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Measuring the determinants of women's empowerment in agricultural index in Bangladesh: application of the structural equation modeling approach

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The study investigates the determinants of women's empowerment utilizing data from the Bangladesh Integrated Household Survey 2018, specifically through the construction of the Women's Empowerment in Agriculture Index. Using structural equation modeling, it assesses how various indicators such as decision-making, freedom of mobility, access to agricultural extension services, group membership, and birth control decisions contribute to women's empowerment outcomes. This index is based on decision-making regarding production, resources, income, leadership, time use, and gender parity sub-index. The study employs structural equation modeling to explore the association among key indicators of women's empowerment, including decision-making, freedom of mobility, access to agricultural extension services, group membership, and birth control decisions. Our findings reveal that access to agricultural extension services, freedom of mobility, group membership, birth control decisions, and decision-making all exert significant direct effects on women's empowerment in Bangladesh. The Women's Empowerment in Agriculture Index itself is also significantly associated with these indicators, highlighting its role as a comprehensive measure. These results suggest that agricultural extension services can serve as a critical pathway to enhancing women's empowerment. The research provides valuable insights for policymakers, donor agencies, academics, and extension workers to effectively allocate resources aimed at advancing women's empowerment in developing countries like Bangladesh.

KEYWORDS

women's empowerment, structural equation modeling, Women's Empowerment in Agriculture Index, determinants, Bangladesh

1 Introduction

Sustainable societal development depends on empowered women (Mason and King, 2001). Achieving gender equality and women's empowerment is essential for global poverty alleviation and economic growth. Women's empowerment entails equipping women with the tools for economic independence, self-sufficiency, and active participation in diverse development initiatives (Kapila et al., 2016). In development economics, empowerment is

defined as enhancing individuals' capacity to make strategic life decisions, particularly where autonomy was previously limited, a definition that remains important amid varied and contested interpretations of empowerment (Gele et al., 2020; Kabeer, 2001). Policy formulation and implementation for women in developing countries like Bangladesh often face challenges due to an insufficient understanding of women's unique issues (Chakrabarti and Biswas, 2012). Effectively addressing the gender gap and supporting women requires a clear grasp of the underlying dynamics. Studies link the gender gap closely to factors influencing women's participation and empowerment (Sell and Minot, 2018; Manfre et al., 2013; OECD, 2015). Beyond policy gaps, cultural norms, gender inequality, and limited resource access also hinder progress. Understanding these diverse factors is crucial for promoting gender equality and economic development. Educated and economically empowered women contribute actively to their development and their families' development, positively impacting education and health outcomes (DFID, 2007; Duflo, 2012; Maertens and Verhofstadt, 2013; Quisumbing and Maluccio, 2011).

The absence of a standardized instrument presents significant challenges in accurately assessing and comparing women's empowerment in agriculture across different regions and contexts. Efforts are ongoing to develop comprehensive tools that can capture the diverse dimensions of women's empowerment in this sector. Existing gender equality indices often overlook agricultural settings, failing to include indicators that reveal gender disparities in rural and farming communities (Kishor and Subaiya, 2008; Malhotra and Schuler, 2005). This gap highlights the pressing need for a specialized tool to evaluate and monitor the impact of agricultural interventions on women's empowerment. The Women's Empowerment in Agriculture Index (WEAI) is the first standardized measure designed specifically for this purpose. It evaluates empowerment across five key domains: production, income, access to and control over resources, leadership, and time use. Multi-dimensional composite indicators are commonly used to assess women's empowerment (Nkwake et al., 2017). Ibrahim and Alkire (2007), for example, developed internationally comparable indicators to measure empowerment at individual, community, and national levels across sectors such as justice, politics, service delivery, and markets. Similarly, the Hunger Project's women's empowerment index captures progress in areas such as agency, income, leadership, resources, and time (Guanabara et al., 2015). In 2012, the Feed the Future initiative began measuring women's agency and inclusion in agriculture, with Alkire et al. (2013) assessing women's engagement across domains such as decision-making in agricultural production, control over productive resources and income, community leadership, and time allocation. To fully understand empowerment, integrating qualitative components into research is valuable, as it allows for a deeper exploration of empowerment's complex and context-specific dimensions (Chung et al., 2013).

Achieving the Sustainable Development Goals (SDGs) requires a comprehensive understanding of the multifaceted nature of women's empowerment and the interconnections among its various dimensions. Indicators play a pivotal role in shaping policy priorities and resource allocation. For example, Malhotra and Mehra (1999) highlighted the disproportionate focus on reproductive health in empowerment metrics, which has significantly influenced the priorities of multilateral agencies, national governments, and non-governmental organizations. While important, this emphasis has sometimes come at the expense of other vital dimensions such as decision-making power and economic agency. To ensure a more balanced and effective approach, it is essential to develop precise and contextually grounded indicators that capture the full spectrum of women's empowerment. These indicators should distinguish between the availability of opportunities and a woman's actual agency to utilize them (Malhotra and Mehra, 1999). Such a nuanced understanding enables policymakers and organizations to design targeted interventions that address the diverse needs, constraints, and capabilities of women across different settings.

While several studies have explored women's empowerment (Quisumbing et al., 2021), significant gaps remain in the literature concerning the diverse factors that influence empowerment, such as access to productive capital, decision-making authority, leadership roles, voting rights, time allocation, and mobility. In particular, critical elements like access to agricultural extension services, autonomy in birth-control decision-making, and freedom of mobility have been under-studied and are frequently overlooked. Despite growing global emphasis on women's empowerment in development discourse (Ferrant and Thim, 2019; Huis et al., 2017; Kabeer, 1999), there is a pressing need for empirical analyses that explore the role of these overlooked factors. To address this gap, the present study aims to identify key determinants of women's empowerment in agriculture and examine the interrelationships among these determinants in the context of Bangladesh.

The paper offers a novel exploration of women's empowerment within the context of agricultural transformation in Bangladesh, employing structural equation modeling (SEM) and path analysis. The agricultural transformation is closely linked to women's empowerment, which is shaped by five key shifts. First, improved access to agricultural extension services enhances women's knowledge and productivity (Meinzen-Dick et al., 2011). Second, greater involvement in household decision-making transforms power dynamics within families (Meinzen-Dick et al., 2011; Shefner-Rogers et al., 1998). Third, increased mobility enables women to access markets and essential services more freely (Cislaghi and Heise, 2020; Shefner-Rogers et al., 1998). Fourth, participation in groups promote collective action and resource sharing (Meinzen-Dick et al., 2011; Shefner-Rogers et al., 1998). Finally, autonomy in reproductive health decisions reinforces both personal and economic agency (Shefner-Rogers et al., 1998). Together, these interconnected shifts advance women's roles in agriculture, fostering a more equitable and productive sector through a holistic empowerment framework (Cislaghi and Heise, 2020). The study investigates various empowerment indicators such as decision-making, freedom of mobility, and access to agricultural extension services, utilizing the WEAI as a measurement tool. It addresses gaps in the existing literature by examining the relationships between women's empowerment and under-studied factors like access to productive capital, decision-making power regarding birth control, and freedom of mobility. The study takes a holistic approach, encompassing a variety of variables connected to women's empowerment. While this approach allows for the identification of correlations, it may be unclear in distinguishing between deterministic factors and mediators, potentially undermining causal interpretation in the absence of a strong theoretical foundation to guide variable selection and analysis. The research specifically examines the factors contributing to women's empowerment in agriculture, with a

particular focus on agricultural extension services. Furthermore, the study provides actionable insights for policymakers by highlighting the critical role of agricultural extension services in enhancing women's empowerment in Bangladesh.

The paper is structured into five sections. Following the introduction, Section 2 presents the conceptual framework. Section 3 details the methodological approach, focusing on SEM. Section 4 presents the results and discusses the findings derived from the analysis in Section 5. Finally, Section 6 offers concise conclusions and policy recommendations, highlighting the broader implications of the study, followed by limitations in Section 7.

2 Conceptual framework

The concept of empowerment is multifaceted, making its measurement and analysis challenging (Akter et al., 2017; Ballon, 2018; Basu and Koolwal, 2005; Gupta and Yesudian, 2006; Parkar, 2005). Empowerment measurement involves considering various indicators that are influenced by diverse conditions and factors. Numerous studies across different disciplines have explored women's empowerment in developing countries, focusing on its developmental dimensions and associated outcomes. However, relatively few studies have specifically investigated outcomes such as fertility and contraceptive use. Notable contributions in this area include the work of Gage (1995), Kritz (2000) and Morgan et al. (2002). Other studies have explored domains such as nutrition, child health, and women's well-being, as seen in Gupta and Yesudian (2006), Basu and Koolwal (2005), Mullany et al. (2005), and Ghuman (2003). Yet, only a limited number of studies have comprehensively examined the impact of individual, household, and community-level factors on women's empowerment. Access to resources and participation in decision-making processes are key components of empowerment, directly influencing productivity and intra-household resource distribution, which in turn affect overall productivity levels.

This conceptual framework highlights the interconnected factors influencing women's empowerment within the context of agricultural transformation in Bangladesh. It includes five key dimensions of empowerment: group membership, freedom of mobility, birth control decisions, access to agricultural extension services, and decision-making power. These dimensions are integrated into the framework through the women's empowerment in agriculture, which serves as a composite measure of empowerment. The framework posits that these dimensions collectively contribute to women's empowerment as captured by the WEAI. SEM and path analysis are employed to examine the relationships among these dimensions, enabling researchers to identify causal pathways and understand how interventions such as improving access to agricultural services or enhancing women's mobility can promote gender equality. Figure 1 visualizes these relationships, showing how group membership, access to extension services, decision-making authority, birth control decisions, and mobility freedom are interconnected and contribute to women's empowerment. The freedom of mobility dimension assesses women's ability to move freely within their communities and access essential services (e.g., markets, healthcare, training), indicating their independence and agency. Birth control decisions indicate women's autonomy over family planning and reproductive health, underscoring their control over personal and family life. Access to agricultural extension services equips women with critical information and resources to improve agricultural practices and livelihoods, thereby enhancing economic empowerment and increasing WEAI scores. Decision-making power relates to women's roles in economic activities such as crop production and household expenditures, highlighting their influence in household and agricultural decisions. Overall, the pathways and correlations depicted in the figure provide a roadmap for understanding how these interrelated factors shape women's empowerment in rural Bangladesh.

To derive causal estimates, we employed SEM, integrating a measurement model for latent constructs with a structural model representing hypothesized relationships (Kline, 2016). Latent variables, including decision-making, mobility, group membership, extension access, and birth control autonomy, were mapped to corresponding observed indicators. Path coefficients were used to estimate both direct and indirect effects on the WEAI, while model fit indices such as Root Mean Square Error of Approximation (RMSEA) and Comparative Fit Index (CFI) assessed the robustness of the model. This SEM approach enables causal inference by capturing complex interrelationships among variables and reducing measurement error (Bollen, 1989).

Previous studies (Malapit et al., 2015; Sraboni et al., 2014; Kabeer, 1999) have identified significant gaps in the literature concerning the determinants of women's empowerment. In particular, dimensions such as decision-making power over birth control and freedom of mobility have been under-researched and frequently overlooked. To address this gap, the present study's conceptual framework explicitly incorporates Freedom of mobility and Birth control decisions as two of the five key dimensions of empowerment alongside group membership, access to agricultural extension services, and decision-making power. The framework posits that these dimensions collectively contribute to the WEAI. Freedom of mobility reflects women's ability to navigate their communities and access essential services, including markets, healthcare, and training, serving as a proxy for independence and agency. Birth control decisions, meanwhile, capture control over reproductive choices, which are fundamental to long-term empowerment (Cornwall and Edwards, 2014). By integrating these under-studied dimensions, this study extends the WEAI framework to include broader social and economic determinants of empowerment (Alkire et al., 2013).

The conceptual framework plays a critical role in structuring the study by linking five key dimensions of empowerment: group membership, mobility, birth control decisions, access to agricultural extension services, and decision-making power to the WEAI. This framework not only guides hypothesis testing and the application of SEM but also addresses notable gaps in the literature and enhances policy relevance through a theory-driven analytical approach (Malapit et al., 2015; Kabeer, 1999; Alkire et al., 2013).

The structural model that connects these latent constructs to empowerment outcomes can be represented as follows:

$$\eta = \gamma 1^{*} \zeta_1 + \gamma 2^{*} \zeta_2 + \gamma 3^{*} \zeta_3 + \gamma 4^{*} \zeta_4 + \gamma 5^{*} \zeta_5 + \zeta$$

Where

The five exogenous latent variables are group membership (ζ_1), birth control decisions (ζ_2),

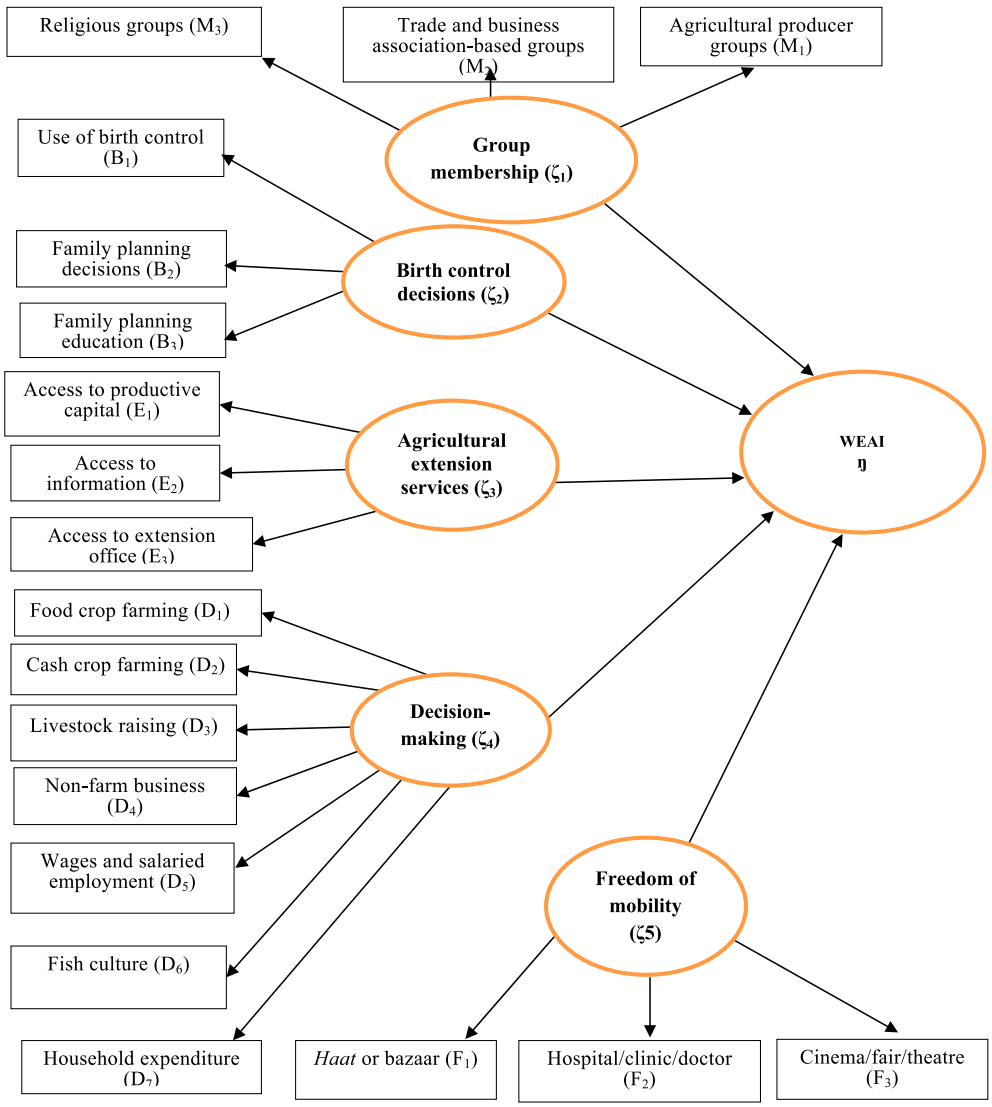

FIGURE 1
Conceptual Framework illustrating the relationship between five dimensions and WEAI.

access to agricultural extension services (ζ_3), decision-making (ζ_4), freedom of mobility (ζ_5).

η is the endogenous latent variable,

ζ are the exogenous latent variables,

γi represents the direct effect coefficient of the latent variable ζi on the latent variable η (WEAI),

ζ denotes the error term capturing unexplained variance.

To test the significance of each latent construct's contribution to women's empowerment, the following hypotheses were formulated.

*H*1: $\gamma 1 = 0$ (Null hypothesis regarding group membership, $\zeta 1$).

*H*2: $\gamma 3 = 0$ (Null hypothesis regarding access to agricultural extension services, $\zeta 3$).

*H*3: $\gamma 4 = 0$ (Null hypothesis regarding decision-making, $\zeta 4$).

*H*4: $\gamma 2 = 0$ (Null hypothesis regarding birth control decisions, $\zeta 2$).

*H*5: $\gamma 5 = 0$ (Null hypothesis regarding freedom of mobility, $\zeta 5$).

These hypotheses assess whether the direct effect of the specified latent variable (ζi) on women's empowerment (η) is statistically different from zero. This study tests five hypotheses concerning women's empowerment in Bangladesh's agricultural sector. Each hypothesis evaluates distinct factors to understand their influence on women's empowerment in agriculture.

3 Methodology

3.1 Data and data sources

Data from the Bangladesh Integrated Household Survey (BIHS) 2018, conducted by the International Food Policy Research Institute (IFPRI), were used in this study. After cleaning the initial dataset of 6,503 respondents, a total final sample of 5,604 agricultural farming households

in rural areas was selected. The IFPRI dataset is publicly available. The study design was reviewed and approved by an institutional review board. All data were collected using the women's empowerment modules designed to measure the WEAI, which includes five established indicators: access to productive capital, resources, income, leadership, and time. In addition to these, the study incorporated several novel indicators: decision-making, freedom of mobility, group membership, birth control decisions, and access to agricultural extension services to capture a broader range of social and economic dimensions that potentially contribute to women's empowerment.

3.2 Model specification

SEM aims to uncover the structural relationships between sets of latent variables and assess how well a conceptual model aligns with collected data (Worthy et al., 2013). Scholars have underscored SEM's significance in elucidating complex relationships and pathways between variables (Bagozzi and Yi, 1988). It provides a robust framework for testing theoretical models and hypotheses, offering deeper insights into individual and societal behaviors. Moreover, SEM serves as a vital tool for evaluating initiatives aimed at promoting gender equality and women's empowerment (Akinyode, 2016). Numerous scholars have applied SEM across diverse contexts (Ab-Rahim et al., 2018; Ballon, 2018; Davcik, 2014; de Carvalho and Chima, 2014; Hasman, 2015; Hoyle, 1995; Hillman and Neustaedter, 2003; Kline, 2013; Pitt et al., 2006; Shimamoto and Gipson, 2019; Teo et al., 2013).

SEM integrates both a measurement model and a structural model. The measurement model establishes the connections between observed variables and latent variables, which are assumed to underlie the observed data. Confirmatory factor analysis within this model assesses how well the observed variables represent the underlying hypothetical constructs. In this study, latent variables such as decision-making (D), freedom of mobility (F), group membership (M), access to agricultural extension services (E), and birth control decisions (B) are each represented by a minimum of three measured variables (indicators), as depicted in Figure 1. The latent variables play a crucial role in defining the WEAI.

Table 1 provides a detailed description of the latent variables and their corresponding indicators. Specifically, within the context of SEM analysis, the objectives are three-fold. First, we identify the observed indicators used to measure the latent variables and assess their contribution to women's empowerment. Second, we derive five latent variables from these indicators. Finally, we construct a model that links the latent variables to the WEAI through a path diagram.

3.3 Construction of WEAI

The WEAI was calculated by using the Alkire–Foster method, which focuses on five interconnected multidimensional domains. It includes two sub-indices, the first of which measures the proportion of women who are empowered across the following domains: time allocation, control over income, access to productive resources, and decision-making authority over those resources (Abebe et al., 2016). In this study, the WEAI domains are used as proxies for women's empowerment and serve as the dependent variable. Table 2 lists these domains, with particular emphasis on time allocation, control over income, access to productive resources, and decision-making authority. These domains are critical indicators of women's empowerment in the agriculture sector.

3.4 Analytical techniques of the SEM model

The data were analyzed using STATA 17 statistical software. The SEM consists of two components: the measurement model, which defines the relationships between latent variables and their observed indicators, and the structural model in Equation 1, which specifies the relationships among the latent variables themselves (Jöreskog and Sörbom, 2007; Toma et al., 2018).

The structural model is as follows

$$\eta = B_{\eta} + \Gamma\xi + \zeta \tag{1}$$

Where, η is an internal latent variable; A is an $m^{*}n$ matrix of coefficients of the ξ variables in the structural model; ξ is an external latent variable; B is an $m^{*}m$ matrix of coefficients of the η variables in the structural model; and ζ is an $m^{*}1$ vector of equation errors.

The measurement models for the endogenous and exogenous variables are expressed in Equations 2, 3, respectively:

$$y = \Lambda_{y}\eta + \varepsilon \tag{2}$$

$$x = \Lambda_{x}\zeta + \varepsilon \tag{3}$$

In this model, x and y are observable variables representing external and internal latent variables, respectively. The measurement model allows these observed variables to reflect their respective latent variable. η is a matrix of $m^{*}1$ coefficients that represents the relationships among the latent endogenous variables. Γ is a matrix of $m^{*}1$ coefficients that models the associations between exogenous latent variables and endogenous latent variables. ζ is a $m^{*}1$ vector representing the external latent variables. $\ddot{E}_{x}$ is a $q^{*}n$ matrix of the coefficients of the regression of x on ξ, capturing how the external latest variables influence observable variables. $\ddot{E}_{y}$ is a $p^{*}m$ matrix of coefficients of regression of y on η. Finally, ε is a $p^{*}1$ vector representing measurement errors in y.

To address potential endogeneity between the WEAI and its predictors, we employed SEM, treating the empowerment dimensions as latent variables. This modeling strategy reduces direct overlap between constructs, thereby minimizing measurement bias and improving the accuracy of estimated relationships by explicitly separating the measurement model from the structural component (Kline, 2016). In addition, we conducted robustness checks and ensured careful model specification to control for confounding variables (Bollen, 1989). Together, these strategies mitigate endogeneity concerns and enhance the validity of inferences drawn from the analysis.

3.5 Descriptive statistics

Table 3 provides a detailed description of the indicators associated with the latent variables used in the SEM analysis. The latent variables

10.3389/fsufs.2025.1547804

TABLE 1 Latent and measurement variables.

Latent variables	Code	Definition	Expected sign
Dependent variable			
Women's empowerment in the agricultural index	WEAI	WEAI is constructed based on five domains and 10 indicators (Alkire et al., 2013)	
Independent variables			
Freedom of mobility (F)	F_1	Access to outside of the community (yourself or combined with husband = 1, 0 otherwise)	+
	F_2	*Haat* or bazaar (yourself or combined with husband = 1, 0 otherwise)	+
	F_3	Hospital/clinic/doctor (yourself or combined with husband = 1, 0 otherwise)	+
	F_4	Cinema/fair/theater (yourself or combined with husband = 1, 0 otherwise)	+/−
	F_5	Participation in training (yourself or combined with husband = 1, 0 otherwise)	+
Birth control decisions (B)	B_1	Use of birth control (yourself or combined with husband = 1, 0 otherwise)	+
	B_2	Family planning decisions (myself = 1, 0 otherwise)	+
	B_3	Family planning education (yourself or combined with husband = 1, 0 otherwise)	+/−
Access to agricultural extension services (E)	E_1	Access to productive capital (if yes = 1, 0 otherwise)	+
	E_2	Access to information (if yes = 1, 0 otherwise)	+
	E_3	Access to an extension office (if yes = 1, 0 otherwise)	+
Decision-making (D)	D_1	Food crop farming (if yes = 1, 0 otherwise)	+
	D_2	Cash crop farming (if yes = 1, 0 otherwise)	+
	D_3	Livestock raising (if yes = 1, 0 otherwise)	+
	D_4	Non-farm economic activities (if yes = 1, 0 otherwise)	+
	D_5	Wages and salaried employment (if yes = 1, 0 otherwise)	+
	D_6	Fishing or fish culture (if yes = 1, 0 otherwise)	+
	D_7	Household expenditure (if yes = 1, 0 otherwise)	+
Membership (M)	M_1	Agricultural producer group(s; if yes = 1, 0 otherwise)	+
	M_2	Trade and business association-based group(s; if yes = 1, 0 otherwise)	+
	M_3	Religious group (if yes = 1, 0 otherwise)	+

Each latent variable is associated with a set of manifest (observable) variables. The individual responses to the questionnaire provided the observable variables used in this study.

TABLE 2 List of domains.

Domain	Variables	Variable label
Production	Input in productive decisions	= 1 if inadequate in input in productive decisions
	Autonomy in production	= 1 if inadequate in autonomy in production
Resources	Ownership of assets	= 1 if inadequate in asset ownership
	Purchase, sale, and transfer of assets	= 1 if inadequate in rights over assets
	Access to credit	= 1 if inadequate in access to, and decisions on, credit
Income	Control over income	= 1 if inadequate in control over the use of income
Leadership	Group membership	= 1 if inadequate in group membership
	Speaking in public	= 1 if inadequate in speaking in public
Time	Workload	= 1 if inadequate in workload
	Leisure time	= 1 if inadequate in leisure
Measuring procedure for the WEAI		
5DE	Empowered	_5DE_id = 1 if the individual is empowered by 5DE
5DE score	Empowerment score	_5DE_score ("empowerment score" for non-empowered persons) = 0 if empowered
GPI	GPI_id	= 1 if a woman enjoys gender parity
GPI_gap	GPI_gap	= 0 if woman has gender parity, "gap" if she does not
WEAI		= (0.9 × _5DE) + (0.1 × GPI)

5DE, the five domains of empowerment; GPI, gender parity index.

TABLE 3 Description of different indicators related to the latent variables.

Latent variables	Item	Questions regarding	Yes (%)	No (%)
Decision-making (D)	D_1	Food crop farming	71.54	28.46
	D_2	Cash crop farming	43.40	56.60
	D_3	Livestock raising	80.87	19.13
	D_4	Non-farm economic activities	12.06	87.94
	D_5	Wages and salaried employment	12.38	7.62
	D_6	Fishing or fish culture	10.92	89.08
	D_7	Household expenditure	73.41	26.59
Freedom of mobility (F)	F_1	Access to the outside of the community	32.08	67.92
	F_2	*Haat* or bazaar access	28.57	71.43
	F_3	Hospital/clinic/doctor access	30.25	69.75
	F_4	Cinema/fair/theater access	8.24	91.76
	F_5	Participation in training	10.15	89.85
Access to agricultural extension services (E)	E_1	Access to productive capital	70.99	29.01
	E_2	Access to information	79.12	20.88
	E_3	Access to an extension office	5.89	94.11
Group membership (M)	M_1	Agricultural producer group(s)	8.32	91.68
	M_2	Trade and business association-based groups(s)	91.58	8.42
	M_3	Religious group(s)	63.29	36.71
Birth control decisions (B)	B_1	Use of birth control	77.30	22.70
	B_2	Family planning decisions	74.52	25.48
	B_3	Family planning education	95.16	4.84

include decision-making (D), group membership (M), birth control decisions (B), access to agricultural extension services (E), and freedom of mobility (F). Each latent variable is constructed from binary observed variables, where a value of 1 denotes a positive response.

The latent variable "decision-making" (D) comprises the following observed variables related to decision-making authority: food crop farming (D_1; 71.54%); cash crop farming (D_2; 43.40%); livestock farming (D_3; 80.87%); non-farming activities (D_4; 12.06%); wages and salaried employment (D_5; 12.38%); fish culture (D_6; 10.92%); and household expenditure (D_7; 73.41%). The latent variable "freedom of mobility" (F) is generated based on: free access to outside of the community (F_1; 32.08%); access to *haats* or bazaars (F_2; 28.57%); access to hospitals/clinics/doctors (F_3; 30.25%); access cinemas/fairs/theaters (F_4; 8.24%); and taking part in training (F_1; 10.15%). The latent variable "group membership" was also extracted as a binary response, yes or no, from the BIHS datasets. Which is constructed from membership of agricultural producer groups (M_1; 8.32%); trade and business association-based group(s; M_2; 91.58%); and religious groups (M_3; 63.29%). Access to agricultural extension services (E) was determined based on three (E_1-E_3) binary indicators, such as E_1 = access to production capital through the Department of Agricultural Extension (DAE), livestock extension services, and NGOs (70.99%). E_2 = access to agricultural productive information, this indicator could include how farmers receive information on best practices, new technologies, and market prices (79.12%), and E_3 = access to the extension office. This measures whether farmers can reach out to extension offices or whether extension agents visit them. It also includes contact methods such as phone calls and access to agricultural support or services provided by non-governmental organizations (NGOs; 5.89%). The latent variable "birth control decisions" (B) is based on three observed variables: making independent decisions regarding birth control use (B_1; 77.30%); family planning decisions (B_2; 74.52%); and receiving family planning education (B_3; 95.16%).

4 Results

4.1 Correlation coefficient for women's empowerment

Table 4 shows the correlation coefficients between the WEAI and its key indicators: access to agricultural extension services, freedom of mobility, group membership, birth control decisions, and decision-making. These coefficients indicate the strength and direction of the relationships between each indicator and the WEAI. The statistically significant correlations offer valuable insights into the factors influencing women's empowerment within the agriculture sector in Bangladesh. Notably, the association between access to extension services and the WEAI appears to be influenced by other contributing factors, as only 5% of women reported direct access to extension offices. We discussed how other components, such as access to agricultural information and productive capital, also contribute to women's empowerment, providing a more comprehensive understanding of these dynamics.

The WEAI shows significant correlations with all empowerment indicators except freedom of mobility, with correlation coefficients ranging from 0.164 to 0.921. Particularly strong correlations are observed between the WEAI and group membership (0.921), as well as with access to extension services (0.858), highlighting the critical role these factors play in advancing women's empowerment in agriculture. Women's groups in Bangladesh contribute to empowerment by fostering social capital, enhancing collective bargaining power, improving access to resources, and facilitating knowledge exchange. These dynamics are particularly impactful within the broader context of agricultural transformation. Overall, the results presented in Table 4 confirm that the WEAI effectively captures multiple dimensions of women's empowerment in agriculture, validating its role as a comprehensive measure.

4.2 SEM path diagram

A path diagram in a SEM visually represents the relationships among latent and observed variables, including their association links. In Figure 2, single-headed arrows indicate regression paths. The regression coefficients for the latent variable decision-making (D) are as follows: $D_1 = 1.000$, $D_2 = 0.622$, $D_3 = 0.417$, $D_4 = 0.112$, $D_6 = 0.057$, and $D_7 = 2.404$ ($Pr > |z| = 0.000$). These results suggest that decisions related to food and cash crop production, as well as household spending, significantly contribute to the overall decision-making construct. Specifically, the coefficients imply that decision-making (D) is positively associated with food crop production decisions (D_1) and cash crop production decisions (D2), and household expenditure decisions (D_3). Notably, the substantial coefficient for D_7 indicates that women who have greater control over healthcare decisions tend to play a significantly stronger role in overall decision-making.

The regression coefficients for group membership (M) are $M_1 = 1.000$, $M_2 = 2.497$, and $M_3 = 3.753$ ($Pr > |z| = 0.000$). These values indicate that participation in agricultural producer groups, trade and business association-based groups, and religious groups is positively associated with increased group membership (or leadership), which in turn enhances women's empowerment. Specifically, membership in trade and business association-based groups significantly contributes to a higher WEAI score by enhancing women's access to resources, market information, and economic opportunities. Such group involvement fosters collective bargaining power, provides training opportunities, and improves financial management skills, thereby boosting women's decision-making power and economic participation in agriculture. Similarly, the regression coefficients for birth control decisions (B) are $B_1 = 1.000$, $B_2 = 0.975$, and $B_3 = 0.019$ ($Pr > |z| = 0.000$). These results suggest that women's autonomy in birth control use, family planning decisions, and especially access to family planning education are significantly associated with empowerment, as captured by the WEAI. Furthermore, the regression coefficients for freedom of mobility are $F_1 = 1.000$, $F_2 = 0.983$, and $F_3 = 0.993$ ($Pr > |z| = 0.000$). This demonstrates a strong positive relationship between freedom of mobility and access to markets (*haats*/bazars), healthcare facilities (hospitals/clinics/doctors), recreational venues (cinemas/ fairs/ theaters), and participation in training programs.

The regression coefficients indicate that E_1 is positively correlated with the availability of agricultural extension services. This indicates that women who are exposed to agricultural extension facilities are more likely to acquire enhanced knowledge and skills related to agriculture, which can lead to increased agricultural productivity and income. The coefficient for E_2 is 0.40, suggesting that women with greater access to credit tend to have better access to agricultural extension services, highlighting the important role of financial resources in facilitating access to these services. Conversely, the relatively small coefficient for E_{11} indicates that other factors, such as proximity to extension centers and cultural barriers, may also influence women's ability to access agricultural extension services. Overall, the coefficients indicate a positive association between access to agricultural extension services and related factors, with the availability of extension services showing the strongest link. These results suggest the potential of enhancing extension services as a key strategy for improving women's empowerment in agriculture.

The regression coefficients for the WEAI are as follows: D = 0.0065; $F = -0.0017$; E = 0.0232; M = 0.0021; and B = 0.0116

TABLE 4 Correlation between women's empowerment indicators and the WEAI.

Latent variables	WEAI	Extension services	Freedom of mobility	Group membership	Birth control decisions	Decision-making
WEAI	1					
Extension services	0.858***	1				
	(0.000)					
Freedom of mobility	−0.024	−0.272***	1			
	(0.974)	(0.000)				
Group membership	0.921***	0.929***	−0.150***	1		
	(0.000)	(0.000)	(0.000)			
Birth control decisions	0.164***	0.516***	−0.145***	0.318***	1	
	(0.000)	(0.000)	(0.000)	(0.000)		
Decision-making	0.238***	0.562***	−0.163***	0.375***	0.942***	1
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	

***Indicates significance at the 1% level.

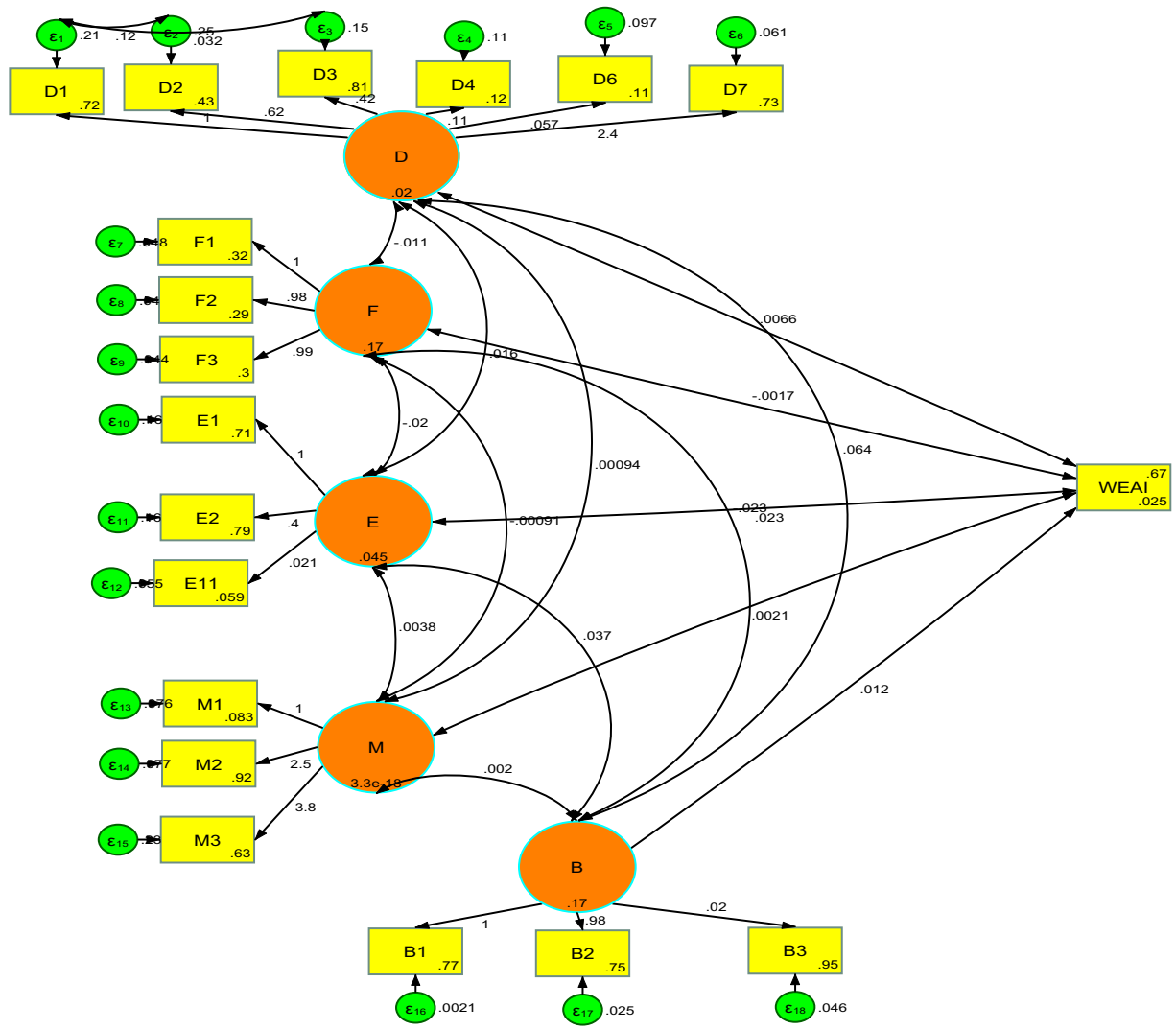

FIGURE 2
Path diagram of the SEM. B, birth control decisions; E, access to agricultural extension services; M, group membership; D, decision-making (regarding production and household expenditure); F, freedom of mobility; and the paper employs SEM and path analysis to examine associations among key indicators of women's empowerment, identifying significant direct effects through standardized path coefficients. While these methods reveal complex interrelations and deepen understanding of empowerment dimensions, we acknowledge that causality cannot be definitively inferred due to the cross-sectional nature of the data and the model's reliance on predefined structures (Alwin and Hauser, 1975; Kline, 2016). The analysis is grounded in a conceptual framework that underpins variable selection and hypothesis testing; however, the study emphasizes that its findings represent associations rather than deterministic causality, similar to Bollen and Pearl (2013) and Malapit et al. (2015). Figure 2 highlights key policy implications derived from the SEM path diagram, underscoring the importance of enhancing women's access to agricultural extension services, decision-making power, mobility, and group membership, each significantly contributing to empowerment, as supported by Kline (2016). The negative association between birth control decisions and the WEAI suggests the need for a nuanced policy response that ensures reproductive rights while promoting empowerment. A holistic, multi-dimensional strategy is essential to effectively addressing intersecting empowerment factors, in alignment with Bollen (1989).

(Pr > |z| = 0.000). Therefore, all variables (decision-making, freedom of mobility, access to agricultural extension services, group membership, and birth control decisions) are positively and significantly associated with the WEAI at the 1% level. The overall likelihood-ratio (LR) test chi-square value is 3,628.24 (Pr > |z| = 0.000), confirming the model's goodness of fit. However, the SEM coefficients (see Table 5) indicate that the WEAI is positively influenced by decision-making, freedom of mobility, access to agricultural extension services, and group membership. Interestingly, the impact of birth control decisions on the WEAI is significantly negative suggests that limited autonomy in reproductive choices reflects broader gender inequalities and constraints in women's empowerment within agricultural households.

4.3 Overall hypothesis test

Table 5 provides the path coefficients and hypotheses regarding the associations between various indicators of women's empowerment and the WEAI. The WEAI shows significant positive relationships with group membership ($p < 0.01$), decision-making ($p < 0.01$), freedom of mobility ($p < 0.01$), and access to agricultural extension services

($p < 0.01$). Conversely, it shows a significant negative relationship with birth control decisions ($p < 0.01$). These results underscore that while the WEAI captures key dimensions of empowerment, it does not encompass all potential variables influencing women's empowerment.

Table 5 shows that freedom of mobility, access to agricultural extension services, and group membership all significantly influence the WEAI among women ($p < 0.001$). All five null hypotheses are rejected at the 1% significance level, indicating statistically significant associations between the WEAI and each of the five empowerment indicators: group membership, access to agricultural extension services, decision-making, freedom of mobility, and birth control decisions. Increasing women's access to extension services can enhance their WEAI scores by implementing women-specific programs, training female extension workers, and ensuring gender-sensitive policies. Addressing mobility and time constraints through flexible training schedules and mobile technology for information dissemination has proven effective. Additionally, engaging men to support women's participation, forming women's groups, and fostering partnerships with NGOs and the private sector create a supportive environment for empowerment. Regular assessments and feedback mechanisms have helped tailor extension services to women's needs, thereby improving their empowerment in agriculture and contributing to higher WEAI scores. Women's participation in agricultural extension services can reduce poverty, improve food security, and promote better family health and nutrition. Although a relatively low percentage of women participate in agricultural extension services, the increasing number of female extension officers has improved accessibility for female farmers. Additionally, the family-centered approach and the resourcefulness of women farmers engaging with extension officers have contributed to more effective outreach and service delivery.

4.4 Model fit

To assess the adequacy of the structural model and how well the dataset fits, several indicators are computed using SEM. A key criterion for overall model fit in SEM is the chi-square test statistic. According to Bagozzi and Yi (1988), a p-value greater than 0.05 and a normalized chi-square value (χ^2/df) below 3 are typically considered acceptable thresholds. In this case, the chi-square value is 3628.24 with $p < 0.001$, indicating a significant lack of fit. The reported Prob > chi^2 value = 0.000, whereas values of 0.01, 0.05, and 0.08 typically indicate excellent, good, and mediocre fit, respectively (Bollen, 1989; Browne and Cudeck, 1992).

The RMSEA is currently the most widely used measure for assessing model fit. The standardized root mean square residual (SRMR) offers an absolute measure of fit by representing the standardized difference between the observed and predicted correlations. SRMR values range from 0.00 to 1.00, with values below 0.08 generally indicating a good fit (Bentler and Chou, 1987). To evaluate comparative model fit, the Akaike information criterion (AIC) is used, where a lower AIC value indicates better fit, making the model with the lowest AIC the preferred choice. Another incremental fit index, the Tucker-Lewis index (TLI), was also assessed. TLI values range from 0.00 to 1.00, with higher values indicating better fit (Cangur and Ercan, 2015; Ding et al., 2016; Schermelleh-Engel et al., 2003). The comparative fit index (CFI), which evaluates how the data fit the hypothesized model, was also analyzed. For the current model (details in Table 6), the LR χ^2 test is significant, RMSEA is below 0.08, CFI and TLI values are close to 1, and SRMR is near 0. Together, these indicators suggest that the model provides valuable insights into strategies for women's empowerment, particularly through increased access to productive capital, decision-making power, leadership, voting rights, and freedom of mobility.

The LR test produces a significant p-value of 0.000, indicating that the model fits the data well. The RMSEA value of 0.068 falls within the recommended range of 0.00 to 0.10, suggesting a reasonable fit. The CFI and TLI values, at 0.911 and 0.888, respectively, are close to 1.00, indicating a good model fit. Additionally, the SRMR value of 0.069 lies within the acceptable range. The CD of 0.999 indicates that the model explains a very high proportion of the variance in the data. Overall, these fit indicators demonstrate strong overall goodness of fit, suggesting that the SEM effectively captures the relationships among variables related to women's empowerment in agriculture in Bangladesh.

4.5 Standardized total and direct effect on the WEAI

Table 7 provides the standardized direct effects of each index on the WEAI, as derived from the latent variable in the SEM. All five indices -freedom of mobility, access to agricultural extension services, group membership, birth control decisions, and decision-making- show a significant direct effect on the WEAI ($p < 0.1$). The magnitude of each variables effect corresponds to its coefficient value and p-value.

The coefficient for access to agricultural extension services is highly significant at the 1% level (0.594***), indicating a strong positive effect on women's empowerment. Similarly, freedom of mobility, group membership, and decision-making also exhibit positive and significant effects on the WEAI, underscoring their vital roles in enhancing women's empowerment. These findings highlight the direct relationships between various empowerment indicators and the WEAI, emphasizing the critical importance of factors such as

TABLE 5 Path coefficients and hypotheses.

Null hypothesis	Coefficient	t-value	Pr > t
H1: No association between the WEAI and group membership	4.669***	31.42	0.000
H2: No association between the WEAI and access to agricultural extension services	0.594***	41.24	0.000
H3: No association between the WEAI and decision-making	0.054***	4.52	0.000
H4: No association between the WEAI and freedom of mobility	0.070***	39.02	0.000
H5: No association between the WEAI and birth control decisions	−0.127***	−26.71	0.000

***Indicates significance at the 1% level.

TABLE 6 Goodness of fit indicators.

Indicators	Estimated value	Recommended value	Sources
LR test of model vs. saturated chi^2	3,628.24		
Prob > chi^2	0.000		
p-value	0.000	< 0.05	
RMSEA	0.068	0.00–0.10	(Browne and Cudeck, 1992; Hair et al., 2006; Hu and Bentler, 1999)
CFI	0.911	0.90–1.00	(Bagozzi and Yi, 1988; Chau and Hu, 2001; Hooper et al., 2008; Jui-Sheng, 2013)
TLI	0.888	0.90–1.00	(Bagozzi and Yi, 1988; Chau and Hu, 2001; Jui-Sheng, 2013)
SRMR	0.069	0–1.0	
Coefficient of determination (CD)	0.999	0.00–1.00	
AIC	49,197.03		
Bayesian information criterion (BIC)	49,667.85		

access to agricultural extension services and decision-making abilities in promoting women's empowerment.

TABLE 7 Summary of the standardized direct effects on the WEAI.

Direct effect	Coefficient	Pr|z|
Access to agricultural extension services	0.594***	0.000
Freedom of mobility	0.070***	0.000
Group membership	4.669***	0.000
Birth control decisions	−0.127***	0.000
Decision-making	0.055***	0.000

***Indicates significance at the 1% level.

5 Discussion

Women's empowerment is pivotal in countries like Bangladesh, where gender disparities persist. It encompasses women's ability to make strategic life choices affecting their well-being and that of their families. The study identifies significant correlations between the WEAI and various empowerment indicators, notably strong correlations with group membership (0.921) and access to agricultural extension services (0.858), both critical drivers of empowerment as emphasized by Akter et al. (2017). Regression coefficients from the SEM path diagram illustrate positive associations of decision-making with food and cash crop production, as well as household expenditure decisions. Group membership emerges as a significant enhancer of empowerment through participation in various organizations. Autonomy in birth control decisions also positively influences empowerment through reproductive health choices. Goodness of fit indicators validate the SEM model, with RMSEA, CFI, TLI, and SRMR values within acceptable thresholds, indicating a robust fit. Direct effects analysis shows that access to agricultural extension services (0.594***), group membership (4.669***), decision-making (0.055***), and freedom of mobility (0.070***) significantly enhance women's empowerment, consistent with findings by Wei et al. (2021). Interestingly, birth control decisions show a negative coefficient (−0.127***), suggesting complex interactions between reproductive autonomy and other empowerment dimensions. This underscores the nuanced relationship between reproductive autonomy, economic participation, decision-making power, and freedom of mobility, which vary depending on contextual factors. Previous research underscores that women's ability to autonomously make decisions on contraception and family planning is critical to overall empowerment. The study reinforces the multifaceted nature of empowerment in agriculture, emphasizing group membership, resource accessibility, decision-making autonomy, and mobility as pivotal factors (FtF, 2018).

These findings align with broader evidence from rural South Asia. For instance, Reddy et al. (2021) document significant gender differences in time allocation between paid and unpaid work in Indian villages, demonstrating how unequal domestic responsibilities constrain women's empowerment and economic participation. Similarly, Reddy and Kumar (2011) highlight underemployment among rural women in Andhra Pradesh, noting that many remain in low-productivity or unpaid roles despite labor force participation. Such insights underlie the necessity to address structural and cultural constraints to women's agency in the South Asian context, reinforcing the importance of multidimensional empowerment approaches. Strengthening access to resources and organizational membership facilitates women's attainment of decision-making autonomy and mobility. Women with greater freedom of movement are more likely to access resources and engage in income-generating activities, underscoring mobility as a crucial empowerment dimension. Increased freedom to move outside the home without needing permission correlates with higher autonomy and economic participation (FtF, 2018). Targeted interventions enhancing these factors could substantially advance women's empowerment within Bangladesh's agricultural sector.

The novelty of the study lies in its empirical investigation of women's empowerment amid Bangladesh's agricultural transformation, utilizing SEM and path analysis. It fills critical research gaps by examining underexplored determinants such as access to agricultural extension services, birth control decision-making power, freedom of mobility, and access to productive capital within the WEAI framework. By integrating these factors, the study provides nuanced insights into the interrelationships shaping empowerment and gender dynamics in agricultural development (Alkire et al., 2013; Malapit et al., 2015).

The study acknowledges a key limitation in relying on cross-sectional data to assess empowerment, a concept that is inherently dynamic and evolves. This approach primarily captures correlations in women's autonomy at a single point, rather than the transformative process through which empowerment unfolds, namely, the progression from limited autonomy toward greater empowerment across time and context. Future studies need to focus on longitudinal data. In addition, this research is primarily validated for rural agricultural contexts, but its potential applicability to urban settings is an area for future research.

6 Conclusion and policy recommendations

The study on women's empowerment in Bangladesh highlights the pivotal role of access to agricultural extension services in enhancing women's decision-making power, freedom of mobility, and overall empowerment. Strengthening access to these services can significantly elevate women's empowerment, thereby contributing to sustainable economic development. Effective development programs and policies must take into account the multidimensional nature of empowerment, specifically, the roles of group membership, decision-making autonomy, birth control decisions, and freedom of mobility. By addressing these pathways comprehensively, interventions can adopt a more holistic and impactful approach to promoting gender equality and advancing women's rights in the agricultural sector. Using SEM, the study evaluated both direct and indirect effects of five key indicators. All five indicators showed significant direct effects on the WEAI, offering robust empirical evidence for empowerment dimensions that have been historically understudied. Based on these findings, the study recommends targeted policy actions to promote women's empowerment in agriculture. These include improving access to gender-sensitive agricultural extension services, increasing the training of female extension workers, and facilitating the formation of women's groups to strengthen collective decision-making and access to resources. To address mobility and time constraints, the study suggests flexible training schedules and the use of mobile platforms for information dissemination. Moreover, engaging men as allies in the empowerment process and fostering partnerships with NGOs and private sector actors can further enhance resource availability and community support. Regular assessments and feedback mechanisms are essential to ensure that services remain responsive to women's evolving needs. Ultimately, understanding the key determinants of empowerment and implementing evidence-based, context-specific interventions can help Bangladesh and similar other developing countries to progress toward achieving gender equality and the SDGs.

Data availability statement

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Author contributions

PS: Conceptualization, Formal analysis, Writing – original draft. MA: Conceptualization, Formal analysis, Funding acquisition, Supervision, Writing – original draft. IB: Conceptualization, Formal analysis, Supervision, Validation, Writing – original draft. DE: Data curation, Investigation, Methodology, Validation, Visualization, Writing – review & editing. FY: Investigation, Methodology, Validation, Visualization, Writing – review & editing. LC: Funding acquisition, Investigation, Methodology, Supervision, Validation, Visualization, Writing – review & editing. AM: Methodology, Validation, Visualization, Writing – review & editing.

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Conflict of interest

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

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The author(s) declare that no Gen AI was used in the creation of this manuscript.

Publisher's note

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