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Exploring the potential of decentralized extension models on the sustainability of livelihoods: a food security lens on aquaculture farmers in Bangladesh

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Small-scale farmers in Bangladesh aquaculture face multiple challenges. Among these challenges are the inadequate supply of quality seed, limited credit access, poor availability of quality fish feed, land-use conflicts, the adverse effects of climate change, and the low adoption of best aquaculture management practices. These challenges spiral into low productivity, low incomes, and low food security of households. Extension has been seen as an important tool for technology and knowledge transfer, resulting in increased farm productivity and household food security. However, small-scale aquaculture farmers in Bangladesh lack access to critical extension service needed to improve productivity and their livelihoods. Using Propensity Score Matching, we test whether more decentralized extension systems yield similar food security outcomes as traditional extension models. Analysing data from 1,017 respondent, we find that decentralized extension models lead to improved food security of aquaculture households compared to non-beneficiaries. We recommend among others, the critical need to synergize extension systems, reduce costs and better target aquaculture farmers. Additionally, public-private partnerships can help leverage strengths from various extension approaches for more effective knowledge dissemination to aquaculture farmers, ultimately enhancing their livelihoods.

KEYWORDS

food security, extension, decentralized, aquaculture, impact, local agents

1 Introduction

In Bangladesh, aquaculture and fisheries play a pivotal role in the livelihoods of rural communities, positioning the country as the fifth-largest aquaculture producer globally (FAO, 2022). The sector employs over 20 million people (DOF, 2022), with small-scale producers making up a significant portion of the workforce. In 2021–2022, Bangladesh produced nearly 2.6 million metric tons of fish through aquaculture (DOF, 2022; FAO, 2022), reflecting the high reliance on fish as a key source of animal protein, accounting for more than half of the total animal protein consumed. The country's geographic suitability for aquaculture production supports this high yield (FAO, 2022; DOF, 2022). Bangladesh is currently self-sufficient in fish production, with the average daily dietary consumption of fish at 63 grams per person (DOF, 2022). Small-scale aquaculture is essential for enhancing food security across the population.

Despite the crucial role small-scale farmers play in Bangladesh's aquaculture sector, they face several challenges, particularly in accessing extension services (FAO and INFOFISH, 2022; Rana et al., 2024; Mitra et al., 2024). Key obstacles to effective extension services include an inadequate fish-farmer ratio, infrequent visits by extension officers, weak relationships with farmers, low motivation among extension agents, and a lack of aquaculture-specific expertise (Obi et al., 2024; Ahmed et al., 2018). These challenges hinder the adoption of advanced production technologies, leading to lower productivity, reduced incomes, and food insecurity for households.

As seen in other regions, effective extension services in Bangladesh have the potential to increase productivity, enhance incomes, and improve food security (Gebresilasse, 2023; Kosim et al., 2021; Parrao et al., 2021; Rahman et al., 2023). However, the limited access to these services for small-scale farmers undermines these potential benefits. Extension service delivery in Bangladesh is characterized by three key structural issues that exacerbate challenges in knowledge dissemination. First, many extension services are delivered through donor-funded projects, leading to discontinuity in interventions and prompting farmers to revert to inefficient practices once projects end (Abhijeet et al., 2023). Second, government-led extension services traditionally employ a top-down approach that often does not align with the needs of local communities (Obi et al., 2024; DOF, 2006; Mohammadzadeh et al., 2017). Lastly, the government, as the primary provider of extension services, faces resource and manpower constraints, limiting its ability to serve the large number of small-scale farmers effectively (Obi et al., 2024). These limitations have led to calls for the decentralization of extension services, increased stakeholder involvement, and a programmatic approach to service delivery (Uddin and Qijie, 2013).

In response to these challenges, private companies, non-governmental organizations, and non-profits play a critical role in extending knowledge interventions to farmers. One key approach to improving knowledge dissemination is through the use of local agents, such as service providers and farmers (Kapia-Mendano, 2012; Ahmed et al., 2018). Decentralized approaches offer several advantages. First, they foster constructive social interactions between farmers and local agents, building trust and improving extension service effectiveness (Atukunda et al., 2021; Kassam et al., 2011). Second, the proximity of local extension providers allows for faster responses to farmers' production challenges (Joshua et al., 2015; Kumar, 1999; Suvedi et al., 2017). Third, local extension providers often have a deeper understanding of the social and cultural contexts of the communities they serve, enabling them to deliver more efficient and culturally sensitive services (Landini, 2016). Finally, decentralization reduces manpower costs, improving the extension agent-to-farmer ratio and overall service delivery efficiency (DOF, 2006). However, decentralized systems also face challenges, including uneven quality of service delivery, poor coordination, limited capacity among local agents, and issues with accountability and sustainability (Abed et al., 2020; Zwane, 2012; Okorley et al., 2011; Maulu et al., 2021; Farazmand et al., 2022), which must be strategically addressed to maximize impact.

In 2019, WorldFish and its partners implemented a decentralized approach to aquaculture extension in Bangladesh, training local agents, primarily aquaculture service providers, in improved production technologies (e.g., integrated aquaculture, feeding and disease management) and nutrition-related topics. These local agents serve as the primary points of contact for farmers, facilitating extension service delivery. The adoption of these technologies is expected to boost productivity, incomes, and food security for beneficiary households. Extensive literature underscores the positive impact of extension services on farmer livelihoods, both in agriculture and aquaculture (Suvedi et al., 2017; Mohammadzadeh et al., 2017; Mbeche et al., 2022; Dam Lam et al., 2022). For example, Suvedi et al. (2017) identified a positive relationship between extension services and technology adoption among rural households in Nepal. Similarly, Dam Lam et al. (2022) demonstrated that knowledge transfer increased fish productivity, diversity, and income among women farmers in Bangladesh. Dompreh et al. (2024) also found that extension services significantly improved food security for farmers.

This study contributes to the literature by assessing the impact of decentralized extension approaches using local aquaculture service providers on the food security of farmers in Bangladesh. The findings will be crucial for enhancing the sustainability of aquaculture production systems and improving the livelihoods of small-scale farmers across the country.

1.1 The aquaculture extension environment in Bangladesh

In Bangladesh, the extension service system operates through two main approaches: centralized and decentralized models. These two systems play synergistic and complementary roles in enhancing the reach and quality of extension service delivery.

In the centralized approach, government institutions, such as the Department of Fisheries (DoF), play a crucial role in providing extension knowledge to aquaculture farmers. The DoF is responsible for implementing extension policies developed at a broader level by the Ministry of Fisheries and Livestock (Government of Bangladesh and FAO, 2014) to disseminate improved technologies. The DoF collaborates with other ministries, including the Ministry of Youth and Sports, to deliver extension services to young people (DOF, 2006) as a means of reducing youth unemployment and integrating them into aquaculture production systems. Primarily, these operations are conducted at the national level, where government institutions often collaborate with international organizations such as WorldFish and FAO (Jahan et al., 2015; Obi et al., 2024) and research institutes like the Bangladesh Fisheries Research Institute (BFRI). However, this setup has limitations in addressing local needs due to the diversity in socioeconomic, ecological, political, and cultural dynamics.

Conversely, decentralized extension systems involve private sector providers, research institutes like BFRI, local government agencies, credit institutions, non-governmental organizations (NGOs), and peer farmers. This system primarily focuses on delivering specific, localized extension services to farmers and other actors in the aquaculture value chain (Emami and Ghorbani, 2011). Organizations in decentralized systems, such as input providers, may not have a direct role in information dissemination but often take on this responsibility to fulfil strategic business, organizational, and project objectives. While decentralized systems are primarily geared toward local-level information dissemination, they are not entirely independent of centralized systems (Obi et al., 2024). Implementation often stems from top-level project and policy agreements that are scaled down to reach target beneficiaries.

Although these approaches tackle extension issues from different perspectives and levels of coordination, it is essential to consider the most suitable delivery method on a case-by-case basis to provide value to farmers, development partners, and the national government (Emami and Ghorbani, 2011). Additionally, guiding the extension process can help mitigate any negative externalities that may arise from exclusively adopting either a centralized or decentralized approach.

2 Methodology

2.1 Treatment intervention

Aquaculture farmers in Bangladesh face limited access to extension services, significantly impacting their productivity, incomes, and food security (Ahmed et al., 2018). To address this issue sustainably, local aquaculture enterprises were recruited and trained on relevant aquaculture production and livelihood modules. Approximately 6,000 aquaculture service providers operate in the divisions. Local extension service agents, primarily input dealers and knowledge transfer companies, were selected based on their interest and motivation to participate in knowledge transfer. These agents underwent capacity-building training conducted by experts from WorldFish and other partners, covering various aspects of aquaculture production and nutrition.

To ensure consistent knowledge dissemination, local extension agents were trained using the same manual and were given identical training materials for later dissemination. The training for local extension agents covered: (i) the basics of aquaculture extension work and farmer-level participatory training approaches; (ii) the importance of aquaculture and the present aquaculture scenario in Bangladesh; (iii) aquaculture practices associated with each phase of the production process; (iv) the role of women in aquaculture; (v) dietary diversity and household nutrition, using the Social Behavior Change Communication (SBCC) approach for providing nutrition advice; (vi) potential benefits of the intervention for local extension agents and farmers; (vii) cultivation of nutritious vegetables and leafy greens through homestead farming and dike cultivation; and (viii) intervention monitoring methods and the creation of work plans for local extension agents (Barooah et al., 2022).

After completing the training, the agents were assigned to different villages within specific unions in the Rangpur and Rajshahi divisions of Bangladesh. They utilized approaches such as demonstration sites, individual farmer pond visits, and providing advice via mobile devices. Key messages disseminated to farmers included aquaculture technologies and better management practices specific to the target areas. Among these practices, farmers were trained in improved feeding practices, dike construction, and postharvest management. This approach aimed to enhance the efficiency of extension service delivery, ultimately improving farm productivity and contributing to better food security for households. In addition, extension service agents facilitate access to production resources such as broodstock and feed. By leveraging the presence of these local extension agents, the following diagrammatic concept (Figure 1) was expected to be realized.

To assess the impact of extension service delivery on household food security, we compared the outcomes of beneficiary households (B1) with non-beneficiary households (B2). The comparison was based on various food security indicators, including the Food Consumption Score (FCS), Household Food Insecurity Access Scale (HFIAS), Fish Consumption per week (FCPW) and Household Dietary Diversity Score (HDDS).

2.2 Study area and sampling

The study was conducted among 1,017 aquaculture farmers distributed across 6 districts in Rangpur and Rajshahi divisions, Bangladesh. A multi-stage sampling approach was used. Using stratified random sampling, we randomly selected 74 project unions and 28 non-project unions from 6 out of the 16 project districts (4 from Rajshahi and 2 from Rangpur). Specifically, there were 180 project unions and 90 non-project unions, which formed the sampling frame of the study. Next, we selected villages within each union and then beneficiary households within those villages. Two (2) villages with high number of ponds and aquaculture farmers were randomly selected from a list provided by union-level government officials. These villages were beneficiaries of the extension program. This intervention targeted 87,782 aquaculture farmers, out of which farmers were selected. To minimize spillover effects, we conducted randomization at the union level rather than the village level, as local extension agents might operate beyond their assigned villages. This approach helped address the challenge of restricting activities from union to union. Additionally, villages adjacent to beneficiary villages were not selected as control villages. Overall, 638 beneficiaries and 379 non-beneficiaries were selected for the study (see Table 1).

Following the sampling, data were collected for the 2019 production season, after training local enumerators. A household questionnaire that included several modules such as nutrition, demographic, production, adoption of better management practices, participation in training, visits by extension agents and income modules. SurveyCTO was used as a data collection tool. These enumerators were trained on both the content of the questionnaire, ethical practices and the use of SurveyCTO to collect household level data. Enumerators operated under the supervision of the research team. To ensure the collection of quality data, a quality check mechanism was established where at the end of each survey enumerators uploaded the data to the central server and the data were promptly reviewed by designated supervisor for errors and inconsistencies. Feedback was given to enumerators in near real-time by both the supervisor and the research team. Respondents were first asked for their consent to participate in the interview and were also informed they could discontinue at any time if they felt comfortable. They were also assured of the confidentiality and anonymity of their data.

2.3 Data analysis

Standardized measures of food security have been employed in literature to understand the state of food security among farmers in

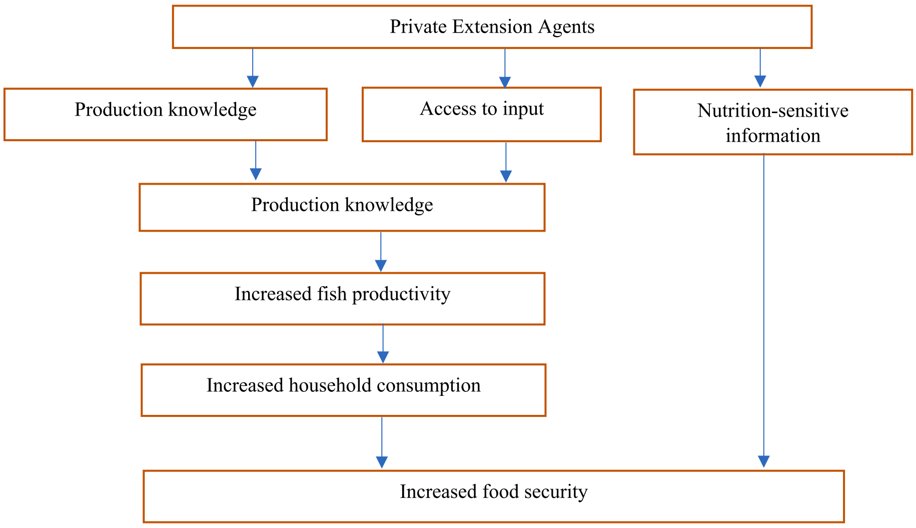

FIGURE 1
Impact conceptualization.

TABLE 1 Sample size.

Farmer category	Description	Sample size
Beneficiary farmers (B1)	Farmers who benefitted from the extension service delivery from the local extension agents	638
Non-beneficiary farmers (B2)	Farmers who live outside extension intervention unions and did not benefit from extension service	379
Total		1,017

TABLE 2 Impact variables.

Variable	Measure	Expectation
Food Consumption Score (FCS)	Continuous (0–112)	+
Household Food Insecurity Access Scale (HFIAS)	Continuous (0–27)	–
Household Dietary Diversity Score (HDDS)	Continuous (0–12)	+
Individual Dietary Diversity Score Women (IDDS-W)	Continuous (0–9)	+
Fish consumption per week	Continuous (kg)	+

Bangladesh and in other contexts (Dompreh et al., 2024; Dam Lam et al., 2022; Ahmed et al., 2019; Mekonen et al., 2023). In estimating food security, we relied on standardized measures of food security. (i) Food Consumption Score (FCS), (ii) Household Food Insecurity Access Scale (HFIAS), (iii) Household Dietary Diversity Score (HDDS) as well as (iv) Fish consumption per week (FCPW) (kg) (see Table 2).

FCS measures the dietary diversity, food frequency and relative nutritional frequency at the household level (WFP, 2008). It is based on the collection of data on 9 food groups consumed in 7 days prior to the survey. These different food groups have different weights as predetermined. The number of days a particular food group is consumed is weighted. The scores obtained are summed and categorized using different predetermined thresholds (poor, borderline and acceptable). High Food Consumption Score shows better/improved food diversity, and thus higher food security (Dam Lam et al., 2022; WFP, 2008).

The HFIAS measures the severity of household food insecurity (Coates et al., 2007). HFIAS measures the access component of food security (Dompreh et al., 2021; Ngome et al., 2019). In addition, the measure provides insights into the nutritional quality of food eaten by households. These dimensions are drawn using nine sets of questions on household behaviors toward food insecurity experienced in 30 days (4 weeks) prior to the survey. These sets of questions consist of whether the behavior occurred and the frequency of occurrence. For each household, the scores range between 0 and 27. The frequency-of-occurrence during the past 4 weeks for the 9-food insecurity-related conditions is summed. The average HFIAS score is calculated by dividing the sum of the individual household scores by the number of households (Coates et al., 2007). Higher scores show high levels of food insecurity.

HDDS refers to the number of different food groups consumed over a given reference period. It is highly correlated with factors such as caloric and protein adequacy and household income (Swindale and Bilinsky, 2006). It is used to measure food security at the household level. To better reflect diet quality, data on 12 food groups are collected. Data is collected for "normal" or "usual" 24 h prior to the survey during the period of greatest food shortage. "Yes or No" questions on different food groups consumed are asked to the person responsible for food preparation. The total number of food groups shows the diversity of food consumed in the household. The higher the value, the higher the food security of the household.

IDDS-W is a measure of diet diversity for women aged between 15 and 49 years. It is a dichotomous indicator measured using 9 food groups. It measures the dietary diversity of women of reproductive age for a selected population (Swindale and Bilinsky, 2006).

Fish consumption per week was measured by calculating the quantity of fish eaten by the household 7 days prior to the survey. It is used to measure the availability of protein source through fish to the household. It is measured in kg.

2.4 Impact elicitation

Inferences about the impact of interventions on subjects have become a part of development interventions. However, there are biases that may cloud the estimation of impacts of interventions. These may include self-selection, compliance failure by treatment as well as participation in the treatment by non-beneficiaries (Bareinboim and Pearl, 2012; Hirano and Imbens, 2001). In addition, there is the need to control for endogeneity to ensure the results obtained are pure reflections of impact (Caliendo and Kopeinig, 2008; Rosenbaum and Rubin, 1983). Among the methods that have been used to evaluate impact, Propensity Score Matching (PSM) has been widely used as an important approach to causal treatment effects (Caliendo and Kopeinig, 2008; Mitiku et al., 2017). The PSM approach compares participants with non-participants of the treatment following similar pre-treatment observable characteristics (Ahmed et al., 2019; Caliendo and Kopeinig, 2008). The difference in the outcomes are estimated and attributed as an impact to the intervention.

Propensity Score Matching follows three stages of estimations. First, a logistic or probit regression model (with the dependent variable being participation or non-participation) is estimated yielding propensity scores (Dompreh et al., 2024; Dam Lam et al., 2022; Kemeze et al., 2018). In this study, the category of dependent variables is 1 = farmers benefitting from extension service from local extension providers and 0 being farmers not benefitting from extension service from local extension providers (nor involved in other extension programmes).

The next stage involves matching the propensity scores using different matching methods based on how the distance of the beneficiaries are treated (Ahmed et al., 2019; Apiors and Suzuki, 2018). In this study, we utilize the radius caliper, nearness neighbor and Kernel matching techniques, and then make a choice of which method gives the best estimate. In PSM estimations, two main treatment effects are estimated: Average Treatment Effects (ATE) and Average Treatment Effects on the Treated (ATT) (Rosenbaum and Rubin, 1983; Caliendo and Kopeinig, 2008; Ran et al., 2023). ATE is expressed as in Equation 1.

$$\tau ATE = E(\tau) = E\left[Y(1) - Y(0)\right]. \tag{1}$$

This equation can however not be estimated because both Y(1) and Y(0) cannot be observed at the simultaneously. What is observed is the following (see Equation 2):

$$Yi = Yi\left(Ki = 1\right) + \left(1 - Ki\right)Yi\left(0\right). \tag{2}$$

where $K = 1$ denotes the ith household benefitting from extension service under the project and $K = 0$ denotes when the ith household is not a beneficiary of the intervention (see Equation 3). It is further specified as;

$$\begin{aligned} ATE = P\left[E\left(Yi\left(1\right)/Ki = 1\right) + E\left(Yi\left(0\right)/Ki = 1\right)\right] \\ +\left(1 - P\right)\left[E\left(Yi\left(0\right)/Ki = 0\right) - E\left(Yi\left(0\right)/Ki = 0\right)\right]. \end{aligned} \tag{3}$$

where P is the probability to benefitting from the intervention. This function is estimated based on the hypothesis that the counterfactual of beneficiaries s if they had not benefitted can be estimated from that of non-beneficiaries (Dompreh et al., 2021).

ATE estimates are very good estimate for checking causality, however it provides a general estimation of impact. ATT may be relevant for policy-specify decision making (see Equation 4). We utilize the ATT estimation because it measures the effect of participation for the beneficiaries compared to ATE which estimates for the general population (Alemu and Tolossa, 2022; Dompreh et al., 2024). It is estimated as;

$$\begin{aligned} & ATT = E\{Yi(1) - Yi(0)/k = 1)\} \\ & = E\left[E\left\{Yi\left(1\right) - Yi\left(0\right)/k = 1), p\left(X\right)\right\}\right] \\ & = E\left[E\left\{Yi\left(1\right)/k = 1, p\left(X\right)\right\} - E\left\{Yi\left(1\right)/k = 0, p\left(X\right)\right\}/k = 1)\right] \end{aligned} \tag{4}$$

where X is a set of matching variables.

Finally, a sensitivity analysis is conducted to check the level at which unobservables could affect the outcome of the intervention. This is because PSM is unable to properly control for the biases due to unobservables but only for observable characteristics. We utilize the Rosenbaum Bounds sensitivity analysis to measure the gamma level at which the outcome of the intervention changes due to unobservable characteristics (Caliendo and Kopeinig, 2008; Khan et al., 2022).

For the PSM estimation, we used STATA version 18 and used MS Excel for other descriptive statistics such as bar charts. The results are reported in Section 3.

3 Results

3.1 Descriptive statistics of farmer characteristics

The results shows that most of the aquaculture farmers interviewed were mostly young adult farmers who can basically read or write (Table 3). This observation is quite good for the sustainability of extension systems because it may be easier for them to understand complex technologies and, also be able to share the knowledge gained with colleague farmers. Also, it is observed that the average aquaculture farmer is male (Table 3). On average, a typical aquaculture farmer is married and lives in a household consisting of 5 members (Table 3), which extends the possibility of receiving household labor support on farms.

Figure 2 illustrates the differences between beneficiary and non-beneficiary aquaculture farmers in their access to new knowledge for aquaculture production. These variables are measured as dummy variables, where 1 indicates access (Yes) and 0 indicates no access

TABLE 3 Descriptive statistics of farmer characteristics.

Household characteristics	Measure	Mean (combined)	Mean	
			Beneficiaries	Control
Age	Number (years)	37.82	37.50	38.54
Educational status	Number of years	3.68	3.70	3.62
Marital status	1 = Married	0.99	0.97	0.99
Household members	Number	4.56	4.65	4.38
Household head status	0 = Household head	0.02	0.03	0.02
Gender	0 = Household head	0.012	0.01	0.01

(No). The access channels include contacting an extension agent, receiving messages via mobile devices, participating in knowledge-sharing events, and attending training workshops. The findings reveal that beneficiaries aquaculture farmers demonstrate higher engagement across all access channels compared to non-beneficiaries. Specifically, 38 percent of beneficiaries participated in training workshops, while only 3 percent of non-beneficiaries accessed information through this medium. Additionally, 37 percent of beneficiaries received information via mobile devices, whereas none of the non-beneficiaries reported utilizing this mode of access. Regarding contact with extension agents, 27 percent of beneficiaries and only 2 percent of non-beneficiaries received information through this channel. These results suggest that the involvement of local extension agents in a decentralized extension system may have substantially enhanced access to knowledge, as evidenced by the notable differences between beneficiaries and non-beneficiaries.

Figure 3 shows the proportion of beneficiaries and non-beneficiary (control) farmers who adopted various better management practices. The data indicates that the most widely adopted practice is fish cleaning after harvesting, with 85 percent of beneficiaries and 81 percent of non-beneficiaries engaging in this practice. However, there are significant differences in the adoption of other better management practices between beneficiaries and non-beneficiaries. For instance, pond dike construction, fish feeding (more than once), fish growth monitoring, black soil removal were adopted by, 32, 32, 31 and 17% of beneficiaries, respectively, compared to only 17, 15, 11, and 6% of non-beneficiaries.

The least adopted better management practice among aquaculture farmers is water quality monitoring. The data shows that beneficiary aquaculture farmers adopted better management practices compared to non-beneficiary farmers. This intimates the potential effect of exposure to local extension agents and other production support, to improved access to improved production practices, which could enhance productivity and household incomes.

3.2 Descriptive statistics of food security status of aquaculture farmers

Figure 4 illustrates the different comparisons between beneficiary farmers and control farmers on food security measures used in this study. In terms of FCS, beneficiary farmers (81.53 points) of the extension programme obtained nearly double units of what control farmers (44.91 points) recorded. This indicates higher food diversity and nutrition because of the intervention. Regarding HFIAS, higher values indicate lower food security. The results of the HFIAS estimation shows that control farmers recorded higher level of food insecurity perception compared to beneficiary farmers, indicating that extension access results in better access and stability of food security among aquaculture farmers.

Higher HDDS shows higher diversity of food available for the household hence higher nutritional diversity. The results show that on average, beneficiary aquaculture farmers consume 9 food groups per day compared to control farmers who consume 8 food groups. IDDS-Women which shows the different food groups consumed by women (15–49 years) also records the same trend as seen in HDDS estimation. Hence, beneficiary households are able to provide more diversified diets for women in the households compared to control. For fish consumption, beneficiary households consume approximately 1 kg of fish more than non-beneficiary households, which is an indication of the improved yield which makes fish accessible to households regularly. The difference between the means is highly significant (1%) across all the measured food security indicators except for the difference between the HFIAS between farmers (Table 4). Overall, the results show that extension services as extended to these aquaculture farmers leads to better food security outcomes.

3.3 Impact estimation results

The descriptive analysis of the difference between food security outcomes of beneficiary farmers and control farmers shows that extension service beneficiaries have higher food security outcomes compared to non-beneficiaries (see Section 3.2). Even though this finding is insightful, it is difficult to make statistical generalizations because observable and unobservable characteristics may bias the outcomes. In Table 5, we present the PSM estimation results to understand the impact of extension service on aquaculture farmers in Bangladesh (see also Supplementary Table S1 and Supplementary Figure S1 Electronic Material for graph of propensity scores between beneficiaries and control farmers). Out of the different matching methods used (radius caliper, nearness neighbor and kernel matching), the kernel matching estimation proved to be robust. The balancing test using Pseudo R-squared, chi squared probability and mean bias shows that there is good matching between the treated and the control (mean biases are less than 5). This is because mean biases less than or equal to 5 are generally accepted as good matching (Dompreh et al., 2024) (see Table 6).

In terms of Food Consumption Score, the results show that beneficiary farmers recorded higher FCS (36.67 points) more than

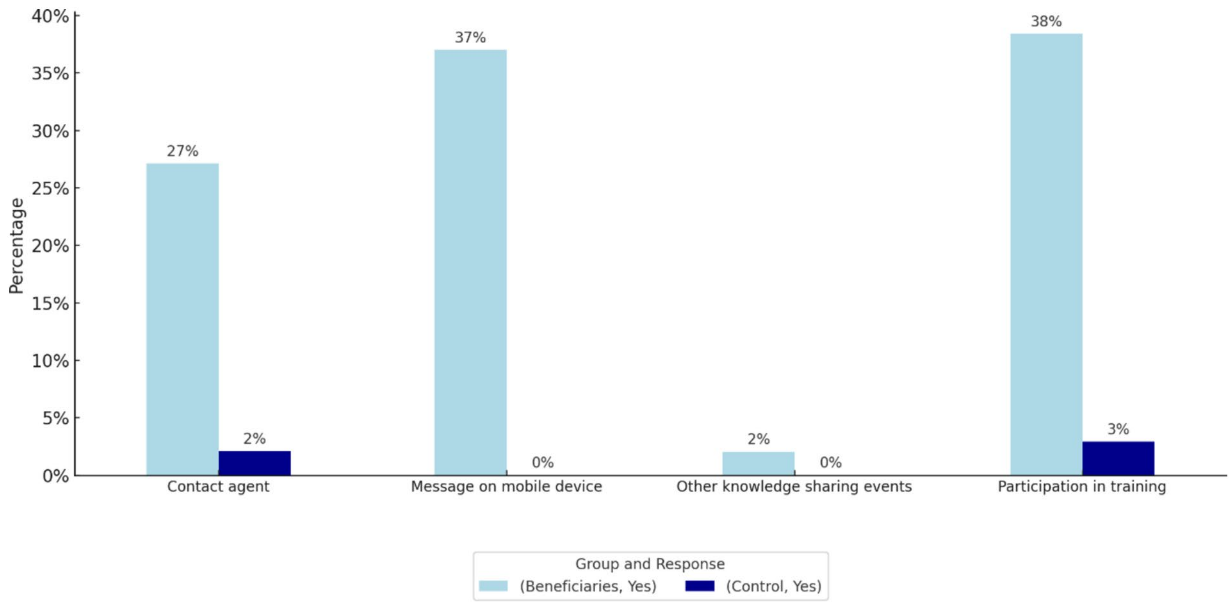

FIGURE 2
Channels of access to extension service.

control farmers (significant at 1%). HFIAS estimations also recorded lower estimates for beneficiaries compared to control although the difference is not statistically significant. Also, PSM estimations for HDDS, IDDS-Women and Fish consumption per week also shows that beneficiary farmers recorded 1.10 (significant at 1%). 1.00 (significant at 1%) and 1.10 (significant at 1%) respectively compared to control farmers. This finding shows that extension service beneficiaries are better off in all indicators compared to control, emphasizing the important role of extension service delivery on livelihoods.

Despite the robustness of this finding, we further check through sensitivity analysis to measure the gamma level at which the results are affected by unobservable characteristics. Although low gamma values imply higher sensitivity to hidden bias (and a very important estimation step), it does not show that the study is poorly implemented neither does higher gamma necessarily authenticate the findings of a study. In this study we recorded gamma values between 2.8 and 6.9 (see Supplementary Table S1 electronic material for more details).

4 Discussion

The findings of this study shows that decentralized extension service has a generally significant impact on the food security of aquaculture farmers and their households. This finding is seen in the highly positive results obtained on Food Consumption Score, HFIAS, HDDS, IDDS-Women and Fish Consumption per week (see Table 5). Similar findings have been found for both aquaculture and other production sectors and contexts (Brenya and Zhu, 2023; Wossen et al., 2017; Dompreh et al., 2024).

Extension is expected to build capacity and enhance access of farmers, and other actors to critical knowledge and technologies to enable desired change in attitude and practices, that eventually leads to increased productivity and incomes and accompanying livelihood outcomes, with the overall goal of rural/community development (Danso-Abbeam et al., 2018; Dompreh et al., 2024). This is confirmed by Brenya and Zhu's (2023) study that found a positive relationship between agriculture extension advisory service and food security. The study also highlights that capital, access to finance and region-specific factors may hinder farmers from benefitting from extension service. In the case of Danso-Abbeam et al. (2018), their findings reaffirmed the positive role agricultural extension plays on the productivity and incomes of farmers in Northern Ghana. In such reinforcing contexts the main emanating mechanisms of change is around increased productivity, food availability for household consumption as well as increased incomes to purchase more diverse food. In some studies, however, negative correlations have been recorded because of the type of extension service delivery, the choice of food security measure and adoption of the technologies extended (Ngome et al., 2019). In the case of Ngome et al. (2019), extension service delivery, which leads to increased incomes, from increased productivity, does not automatically lead to increased food security of households (Ngome et al., 2019). This finding points to the fact that extension service delivery does not necessarily lead to increased food security but that it should be properly tailored to enhance such outcomes. In this case, extension should be properly linked to nutrition knowledge, enhanced market, finance, support services as well as continuous support system for sustained adoption (Kalogiannidis and Syndoukas, 2024; Kumar, 1999). This is confirmed by N'souvi et al. (2021) and Boateng et al. (2022) that aquaculture farmers that receive extension service and other support services are more likely to invest in new technologies that enhances their productivity and incomes, and other socioeconomic outcomes.

In the available plethora of literature on the impact of extension service on aquaculture farmers, four main individual and wider impact trajectories emerge: (i) consistent knowledge transfer; (ii) local relevance; (iii) cost effectiveness; and (iv) community empowerment.

First, through the decentralized system, aquaculture farmers can access knowledge on a sustained basis to enhance their livelihoods.

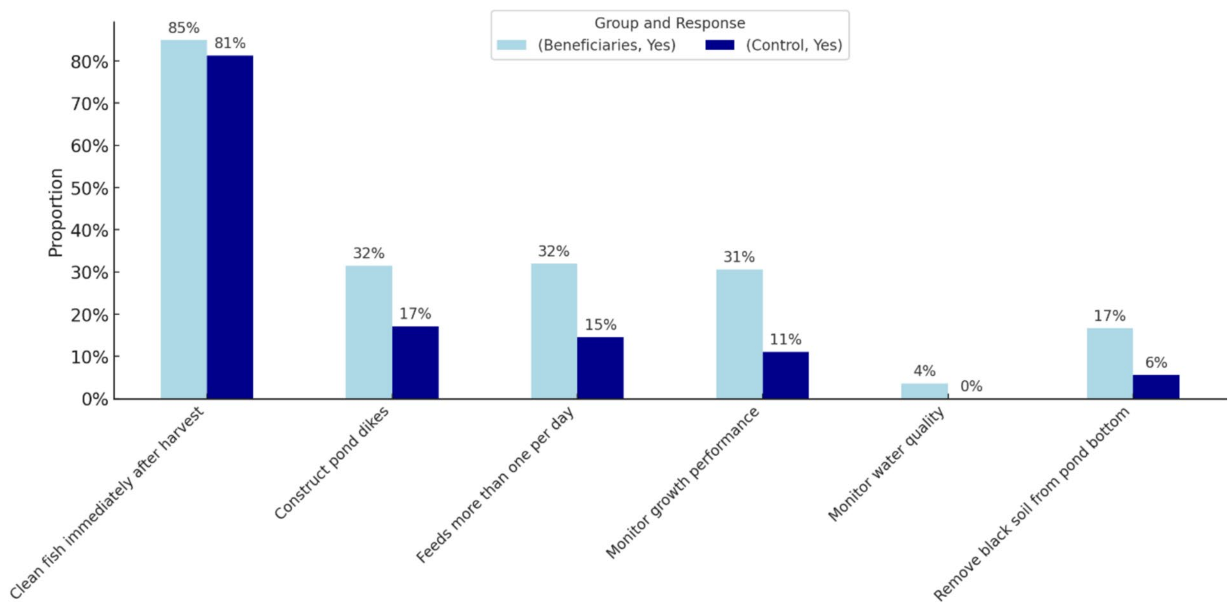

FIGURE 3
Adoption aquaculture practices.

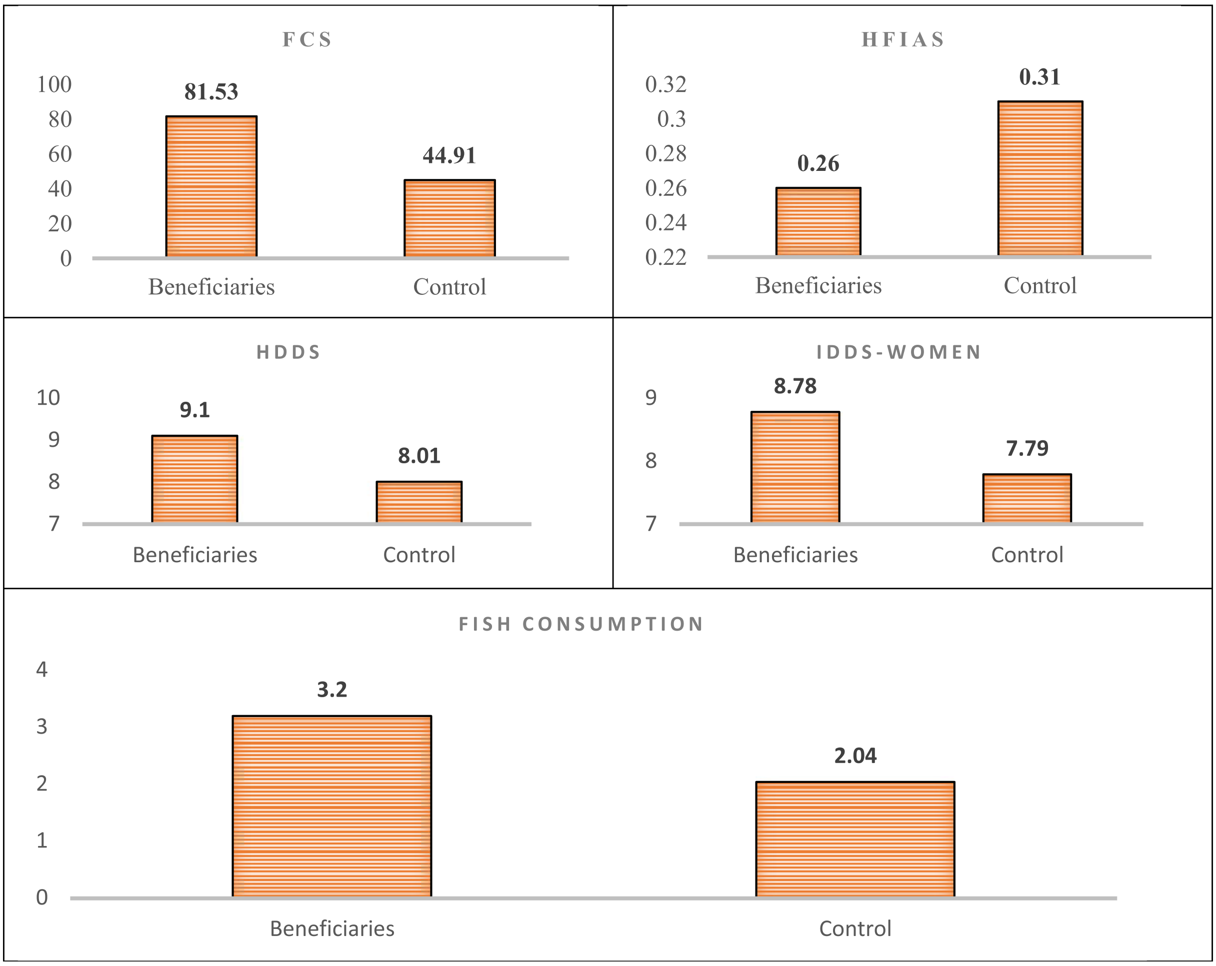

FIGURE 4
Descriptive statistics of food security status of aquaculture farmers.

This is because normally for the top-down approach, the number of extension agents is typically insufficient to meet the demand for extension support among aquaculture producers (Ayisi et al., 2016; Kumar, 1999; Ifeanyi-Obi and Corbon, 2023; Oyegbami, 2018). With the decentralized system such as the ones that makes use of local service providers, aquaculture farmers are much closer to information source and have a better opportunity to clarify information received from extension agents. This stimulates better adoption and enhances productivity, food security and other livelihood outcomes.

Second, the implementation of decentralized extension services ensures relevance of the information disseminated to local context issues (Kumar, 1999). Local extension providers are close to aquaculture farmers and better understand the nuanced local production and livelihood problems of aquaculture farmers (Landini, 2016). In addition, they are much more familiar with local culture and circumstances, and direct dissemination that suits the context. Additionally, local extension providers and farmers are easily able to establish trust. This helps to enhance technology uptake, implement swift production interventions and livelihood improvement.

Third, the implementation of decentralized extension systems ensures cost effectiveness of extension delivery systems on the government side (Nambiro et al., 2006), that releases funds for other productive resources. However, it imposes additional production cost on farmers, which may preclude poor households from benefitting. This means that implementation strategies should consider affordability and flexibility in payment of the service, to avoid entrenching local inequalities (Alex et al., 2000; Joffre et al., 2019).

Finally, the implementation of decentralized extension systems enhances community empowerment. Through the agency of this system, rural communities have greater access to production and other livelihood information through local extension providers (Nambiro et al., 2006; Danso-Abbeam et al., 2018; Kumar, 1999). This is an important block for improved production and livelihood empowerment.

TABLE 4 *T*-test of food security variables.

Variables	Beneficiaries	Means	Difference
FCS	B1 *vs*	81.53(0.66)	−36.62***(1.35)
	B2	44.91(1.35)	
HFIAS	B1	0.26(0.055)	0.047(0.082)
	B2	0.31(0.05)	
HDDS	B1	9.10(0.075)	−1.09***(0.12)
	B2	8.01(0.081)	
IDDS-Women	B1	8.78(0.08)	−0.99***(0.12)
	B2	7.79(0.09)	
Fish consumption	B1	3.20(0.06)	−1.16***(0.093)
	B2	2.04(0.07)	

***significant at 1%; no star: not significant.

4.1 Decentralized extension: one and only golden egg?

In the context of decentralized extension service delivery, multiple literature points to the much higher advantage of decentralized extension to the common top-down centralized approach (Allahyari, 2019; Nambiro et al., 2006; Alex et al., 2000; Hörner et al., 2019). Nambiro et al. (2006) found that in areas with much more decentralized extension service, farmers showed improved awareness of extension channels resulting in improved production knowledge, which is a major precursor for livelihood enhancement. Hörner et al., 2019, using a Randomized Control trial found a positive relationship between decentralized extension service delivery and technology uptake. In such instances, affordable options and the income of farmers were seen to have a major impact on access (Nambiro et al., 2006). This suggests that for such pluralistic systems to work, there is the need for much more synergies between local extension providers, and developing a strong institutional framework that guides operations, reduce negative competition and encourage synergies between groups and providers (Kumar, 1999).

Despite the positive findings, it should not be misunderstood as a criticism of centralized extension systems but also to realize the different roles of different extension delivery approaches on livelihoods. For example, approaches that benefit from economies of scale, provide support for broader national or regional level dissemination strategies or necessitate higher technical capacity could be managed at the top level while the technology is disseminated to farmers at the grassroots. Hence, it is imperative to synergize these approaches to deconcentrate extension, decrease cost and better target aquaculture farmers (Allahyari, 2019). In addition, public-private partnerships offer a favorable opportunity for increasing the effectiveness of extension services delivery. Such partnerships can take advantage of the wider reach and resources of the public sector with the technology, speed, and technical expertise often found in the private sector. As projects take advantage of these two systems, it can enhance the transfer of improved knowledge and technical capacity to aquaculture farmers (Ayisi et al., 2016), which could lead to

TABLE 5 Propensity score matching estimation results between beneficiary and control aquaculture farmers.

Impact variables	Treatment effect (ATT)	Balancing test			Rosenbaum bounds gamma	Remarks
		Ps R2	Pchi2	Mean bias		
FCS	36.67***(1.62)	0.001	0.977	2.3	-	Good matching
HFIAS	−0.018(0.062)	0.001	0.910	3.1	5.6	Good matching
HDDS	1.10***(0.10)	0.001	0.910	3.1	2.8	Good matching
IDDS-Women	1.00***(0.11)	0.001	0.910	3.1	2.9	Good matching
Fish consumption	1.10***(0.09)	0.001	0.910	3.1	6.9	Good matching

TABLE 6 Balancing test for beneficiaries and control aquaculture farmers.

	No. Of significant. variables	Pseudo R^2	p-chi square	Mean bias
FCS				
Before matching	2	0.015	0.002	9.1
Radius Caliper (0.1)	1	0.004	0.385	4.9
Nearness neighbor	1	0.002	0.631	3.3
Kernel common trim (0.1)	0	0.001	0.977	2.3
HFIAS				
Before matching	1	0.010	0.033	7.5
Radius Caliper (0.1)	–	–	–	–
Nearness neighbor	1	0.004	0.278	5.6
Kernel common trim	0	0.001	0.910	3.1
HDDS				
Before matching	1	0.053	0.152	18.9
Radius Caliper (0.1)	3	0.005	0.182	5.2
Nearness neighbor	1	0.004	0.278	5.6
Kernel common trim	0	0.001	0.910	3.1
IDDS-Women				
Before matching	1	0.010	0.033	7.5
Radius Caliper (0.1)	3	0.005	0.182	5.8
Nearness neighbor	1	0.004	0.278	5.6
Kernel common trim	0	0.001	0.910	3.1
Fish consumption per week (kg)				
Before matching	1	0.010	0.033	7.5
Radius Caliper (0.1)	3	0.005	0.182	5.8
Nearness neighbor	1	0.004	0.278	5.6
Kernel common trim (0.1)	0	0.001	0.910	3.1

improved productivity, food security and overall livelihood sustainability.

While taking advantage of the benefit of decentralized systems, it is critical to note that decentralized extension approaches have several challenges, which could threaten the advantage of the decentralized approaches. These challenges could include uneven quality of delivery, ineffective coordination, limited capacity of local implementing agents, poor accountability and sustainability.

Firstly, the uneven quality of extension service delivery across different geographies and among different extension agents is an important shortcoming of decentralized extension systems (Okorley et al., 2011). In decentralized systems, where local entities take charge of service delivery, disparities often arise due to variations in resource allocation, capacity, and expertise (Zwane, 2012). This contradictions in the information and capacity building quality can be more challenging in rural zones, where there is limited number and capacity of local extension service delivery agents. In this case, the core objectives of extension interventions, could be defeated owing to the inequitable service delivery to the target beneficiaries (Abed et al., 2020; Zwane, 2012).

Moreover, decentralized extension systems suffer from the challenge of ineffective coordination among the various implementing entities, local agents, and other stakeholders involved in the extension service delivery. Such challenges could result in poor implementation which could lead to duplication of efforts, or even conflicting messages being delivered to farmers (Rahman et al., 2021). These challenges could affect the quality, frequency and the relevance of the information being disseminated to the farmers, which could reduce the impact of the extension service on livelihoods (Rivera and Alex, 2004).

Another key challenge associated with decentralized extension systems is the deficient capacity of local implementing agents and agencies in the target intervention areas. In many cases, these local institutions have limited technical know-how, infrastructure, and funds to deliver at the level of efficiency and quality that is required (Zalengera et al., 2020). This gap in capacity needs could require additional resources to enhance the capacity of implementing agents and other stakeholders. This could reflect in extra time requirements as well as costs. Additionally, extra effort is required to effectively monitoring and support the implementing agents to ensure that information and capacity building interventions are delivered to the best quality as expected (Kalbar and Lokhande, 2023).

Furthermore, there is the difficulty in ensuring accountability (Farazmand et al., 2022). This is primarily because when the delivery of extension is distributed across different extension agents and stakeholders, maintaining supervision and ensuring effective use of resources becomes difficult, when no robust management and control structures have been put in place. Decentralized extension delivery systems can be disposed to inefficient resource use and corruption, which can negatively affect the effective delivery of extension services. Such inefficiencies could impede the scaling of technologies or new production approaches due to distrust in the governance system of interventions (Maulu et al., 2021).

Finally, challenges related to the sustainability of extension delivery conducted through decentralized systems must be addressed since most of decentralized extension systems are based on projects (Abed et al., 2020). Many decentralized extension programs rely on external funding or specific project cycles, which can create uncertainty about the continuity of services (Mohammadzadeh et al., 2017; Allahyari, 2019; Antwi-Agyei and Stringer, 2021). After the conclusion of projects that utilize decentralized models, there are often high possibilities of extension services ceasing, which implies that farmers will lose the support needed to enhance their production and other value chain activities. This abrogates the gains made in enhancing productivity and livelihoods (Allahyari, 2019).

Despite these challenges, decentralized extension service systems are critical for enhancing the efficiency, and reach of extension services (Abed et al., 2020). By bringing critical information and technologies closer to aquaculture farmers, decentralized extension systems can work to meet the specific local needs of farmers. However, to realize this possibility, there is a need for strategic planning, and the establishment of effective structures to ensure that local agents and other implementing stakeholders are well-equipped to effectively extend knowledge, and resources to aquaculture farmers and other value chain actors (Zwane, 2012). To ensure effective decentralized extension services, there is the need to ensure accountability, improved coordination, and securing long-term funding and institutional support to sustain the benefits of decentralized extension services beyond the lifespan of individual projects.

5 Conclusion

Extension service is a tool for rural development (Maulu et al., 2021; Kumar, 1999). It offers an important precursor to improve productivity, incomes and food security. To meet this objective of rural development and livelihood enhancement of farmers, extension programme development should be holistic, and plural to unearth the improved productivity outcomes, incomes, food security and other accompanying socioeconomic impacts (Danso-Abbeam et al., 2018; Abhijeet et al., 2023). However, since decentralized systems are mostly project-based, there is the need to examine how public expenditure could be directed to decentralized systems and whether it can create change as have been seen in the study results, in order not to create a one-size fits all narrative. This should include appropriate support systems and complementary services such as market information systems, financing and input support. This will help contribute to the achievement of the Sustainable Development Goals such as Zero hunger (2), no poverty (SDG 1) and Sustainable cities and communities (SDG 11).

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found at: Harvard Dataverse in the link: https://doi.org/10.7910/DVN/W0SUCH.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent was obtained from the [patients/ participants OR patients/participants legal guardian/next of kin] to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

ED: Formal analysis, Methodology, Software, Visualization, Writing – original draft. TM: Methodology, Writing – review & editing. DL: Writing – review & editing. M-e-JK: Writing – review & editing. RD: Writing – review & editing. CR: Conceptualization, Supervision, 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.

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2024.1499081/full#supplementary-material

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