countries. As the two types of species do not interfere with each other, carp production can generate income, while SIF production will add to the micronutrient availability of rural families (Rai *et al.*, 2014; Karim *et al*., 2017). Sixty-three percent of the experts in the survey were of the opinion that polyculture of IMC with minor/medium carps will help in building resilience to climate change, risks, and shocks ($p<0.05$) (Table 2). This is because, shorter culture period of these species reduces production risks and provide additional income to the farmers.

Production of stunted juveniles/yearlings of IMCs at village level for replenishment of stocks during grow-out culture

Stunted yearlings/juveniles are the individuals that are having slow growth rate, early maturation and small size (Mishra *et al*., 2020). The production of stunted juveniles at village level and it's grow-out culture will result in higher productivity and income when compared to the farmers' practice of stocking fingerlings, as opined by 90% of the experts. It can be popularised among farmers as a climate-smart practice as it supports both pillars 1 ($p<0.05$) and 2 ($p<0.05$) of CASq (Table 2). Since carps exhibit faster growth rate during their second year of culture, stocking ponds with stunted yearlings (8-12 months old) of 100-150 g, instead of fry or fingerlings can be beneficial for the farmers (Nandeesha *et al*., 1994; Mishra *et al*., 2020). These are suitable stocking material for grow-out carp culture because of their higher survival rate, lesser vulnerability to predation, disease resistance and tolerance to environmental fluctuations. One of the major constraints faced by rural aquafarmers is the non-availability of good quality and quantity of seed at their doorstep during grow-out season. Production of stunted fingerlings and yearlings in their respective villages can serve as a solution to this constraint. Production of stunted juveniles at village level will help farmers in adopting multiple stocking and multiple harvesting wherein the fingerlings for replenishing the stock are available in their village itself. Sixty percent of the experts opined that the production of stunted juveniles helps in adapting and building resilience to climate related shocks and risks ($p<0.05$). Stunted fingerlings will also enable farmers in temperate areas and areas with scanty water supply to produce table-sized fish in a short duration of time. For example, in states with severe winters, farmers need to stock the ponds during March-April. But the non-availability of seeds during the peak season results in financial loss to the farmer. In such a situation, the production of stunted juveniles through overwintering will help the farmer in procuring seeds for the growing season.

Fencing of ponds with nets to prevent loss of stock during flood

Sixty-seven percent of the experts opined that protecting the pond by fencing will help in building adaptation and resilience towards climate changes, risks and shocks ($p<0.05$) (Table 2). The practice has been adopted by farmers throughout the country to protect the stock from being washed away in floods. For example, in Assam, many farmers (55%) erect net fencing around the pond in order to prevent fish escape as well as to avoid the entry of predatory fish during inundation by flood waters (Chand *et al*., 2022). Adhikari *et al.* (2018) pointed out the use of this strategy by 23 to 80% of aquaculture farmers of the coastal states like Andhra Pradesh, West Bengal, Odisha and Gujarat as a climate change mitigation practice. Fencing and netting around the ponds has been reported as one of the key strategies used to prevent the escape of stocked fish as well as to prevent entry of other predator fish during floods in the Sundarbans delta (Dubey *et al*., 2016). Mishra (2020) also has reported the adoption of strategies like use of bamboo screens, net screens, provision of inlet/outlet and raising of embankment, by aquafarmers of Uttar Pradesh. The construction of higher pond dikes and additional cropping such as planting fruit trees and vegetables on dikes, can help protect aquaculture farms from soil erosion and sedimentation during floods.

Late stocking of homestead ponds with stunted juveniles/advanced fingerlings in flood-prone areas

The practice can help farmers to improve their income (pillar 1) and to adapt and/or build resilience to the climatic shocks or risks (pillar 2), as can be seen in Figs. 1 and 2. Reducing crop period by using larger stocking size of fish or stunted juveniles is in practice in many parts of India (Ramakrishna *et al*., 2013; Belton *et al*., 2017). This practice has increased the opportunity for multiple cropping with the added advantages of short-term investment, quick return and reduced risk period. The stunted juveniles/advanced fingerlings generally have a higher survival rate and the stunted juveniles exhibit compensatory growth in grow-out ponds. Changing the time of first stocking of fish has been practiced by farmers as a reactive approach. *i.e*., the adaptation strategy that is being applied after the impacts of the climate change are felt in Uganda, as reported by Oyebola *et al*. (2021). As per Hossain *et al.* (2021), farmers avoid stocking fingerlings during conditions like heavy rainfalls, high temperatures, and cold spells in Bangladesh in order to prevent the loss of stock due to these extreme weather conditions. By adopting the practice, farmers inhabiting flood-prone areas can avoid the loss of crop by stocking the stunted juveniles/advanced fingerlings in the post-flood season. Short term (5 day or weekly) and seasonal forecasts can help farmers to decide on the time of stocking especially during natural calamities.

Culture of short-term species like tilapia or minor carps in seasonal ponds

The practice of farming of short-term fish species in seasonal ponds can support pillar 1 ($p<0.05$) and pillar 2 ($p<0.05$) of CSAq (Table 2). Most farmers in rural areas have access to waterbodies such as seasonal ponds, ditches and canals that retain water for 5 to 6 months (from June to November), which can be used for aquaculture of short-cycle species such as silver barb (*Puntius gonionotus*) or tilapia. In recent years, frequent droughts have led to the conversion of once-perennial ponds into seasonal ponds, even in coastal floodplain areas. Silver barbs have been found ideal for seasonal ponds as they reach marketable size within 4-5 months (Gupta, 1990). The short duration fish farming offers huge scope as an excellent adaptation strategy for flood-prone areas too. Here the fish culture can be taken up profitably in post-winter and pre-flood period. In Bangladesh, farmers adopting sliver barb culture in seasonal ponds could meet production cost from the sale of just 30% of the fish (Gupta and Rab, 1994), indicating the feasibility of this practice as a climate-smart approach. The faster growth rate of these fish allows them to reach market size more quickly, whereas IMCs should be stocked at a length of 14 to 16 cm to attain market size during the wet season in seasonal ponds (Felsing *et al.,* 2003). Farmer-oriented studies have confirmed the viability of culturing silver barb (*P. gonionotus*) and Nile tilapia (*Oreochromis niloticus*) in seasonal ponds with a production of 1.2-2.1 t ha^{-1} and 1.5-2.3 t ha^{-1} of P. *gonionotus* and tilapia, respectively, within 4 months (Gupta, 2019). In the survey, 87 and 63% of the experts were of the opinion that the culture of tilapia and minor carps in seasonal ponds will be a climate-smart approach in terms of its contribution to improving production and income and by helping in and building resilience to climate change related risks (Table 1).

Use of farm-made aquafeeds prepared using locally available raw materials

Feed production and transportation are major contributors to GHG emissions in aquaculture. Feeds not only account for 40-80% of production costs but also contribute 50 to 80% of energy consumption in intensive farming systems through raw material procurement, feed production, transportation and fuel consumption by feeding devices (Barange *et al.,* 2018). But generally, feed for species like IMCs grown under extensive or modified extensive systems are usually limited to farm-made feeds, or locally produced small-scale commercial feeds comprising only one or two ingredient sources (Ramakrishna *et al*., 2012; Sarder, 2013). This will result in reduced energy expenditure. For resource-poor farmers, the raw materials are available in their locality at an affordable price so that they can prepare relatively low cost feeds in their own farms. This can help mitigate risks faced during natural calamities such as floods ($p<0.05$) (Table 2). Furthermore, using cost-effective, farm-made feed formulations that are water-stable, palatable, and nutritionally tailored to the species and developmental stage of the fish can enhance production, improve economic viability and reduce environmental impact (Hasan and New, 2013). Expert opinions suggest the potential of this practice in reducing or eliminating GHG emissions ($p<0.05$) (Table 2).

Feeding management

The rising feed cost and pollution originating from uneaten feed have long been key concerns for aquaculture researchers. Adoption of an optimal feeding regime can help reduce feed costs, minimise nutrient loading in ponds and ultimately reduce environmental impacts of aquaculture practices. Correspondence analysis of the data on experts' opinions suggests strong association of this practice with pillar 3 (Fig. 1). Effective feeding management can minimise feed wastage, prevent feed decomposition and improve fish health. Mixed feeding schedules have been proposed as a key feeding management strategy to reduce feed costs and pollution in the face of changing climatic conditions and have been successfully tested across various fish species (De Silva, 2007). Mixed feeding includes strategies such as pulsed or intermittent feeding and alternating high protein and low protein diets. The applicability of mixed feeding schedules in reducing feed costs and improving nutrient utilisation has been demonstrated in Indian carps, *Catla catla* and *Labeo rohita* (Nandeesha *et al.,* 1993); common carp, *Cyprinus carpio* (Nandeesha *et al.,* 1995, 2002); Nile tilapia, *Oreochromis niloticus* (Rodjaroen, 2020); sutchi catfish, *Pangasius hypophthalmus*; and silver carp, *Hypophthalmichthys molitrix* (Ali *et al.,* 2005). Bjørnevik *et al.* (2021) demonstrated that feeding costs can be drastically reduced without compromising biomass growth by feeding on alternate days during the on-growing period of Atlantic cod. Lin and Yi (2003) reported that Nile tilapia reared in fertilised ponds and fed supplemental diets at 50% satiation achieved a considerable reduction in production costs and in nutrient loading.

Multiple stocking and multiple harvesting practices

The multiple stocking and multiple harvesting (MSMH) method in composite fish farming significantly enhances fish production, allowing farmers to begin earnings within four months. This approach offers several benefits with the primary advantage being a substantially higher yield compared to the traditional annual composite fish culture system. Nearly all experts (97%) agreed that MSMH contributes to the sustainable growth of aquaculture productivity and income. Jena *et al.* (2002) reported higher fish yields and reduced FCR in single stock-multiple harvest (SSMH) cropping and multiple-cropping (two crops) of IMCs compared to the conventional single stock-single harvest (SSSH) system within the same culture period. The practice is closely related to pillar 1 and 2 of CSAq as evident in the correspondence analysis (Fig. 1) and cluster analysis (Fig. 2). Regular netting followed in this practice facilitates release of noxious gases and promotes mixing of bottom nutrients with surface water, enhancing the pond's primary productivity. The marked increase in dissolved oxygen and pH levels of pond water following partial harvest at 180-225 days further facilitates mineralisation and improves conversion of nitrogenous byproduct into usable forms, thereby boosting pond productivity (Das *et al.* 2018). Periodic fish harvesting not only provides farmers with a steady income ($p<0.05$), but also enhances resilience against risks and shocks, such as crop loss due to floods or cyclones ($p<0.05$) (Table 2).

Use of passive harvesting gears like gillnets

An environmentally friendly and sustainable fishing technology minimises negative environmental impacts. Sustainability of the gear can be assessed based on the extent of pond bottom disturbance caused by the gear, the risk of lost fishing gear leading to ghost fishing and the selectivity of the gear for target species, particularly its impact on catch composition, including bycatch and juvenile fish. The gillnet is a versatile fishing gear, as it can be operated at various depths (surface, column or bottom layers) and can target small as well as large fishes, due to its mesh size selectivity. Many studies have reported the low energy requirement for traditional non-motorised gillnetting in sharp contrast to motorised and mechanised fishing operations (Bhoopendranath and Hameed, 2009)). As per Vivekanandan *et al.* (2013), among mechanised craft, gillnetters emit less CO_2 (0.56-1.07 t CO_2 t^{-1} of fish) than trawlers (1.43 t CO_2 t^{-1} of fish). Among various fishing gears, gillnets are considered to have minimal environmental impact, as they typically have little or no interaction with the sea bed or pond bottom in most circumstances (Thomas, 2019). However, in the online survey, only 43% of the experts had the opinion that using gillnets for fish harvesting would help mitigate the effects of climate change ($p<0.05$) (Table 2). The use of gillnets can be promoted as a women friendly practice, as their passive fishing nature reduces the physical effort required, thereby reducing the drudgery in fishing activities (Tanuja *et al.*, 2023).

Use of solar dryers for post-harvest drying of fish and vegetables for use in the lean season

Drying is widely regarded as a cost-effective method for extending shelf-life of various agricultural products. In tropical countries, open-air sun drying is the most preferred method, especially among small and marginal farmers, due to its affordability. However, this drying process greatly relies on ambient conditions and is prone to contamination from dust, rain, wind, pests, and rodents (El Hage *et al*., 2018), resulting in inferior quality products and financial loss (Aravindh and Sreekumar, 2016; Rajarajeswari and Sreekumar, 2016;). Attempts to reduce GHG emissions by switching to solar energy-based technologies is being attempted by governments and industries worldwide. Use of solar dryers for drying vegetables and fish will support the 3rd pillar of CSAq by reducing the emission of GHGs as evident in the statistical analysis (Figs. 1, 2 and Table 2). The solar drying system is remarkable in its energy efficiency and resultant product quality. As reported by Rajaraeshwari *et al.* (2018), the use of solar dryers can prevent emissions of 434 gCO_2e kg^{-1} of fresh apples, 467 gCO_2e kg^{-1} of fresh tomato, 410 gCO_2e kg^{-1} of onions, 480 gCO_2e kg^{-1} of pineapple, and 382 gCO_2e kg^{-1} of tapioca. In their study on sustainability assessment of hybrid active greenhouse solar dryer, Singh and Goar (2021) reported a mitigation of 169.10 t of CO_2. Arata *et al.* (1993) found that a solar dryer system operating at 40% efficiency can reduce conventional energy consumption by 27–80%. In addition, the use of solar energy can significantly improve public health, as various epidemiological studies have linked GHG emissions to elevated risks of non-allergic respiratory and cardiovascular morbidity, cancer, allergic conditions and adverse pregnancy and birth outcomes.

The effects of climate change are becoming increasingly evident in inland aquaculture. Blindly popularising and implementing aquaculture interventions, without expert input and empirical evidence can undermine the foundations of climate-smart aquaculture, significantly impacting the livelihoods, income and nutrition of rural communities. This study, assessed the climate-smartness of fourteen freshwater aquaculture, harvest and post-harvest practices using expert opinions and evidence-based approach, evaluating their alignment with the pillars of Climate-Smart Aquaculture (CSAq). Although CSAq strives to simultaneously support the three pillars of production, adaptation and climate change mitigation, it acknowledges that not all recommended practices can achieve such a triple win. The results indicated that the productivity and adaptation pillars were the most strongly supported, with ten of the fourteen selected CSAq practices contributing to these aspects. A clear understanding of the climate smartness of these practices is crucial for informing recommendations to farmers and policymakers, facilitating the effective implementation and advancement of CSAq practices. In addition, we recommend that future studies incorporate small homestead pond owners, including women in coastal flood-prone areas, to further validate these findings.

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References

Adhikari, S., Chaudhury, A. K., Barlaya, G., Rathod, R., Mandal, R. N., Ismail, S., Saha, G. S., De, H. K., Sivaraman, I., Mahapatra, A. S., Sarkar, S., Routray, P., Pillai, B. R. and Sundaray, J. K. 2018. Adaptation and mitigation strategies of climate change impact in freshwater aquaculture in some states of India. *J. Fish. Sci. Com*., 12(1): 016-021.

Aggarwal, P., Jarvis, A., Campbell, B., Zougmoré, R., Khatri-Chhetri, A., Vermeulen, S., Loboguerrero, A. M., Sebastian, L., Kinyangi, J. and Bonilla-Findji, O. 2018. The climate-smart village approach: Framework of an integrative strategy for scaling up adaptation options in agriculture. *Ecol. Soc*., 23(1). https://doi.org/10.5751/ES-09844-230114.

Ahmed, N., Bunting, S. W., Glaser, M., Flaherty, M. S. and Diana, J. S. 2016. Can greening of aquaculture sequester blue carbon? *Ambio*, https://doi.org/10.1007/s13280-016-0849-7.

Ahmed, N. and Diana, J. S. 2015. Does climate change matter for freshwater aquaculture in Bangladesh? *Reg. Environ. Change*, 16:1659-1669.

Akankali, J. A. and Jamabo, N. A. 2012. Effects of flooding and erosion on fisheries resources in Niger Delta, Nigeria. *Eur. J. Sci. Res*., 90: 14-25.

Ali, Z., Hassain, A. and Mazid, A. 2005. Effect of mixed feeding schedules with varying dietary protein levels on the growth of sutchi catfish, *Pangasius hypophthalmus* (Sauvage) with silver carp, *Hypophthalmichthys molitrix* (Valenciennes) in ponds. *Aquac. Res*., 36: 627-634. https://doi.org/10.1111/j.1365-2109.2005.01262.x.

Arata A., Sharma, V. K. and Spagna, G. 1993. Performance evaluation of solar assisted dryers for low temperature drying application-II: experimental results. *Energy Convers. Manag*., 34: 417-426. https://doi.org/10.1016/0196-8904(93)90091-N.

Aravindh, M. A. and Sreekumar, A. 2016. Efficiency enhancement in solar air heaters by modification of absorber plate-a review. *Int. J. Green Energy*, 13(12): 1209-1223. https://doi.org/10.1080/15435075.2016.1183207.

Barange, M., Bahri, T., Beveridge, M. C. M., Cochrane, A. L., Funge-Smith, S. and Paulain, F. 2018. Impacts of climate change on fisheries and aquaculture, synthesis of current knowledge, adaptation and mitigation options. *FAO Fisheries and Aquaculture Technical Paper No. 627*, Food and Agriculture Organisation of the United Nations, Rome, Italy, 628 p.

Belton, B. and Azad, A. 2012. The characteristics and status of pond aquaculture in Bangladesh. *Aquaculture*, 358-359(1): 196-204. https://doi.org/10.1016/j.aquaculture.2012.07.002.

Belton, B., Padiyar, P. A., Ravibabu, G. and Rao, K. G. 2017. Boom and bust in Andhra Pradesh: Development and transformation in India's domestic aquaculture value chain. *Aquaculture*, 470: 196-206. https://doi.org/10.1016/j.aquaculture.2016.12.019.

Bjørnevik, M., Imsland, A. K. D., Hanssen, H., Roth, B., Vikingstad, E. and Atle Foss 2021. The effect of alternate-day feeding on growth and feed conversion in Atlantic cod *Gadus morhua*. *Aquac. Nutr*., 27(4): 1206-1211.

Bhoopendranath, M. R. and Hameed, M. S. 2009. Energy analysis of traditional non-motorised gillnet operations, in Vembanad Lake, Kerala, India. *Fish. Technol*., 46(1): 15-20.

Chand, B. K., Rajendran, S. and Mohan, C. V. 2022. *Climate resilient technologies/practices to support pond aquaculture and beel fisheries under APART, Assam, India*. WorldFish, Penang, Malaysia, 281 p.

Colgan, J., McDougall, C., Murray, U., Spillane, C., McKeown, P. and Hossain, M. 2019. *Can climate-smart aquaculture enable women's empowerment in rural Bangladesh? Program Brief: FISH-11*.CGIAR Research Program on Fish Agri-Food Systems, Penang, Malaysia, 24 p.

Das, P. C. and Mishra, B. 2016. Multi-species farming of major and minor carps for enhancing fish production in freshwater aquaculture. *Indian J. Fish*., 63(2): 55-61.

Das, P. C., Kamble, S. P., Velmurugan, P. and Pradhan, D. 2018. Evaluation of minor carps intercropping in carp polyculture *vis-à-vis* other grow-out cropping patterns of carp farming. *Aquac. Res*., https://doi.org/10.1111/are.14034.

De Silva, S. S. 2007. Reducing feed costs through adoption of mixed feeding schedule practices in semi-intensive aquaculture. *Int. Aquac. Feed*. 10(5): 18-22.

DoF 2022. *Handbook on fisheries statistics*. Department of Fisheries, Ministry of Fisheries, Animal Husbandry and Dairying, Government of India, New Delhi, India, 218 p.

Dubey, S. K., Chand, B. K., Trivedi, R. K., Mandal, B. and Rout, S. K. 2016. Evaluation on the prevailing aquaculture practices in the Indian Sundarban delta: An insight analysis. *J. Food. Agric Environ*., 14: 133-141.

El Hage, H., Herez, A., Ramadan, M., Brazzi, H. and Khaled, M. 2018. An investigation on solar drying: A review with economic and environmental assessment. *Energy*, 157: 815-829.

FAO 2013. *Climate-smart agriculture (CSA) sourcebook*, 1st edn. Food and Agriculture Organisation of the United Nations, Rome, Italy, 557 p.

Felsing, M., Haylor, G., Dutta, G., Kumar, B., Shweta, S., Natarajan, A., Arora, G. and Singh, V. 2003. Carp production in seasonal water bodies in Eastern India. *Asian Fish. Sci*., 16: 1-15.

Ghoshal, T. K., De, D., Biswas, G., Kumar, P. and Vijayan, K. K. 2019. Brackishwater aquaculture: Opportunities and challenges for meeting livelihood demand in Indian Sundarbans. In: Sen, H. S. (Ed.), *The Sundarbans: A disaster-prone eco-region.* Springer Cham, pp. 321-349.

Gupta, M. V. 1990. Rural women in aquaculture: Bangladesh. *Naga, ICLARM Quarterly*, 13(3): 8.

Gupta, M. V. 2019. *Low-input technologies for rural aquaculture development in Bangladesh.* International Center for Living Aquatic Resources Management (ICLARM), Makati, Manila, Philippines, 12 p.

Gupta, M. V. and Rab, M. A. 1994. *Adoption and economics of silver barb (Puntius gonionotus) culture in seasonal waters in Bangladesh*. *ICLARM Technical Report No. 41,* International Center for Living Aquatic Resources Management (ICLARM), Makati, Manila, Philippines, 39 p.

Hasan, M. R. and New, M. B. 2013. On-farm feeding and feed management in aquaculture. *FAO Fisheries and Aquaculture Technical Paper No. 583*. Food and Agriculture Organisation of the United Nations, Rome, Italy, 67 p.

Hossain, P. R., Babu, T. S. A., Krupnik, T. J., Braun, M., Mohammed, E. Y. and Phillips, M. 2021. Developing climate information services for aquaculture in Bangladesh: A decision framework for managing temperature and rainfall variability-induced risks. *Front. Sustain. Food Syst.*, 5: https://doi.org/10.3389/fsufs.2021.677069.

Hossain, M. B., Pingki, F. H., Sultana, M., Salim, N. M., Islam, M. M., Rahman, A. F. M. A., Paray, B. A. and Arai, T. 2024. The contribution of homestead pond fish culture to household food security and dietary diversity in central coast of a developing country. *Heliyon*, 10(7): e28598.

IPCC 2014. Climate change 2014. In: Pachauri, R. K. and Meyer, L. A. (Eds.), *Synthesis report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Intergovernmental Panel on Climate Change, Geneva, Switzerland, 151 p.

Islam, M. M., Sallu, S., Hubacek, K. and Paavola, J. 2014. Vulnerability of fishery-based livelihoods to the impacts of climate variability and change: insights from coastal Bangladesh. *Reg. Environ. Change*, 14: 281-294. https://doi.org/10.1007/s10113-013-0487-6.

Islam, Md. M., Barman, A., Kundu, G. K., Kabir, Md. A. and Paul. B. 2019. Vulnerability of inland and coastal aquaculture to climate change: Evidence from a developing country. *Aquac. Fish*., 4(5): 183-189. https://doi.org/10.1016/j.aaf.2019.02.007.

Jena, J. K., Ayyappan, S. and Aravindakshan, P. K. 2002. Comparative evaluation of production performance in varied cropping patterns of carp polyculture systems. *Aquaculture*, 207: 49-64. https://doi.org/10.1016/S0044-8486(01)00800-6.

Johnson, T. P. 2014. Snowball sampling: Introduction. In: *Wiley StatsRef. Statistics Reference Online*, John Wiley and Sons, Ltd., Hoboken, New Jersey, USA. https://onlinelibrary.wiley.com/doi/abs/10.1002/97 811184 45112.stat05720.

Kaminski, A. M., Cole, S. M. and Johnson, J. 2024. Smallholder aquaculture diversifies livelihoods and diets thus improving food security status: evidence from northern Zambia. *Agric. Food Secur*. 13(1). https://doi.org/10.1186/s40066-023-00452-2.

Karim, M., Ullah, H., Castine, S., Islam, M. M., Keus, H. J. and Kunda, M. 2017. Carp–mola productivity and fish consumption in small-scale homestead aquaculture in Bangladesh. *Aquac. Int*., 25: 867-879.

Karvonen, A., Rintamäki, P., Jokela, J. and Valtonen, E. T. 2010. Increasing water temperature and disease risks in aquatic systems: Climate change increases the risk of some, but not all, diseases. *Int. J. Parasitol*., 40(13): 1483-1488. https://doi.org/10.1016/j.ijpara.2010.04.015.

Lin C. K. and Yi, Y. 2003. Minimizing environmental impacts of freshwater aquaculture and reuse of pond effluents and mud. *Aquaculture*, 226(1): 57-68. https://doi.org/10.1016/S0044-8486(03)00467-8.

Lipper, L. and Zilberman, D. 2018. *A short history of the evolution of the climate smart agriculture approach and its links to climate change and sustainable agriculture debates*. In: Lipper, L., McCarthy, N. and Zilberman, D. (Eds.), *Climate smart agriculture, natural resource management and policy,* Vol 52. Springer, Cham, pp. 13-30.

Lundeba, M., Mudege, N. N. and Siamudaala, V. 2023. *Climate-smart Aquaculture for smallholder fish farmers: Integrated fish and small livestock farming*. WorldFish, Penang, Malaysia, 72 p.

MacLeod, M. J., Hasan, M. R., Robb, D. H. F. 2020. Quantifying greenhouse gas emissions from global aquaculture. *Sci. Rep*., 10: 11679. https://doi.org/10.1038/s41598-020-68231-8.

Mishra, A. and Gadeberg, M. 2022. *Six practical steps to support women farmers to drive climate resilience, Nairobi, Kenya: CGIAR GENDER Impact Platform.* https://gender.cgiar.org/news/six-practical-steps-support-women-farmers-drive-climate-resilience. (Accessed 11 November 2023).

Mishra, I. R. P., Mishra, C., Kumar, N. and Das, S. K. 2020. A study on growth and economic parameters of stunted yearling (Indian major carp) culture technique in nine village ponds of Angul district, Odisha. *Int. J. Curr. Microbiol. Appl. Sci*., 9(4): 1414-1420.

Mishra, Y. 2020. Climate change risks and mitigating measures of freshwater aquaculture in unmanaged ponds of Kaushambi District U.P. *GSC Biol. Pharm. Sci*., 13(2): 253-259. https://doi.org/10.30574/gscbps.2020.13.2.0385.

Mulokozi, D. 2021. *Integrated Agriculture and Aquaculture systems (IAA) for enhanced food production and income diversification in Tanzania Deogratias*. Doctoral Thesis, in Stockholm University, Sweden, 72 pp.

Nandeesha, M. C., De Silva S. S. and Krishnamurthy D. 1993. Evaluation of mixed feeding schedules in two Indian major carps, catla (*Catla catla*) and rohu (*Labeo rohita*). In: Kaushik, S. J. and Luquet, P. (Eds), *Proceedings of the Fourth International Symposium on Nutrition and feeding in fish*, INRA, Paris, France, pp. 753-767.

Nandeesha, M. C., De Silva S. S. and Krishnamurthy, D. 1995. Use of mixed feeding schedules in fish culture performance of common carp, (*Cyprinus carpio* L.) on plant and animal protein-based diets. *Aquac. Res*., 26: 161-166.

Nandeesha, M. C., Gangadhara, B. and Manissery, J. K. 2002. Further studies on the use of mixed feeding schedules with plant- and animal-based diets for common carp (*Cyprinus carpio* L.). *Aquac. Res*., 33: 1157-1162.

Nandeesha, M. C., Dathathri, K., Krishnamurthy, D., Varghese, T. J., Gangadhar, B. and Umesh, N. R. 1994. Effect of varied level of protein on the growth and tissue biochemistry of stunted yearlings of rohu (*Labeo rohita*) in the absence and presence of natural food. In: Silva, De. S. S. (Ed.), *Fish nutrition research in Asia: Proceedings of the fifth Asian Fish Nutrition Workshop*, *Asian Fisheries Society special publication No. 9*. Asian Fisheries Society, Manila, Philippines, pp. 93-100.

Newaj, R., Chaturvedi, O. P. and Handa. A. K. 2016. Recent development in agroforestry research and its role in climate change adaptation and mitigation change adaptation and mitigation*. Ind. J. Agrofor*., 18: 1-9.

Olagunju, E. O., Ariyo, C. O., Olagunju, S. O., Oluwaseyi, K., Alabi, O. F., Ganiy, L. 2021. Assessment of participation level of rural women in fish farming in Kaduna state, Nigeria. *Russian J. Agric. Socio-Econ. Sci*., 3(111): 141-495. https://doi.org/10.18551/rjoas.2021-03.16.

Omeje, J. E., Achike, A. I., Sule, A. M., and Arene, C. J. 2021. Gender roles and economic differentials in aquaculture of Kainji Lake basin, Nigeria. *Res. World Agric. Econ*., 2 (2). https://doi.org/10.36956/rwae.v2i2.353.

Oyebola, O. O., Eftre, J., Musinguzi, L. and Falaye, A. E. 2021. Potential adaptation strategies for climate change impact among flood prone fish farmers in climate hotspot Uganda. *Environ. Dev. Sustain*, 23: 12761-12790.

Parrao, C. G., Shisler, S., Moratti, M., Yavuz, C., Acharya, A., Eyers, J. and Snilstveit, B. 2021. Aquaculture for improving productivity, income, nutrition and women's empowerment in low and middle income countries: A systematic review and meta-analysis. *Syst. Rev*., https://doi.org/10.1002/cl2.1195.

Preston, B. L., Westaway, R. M. and Yuen. E. J. 2011. Climate adaptation planning in practice: An evaluation of adaptation plans from three developed nations. *Mitig. Adapt. Strateg. Glob*. *Chang*., 16: 407-438. https://doi.org/10.1007/s11027-010-9270-x.

Qasemi, M., Allahyari, M. S., Hassen, T. B., Askari, M. I. and Bilali, H. E. 2023. Cultivating change: Perceptions and attitudes of agricultural experts towards the Sustainable Development Goals. *Land*, 12(8): 1604. https://doi.org/10.3390/land12081604.

Rahman, O. 2018. *Mini pond as a climate change adaptation technology for drought prone area Porsha Upazila of Naogoan District in Bangladesh.* Thesis, Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, Bangladesh, 72 p.

Rai, S., Thilsted, S. H., Shrestha, M. K., Wahab, Md. and Gupta, M. C. 2014. Carp-SIS Polyculture: A new Intervention to improve women's livelihoods, income and nutrition in Terai, Nepal. Gender in Aquaculture and Fisheries: Navigating Change. *Asian Fish. Sci. Special Issue*, 27S: 165-174.

Rajarajeswari, K. and Sreekumar, A. 2016. Matrix solar air heaters - A review. *Renew. Sust. Energ. Rev*., 57: 704-712. https://doi.org/10.1016/j.rser.2015.12.127.

Rajarajeswari, K., Hemalatha, B. and Sreekumar, A. 2018. Role of solar drying systems to mitigate CO_2 emissions in food processing industries. *Green Energy Technol*., https://doi.org/10.1007/978-981-10-7326-7_4. I.

Ramakrishna, R., Shipton, T. A. and Hasan, M. R. 2013. Feeding and feed management of Indian major carps in Andhra Pradesh, India. *FAO Fisheries and Aquaculture Technical Paper No 578*. Food and Agriculture Organisation of the United Nations, Rome, Italy, 90 p.

Rodjaroen, S., Thongprajukaew, K., Jaihao, P., Saekhow, S. and Nuntapong, N. 2020. Mixed feeding schedules switching between dietary crude protein levels for mono-sex male Nile tilapia (*Oreochromis niloticus*). *Aquac. Rep*., 18: https://doi.org/10.1016/j.aqrep.2020.100509.

Rossignoli, C. M., Lozano L. D. P., Kumar, B. B., Brako, D. E., Timothy, M., Quanli, W., Rodolfo, D. M., Roberta, M., Alvaro, P. M. and Alexandros, G. 2023. Multi-stakeholder perception analysis of the status, characteristics, and factors affecting small-scale carp aquaculture systems in Bangladesh. *Front. Sustain. Food Syst*., 7. https://doi.org/10.3389/fsufs.2023.1121434.

Salgueiro-Otero, D, Barnes, M. L. and Ojea, E. 2022. Transformation in times of climate change: What makes a fisher diversify livelihoods? *Front. Mar. Sci*., 9: 888288. https://doi.org/10.3389/fmars.2022.888288.

Sarder, M. R. I. 2013. On-farm feed management practices for three Indian major carp species (Rohu *Labeo rohita*, Mrigal *Cirrhinus cirrhosus* and catla *Catla catla*) in Bangladesh: A case study. In: Hasan, M. R. and New, M. B. (Eds.), On-farm feeding and feed management in aquaculture. *FAO Fisheries and Aquaculture Technical Paper No. 583*. Food and Agriculture Organisation of the United Nations, Rome, Italy, pp. 213-239.

Singh. P., and Gaur, M. K. 2021. Sustainability assessment of hybrid active greenhouse solar dryer integrated with evacuated solar collector. *Curr. Res. Food Sci*., 2(4): 684-691. https://doi.org/10.1016/j.crfs.2021.09.011.

Shipton, T. A. and Hasan, M. R. 2013. An overview of the current status of feed management practices. In,: Hasan, M. R. and New, M. B. (Eds.). On-farm feeding and feed management in aquaculture, *FAO Fisheries and Aquaculture Technical Paper No. 583*. Food and Agriculture Organisation of the United Nations, Rome, Italy, pp. 3-20.

Starkloff, N. W. and Pant, J. 2011. *Gender and aquaculture: sharing the benefits equitably.* The WorldFish Center, Penang, Malaysia. Issues Brief 32: 12 p.

Tanuja, S., Sarkar, A., Moharana, G. and Mhatre, C. S. 2023. Improving household fish and vegetable availability though participation of rural women: A case study. *Indian J. Fish*., 70(3): 122-127. https://doi.org/10.21077/ijf.2023.70.3.134706-16.

Thaker, J. 2012: *Climate change in the Indian mind: Role of collective efficacy in climate change adaptation*. Ph. D. thesis, George Mason University, Virginia, USA. 144 p.

Thomas, S. N. 2019. Sustainable gillnet fishing. In: Leela Edwin, Thomas, S. N., Remesan, M. P., Muhamed Ashraf, P., Baiju, M. V., Manju Lekshmi, N. and Madhu, V. R. (Eds.), *Course Manual, ICAR Winter School on Responsible Fishing: Recent advances in resource and energy* *conservation*, 21 November - 11 December 2019, ICAR-Central Institute of Fisheries Technology, Kochi, India, pp. 239-250.

Vivekanandan, E., Singh, V. V. and Kizhakudan, J. K. 2013. Carbon footprint by marine fishing boats of India. *Curr. Sci*., 105(3): 361-365.

Yengkokpam, S., Debnath, D., Bhattacharjya, B. K., Sarkar, U. K., Medhi, K., Gogoi, K. and Das, B. K. 2022. Exploring polyculture of small indigenous fishes with major carps in pens as a climate resilient adaptation strategy for northeastern wetlands of India. *Mitig. Adapt. Strateg. Glob. Chang*., 27(1): https://doi.org/10.1007/s11027-021-09981-2.