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Effect of socio-technical innovation bundles on male and female smallholder farmers' empowerment in selected counties in Kenya

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Smallholder farmers' vulnerability to systemic barriers, weather variability and climate change has resulted in low farm productivity, derailing farmers' chances for empowerment. Existing interventions aimed at enhancing smallholder farmers' empowerment are largely technocentric. They focus on technical and technological innovations, assuming a one-size-fits all approach with little regard for farmers' unique local contexts. With the over-reliance on technical and technological innovations, social innovations are often ignored, yet they capture the vital dimensions of farmers' local contexts. Moreover, gender considerations are treated as peripheral, not embedded into the innovation's layers. Co-designed socio-technical innovation bundles that integrate social, technical and technological innovations can address these limitations. However, their effect on smallholder farmers' empowerment is less explored. This study sought to determine the effect of co-designed socio-technical innovation bundles on male and female smallholder farmers' empowerment. Data were collected from 742 respondents, with 371 in the treated group and 371 in the control group. Using an ordered logistic regression model, the study determined that co-designed socio-technical innovation bundles significantly influenced smallholder farmers' empowerment. Farmers who participated in the co-design and use of socio-technical innovation bundles experienced higher levels of empowerment, demonstrating that context-specific socio-technical innovations effectively mitigate demographic and socio-economic disparities in empowerment. The findings further suggest that co-designed STIBs were associated with enhanced farmers' social and technical capacities and opportunities, significantly improving their empowerment levels. As a result, smallholder maize and bean farmers achieved higher degrees of decision-making and resource access, underscoring the transformative potential of co-designed STIBs in mitigating demographic disparities, enabling smallholder farmers, particularly female farmers, to act on their choices and influence their own circumstances. Incorporation and scaling co-designed STIBs in the agri-food system is thus a potential strategy to help realize gender-sensitive and sustainable agricultural production and development.

KEYWORDS

co-design, empowerment, innovation, resilience, socio-technical innovation bundle, gender

1 Introduction

Smallholder farmers in sub-Saharan Africa are a heterogeneous group operating in diverse ecological zones. They face unique challenges that affect their productivity, making a one-size-fits-all approach inappropriate for addressing their needs, preferences and constraints. Innovation bundling can potentially address multiple challenges facing food, land and water systems and thus transform the agri-food system (Barrett et al., 2020). Innovation bundling, combining technological innovations with social and technical innovations, is a potential approach for enhancing agriculture production amidst constraints such as gender inequalities and climate change. It promotes context-specific innovations that fit farmers' needs in their respective local and social contexts to enable them to address their unique challenges.

The CGIAR's Gender Equality Initiative (HER+), in collaboration with the International Institute for Environment and Development (IIED), developed a systematic STIBs framework designed to address gender-specific barriers and enhance women's empowerment and resilience in agri-food systems across Africa and Asia (Nchanji et al., 2023b,c). A socio-technical innovation bundle (STIB) is a co-designed bundle comprising social, technical, and technological innovations (Nchanji et al., 2023b,c; Thomas et al., 2023). Social innovations create enabling conditions for technological and technical innovation use. Examples of social innovations include farmer memberships to organizations, policy and institutional arrangements, business models, strategies, concepts, finance, partnership models, and public/private delivery strategies. Technical innovations strengthen farmers' capacity. Examples include training programs, manuals, guides, animations, and incubator programs, enabling the necessary knowledge and information to optimize existing technological innovations' adoption, usage, and benefits. Technological innovations are products, tools, or practices that can be used to achieve a specific objective, such as increased productivity, food security, and nutrition. Examples include crop varieties, animal breeds, crop and livestock management practices and digital applications. STIBs, as a holistic approach, recognize the benefits of integrating these three dimensions to create a comprehensive pathway for sustainable and equitable agricultural development.

In this study, STIBs is operationally defined as integrated innovation package combining social, technical and technological innovations. Social innovations refer to institutional arrangements. These include farmer group memberships, market linkage platforms, and policy advocacy networks. Technical innovations are capacity-strengthening interventions providing knowledge and skills. They include participatory training programs on climate-smart agriculture, peer-to-peer learning exchanges, farmer field schools, and gender-responsive agricultural extension services. And lastly technological innovations are the physical tools, material elements and practices enhancing productivity. These comprise drought-tolerant maize and bean varieties, improved storage technologies, labor-saving tools and equipment and digital agricultural advisory services. Critically, farmers were classified as STIB users only if they simultaneously adopted components from all three categories within the 12 months preceding the survey. This strict definition was critical to ensure that the study captures the synergistic effects of bundled innovations rather than isolated technology adoption.

In Kenya, the agricultural sector is a key driver of economic development, employment, and food security. Key players in this sector are smallholder farmers (Kathula, 2023). They play a major role in helping sustain national food production. Nonetheless, changes in weather variability and climate change exposed them to a wide range of challenges, including unpredictable rainfall patterns, increased pests and diseases, water scarcity, soil degradation, and loss of biodiversity affecting their overall agricultural production (Kogo et al., 2021; Kalele et al., 2021). Moreover, smallholder farmers' contributions to national food production are hampered by limited access to innovative technologies. Gender disparities further compound these challenges. Male and female farmers experience differing levels of access to innovations, resources and decision-making power, with female farmers in Kenya being more disproportionately socioeconomically disadvantaged and affected by climate change, resulting in low and disproportionate levels of empowerment.

Nakuru and Embu counties are characterized by high potential zones, lower highlands, and semi-arid zones (County Government of Nakuru, 2023; County Government of Embu, 2023). Therefore, they support diverse types of crops including potatoes, maize, beans and wheat among other crops making them potential agricultural counties in Kenya. However, Nakuru and Embu counties experience unpredictable rainfall and periods of drought, which affect crop yields. Nakuru and Embu are also characterized by declining soil fertility due to continuous farming and inadequate soil management practices. As a result, they both experience continuous decline in agricultural productivity despite their potential. Makueni county on the other hand is emblematic of regions grappling with chronic food insecurity (County Government of Makueni, 2023). Characterized by semi-arid farming conditions, farmers in Makueni are disproportionately disempowered, their agricultural productivity and economic stability are undermined by the county's vulnerability to repeated episodes of drought that underscore Makueni's ongoing challenges in ensuring stable food access. Because of these challenges, smallholder farmers across the three counties, especially women, are continually exposed to heightened vulnerabilities characterized by limited access to resources, markets, financial services, and decision-making power. The choice of Embu, Nakuru, and Makueni counties is informed by two key considerations. First, they serve as learning labs where CGIAR's HER+ and Ukama Ustawi initiatives are implementing socio-technical innovation bundles (STIBs). Second, farmers in these counties experience distinct challenges and vulnerabilities, making them ideal contexts for evaluating how co-designed STIBs can address specific constraints. Consequently, selecting these counties provides a unique opportunity to assess the effect of STIBs on enhancing smallholder farmers' empowerment across diverse agroecological and socio-economic conditions.

Existing gender disparities in agriculture are rooted in traditional social norms. Smallholder farmers in Kenya, particularly women, bear the brunt of these social and cultural norms. They experience inadequate access to resources, have limited decision making power and lack resources to invest in agriculture. Therefore, despite being major players in the sector, smallholder farmers, particularly women, have limited ability to improve productivity and fully engage in agricultural decision-making (Diuro et al., 2018; Ogolla et al., 2022). These gender-based inequalities undermine the overall productivity and

economic potential of smallholder farming in Kenya. To address existing gender disparities, use of innovation bundles has proved essential.

Socio-technical innovation bundles (STIBs) have been around in Kenyan agriculture, promising solutions capable of driving systemic changes in the agrifood system. For example, *DigiFarm* integrates partnership models, mobile-based advisory services, and training on agronomic practices to boost smallholder farmers' productivity and market access. A similar bundle is the climate-smart seed system. This bundle integrates drought tolerant varieties, a technological component of the bundle, with cooperative-led seed distributions, a social component of the bundle and farmers training, a technical component of the bundle, to enhance resilience. These bundles have helped improve yields, particularly for marginalized farmers, demonstrating that STIBs offer a holistic approach to overcoming barriers in agriculture with the potential to positively influence male and female farmers productivity (Johnstone et al., 2023). However, the extent to which these innovations address gender disparities and enhance empowerment among male and female farmers remains underexplored. Gaps in empowerment are persistent, particularly for women farmers, due to uneven and unsystematic bundling, which fails to tackle structural barriers, subsequently failing to address existing gender divides. Existing bundles treat gender as peripheral rather than embedding equity into the innovation bundles. Closing this gap requires intentional co-designing of STIBs that integrate context-specific social, technical, and technological innovations to address innovation trade-offs and facilitate the adaptation and diffusion of beneficial innovations to create sustainable food systems (Nchanji et al., 2023b,c).

Co-designed STIBs are central to addressing existing gaps in farmer empowerment, integrating context-specific social, technical and technological innovations. Co-designed STIBs address lack of intentionality in innovation bundling and ensure that STIBs are impactful, recognizing that one-size-fits all bundles fail where social norms, climate vulnerabilities and resource access differ. Grounding co-design in innovation bundling ensures that innovations resonate with local priorities and conditions, thus closing existing empowerment gaps while building adaptive frameworks for replication of equity-centered STIBs across diverse settings.

This study evaluates how existing co-designed STIBs implemented through the CGIAR Gender Equality Initiative (HER+) influence empowerment outcomes for male and female smallholder maize and bean farmers in selected counties in Kenya. Employing a demand-driven, context-specific approach to bundling social, technical, and technological innovations, developed collaboratively with farming communities, the HER+ initiative helps address gender-specific barriers in the agri-food system. Using a quasi-experimental design, the study compares empowerment levels between farmers who participated in HER+ STIB co-design activities (UU farmers) and non-participating farmers (non-UU farmers) across three counties in Kenya representing diverse agroecological zones. This approach helps empirically determine whether co-designed STIBs effectively enhance empowerment among sub-Saharan African smallholder farmers, with particular attention to differential effects by gender. Specifically, the study addresses the following research question: What is the effect of co-designed socio-technical innovation bundles on the empowerment of male and female smallholder farmers in Kenya?

1.1 Theoretical framework

The Capability Approach theory, developed by Amartya Sen, provides a foundation for understanding empowerment in the context of creating enabling conditions for male and female smallholder farmers in Kenya to overcome barriers and achieve freedoms critical for their wellbeing. Empowerment can be achieved by focusing on individual capabilities (Kuklys, 2005). This aligns with the theory's assertion that individuals' own values and choices must drive development. The theory underscores the importance of the context-dependent aspect of co-designed STIBs, which considers the influence of social, cultural, and contextual factors on an individual's ability to make choices and lead a fulfilling life. Access to resources, decision-making authority, group membership, education and leadership are influenced by cultural and contextual factors (Noman and Gurr, 2020; Teboul and Damier, 2023). The Capability Approach theory offers a comprehensive lens through which the effects of co-designed STIBs on empowerment can be understood by positioning co-designed STIBs as a mechanism for expanding male and female farmers' substantive freedoms, ensuring that innovations are not just adopted but owned by the male and female farmers they aim to empower.

Socio-technical innovation bundles are crucial in addressing the intertwined challenges of low productivity and disempowerment. However, a lasting impact is achieved if they are co-designed to integrate context-specific technological, social, and technical innovations. Co-designed STIB create enabling conditions by enhancing smallholder farmers' capabilities to improve agricultural productivity and resilience (Jacobson, 2016). Conventionally, male farmers have greater access to resources and decision-making power while female smallholder farmers remain relegated to supportive roles, limiting their potential to realize their full agricultural and economic capabilities. This theory thus provides a framework to evaluate how co-designed STIBs enhance farmers' capabilities.

The theory effectively guides the analysis of how co-designed STIB expand male and female farmers' substantive freedoms, framing empowerment as what male and female farmers can do and be—capabilities—rather than merely what they possess—resources or achieve—outcomes. It considers broader social and cultural dynamics, ensuring that empowerment is not viewed solely through the lens of economic outcomes but gives an alternative approach focusing on access to resources and agency (Kabeer, 1999; Kuhumba, 2018). Because empowerment is shaped by socio-cultural factors, gender norms, and access to resources, this theoretical framework ensures that the evaluation of empowerment analyzes how co-designed STIB affects capabilities necessary for smallholder farmers to thrive in a rapidly changing agricultural landscape. Through this lens, practical insights into how context specific interventions can better address disparities in empowerment between male and female smallholder farmers is understood to foster inclusive and sustainable agricultural development.

1.2 Conceptual framework

Resource ownership, group membership, leadership, education, and decision-making are key variables rooted in empirical evidence for measuring empowerment. Resource ownership gives smallholder farmers control over resources, reflecting an individual's ability to

exercise agency (Kabeer, 1999; Njuki et al., 2019; Anderson et al., 2021). Group membership provides the required support system, including access to networks, necessary for empowerment (Othman et al., 2021; Baruah et al., 2022). Leadership as an indicator of empowerment demonstrates the capacity to guide decisions, inspire collective action and advocate for change (Malhotra and Schuler, 2005). Education equips farmers with knowledge, skills and confidence to challenge inequalities, make informed decisions, and participate effectively in societal processes (Doss et al., 2020; Othman et al., 2021). Decision-making demonstrates the ability to influence decisions, reflecting autonomy and capacity to shape one's environment (Alsop and Heinsohn, 2005). A description of variables used to explain the dependent variable is given in Table 1 below.

2 Materials and methods

2.1 Study area

The study was conducted in Nakuru, Embu and Makueni counties of Kenya (Figure 1). Nakuru County located between longitude 35° 28' and 35° 36' East and Latitude 0° 13' and 1° 10' South and Embu County located between longitude 37° 3' and 37° 9' East and Latitude 0° 8' and 0° 50' South have diverse agroecological zones making them important agricultural counties (County Government of Nakuru, 2023; County Government of Embu, 2023). Makueni County, located between longitude 37° 10' and 38° 30' East and latitude 1° 35' and 2° 59' South, is adaptable to drought-tolerant crops, making it an important county for climate-resilient agriculture in Kenya. The

county has significant agricultural potential despite being classified as an arid and semi-arid land (ASAL) (County Government of Makueni, 2023).

2.2 Research and sampling design

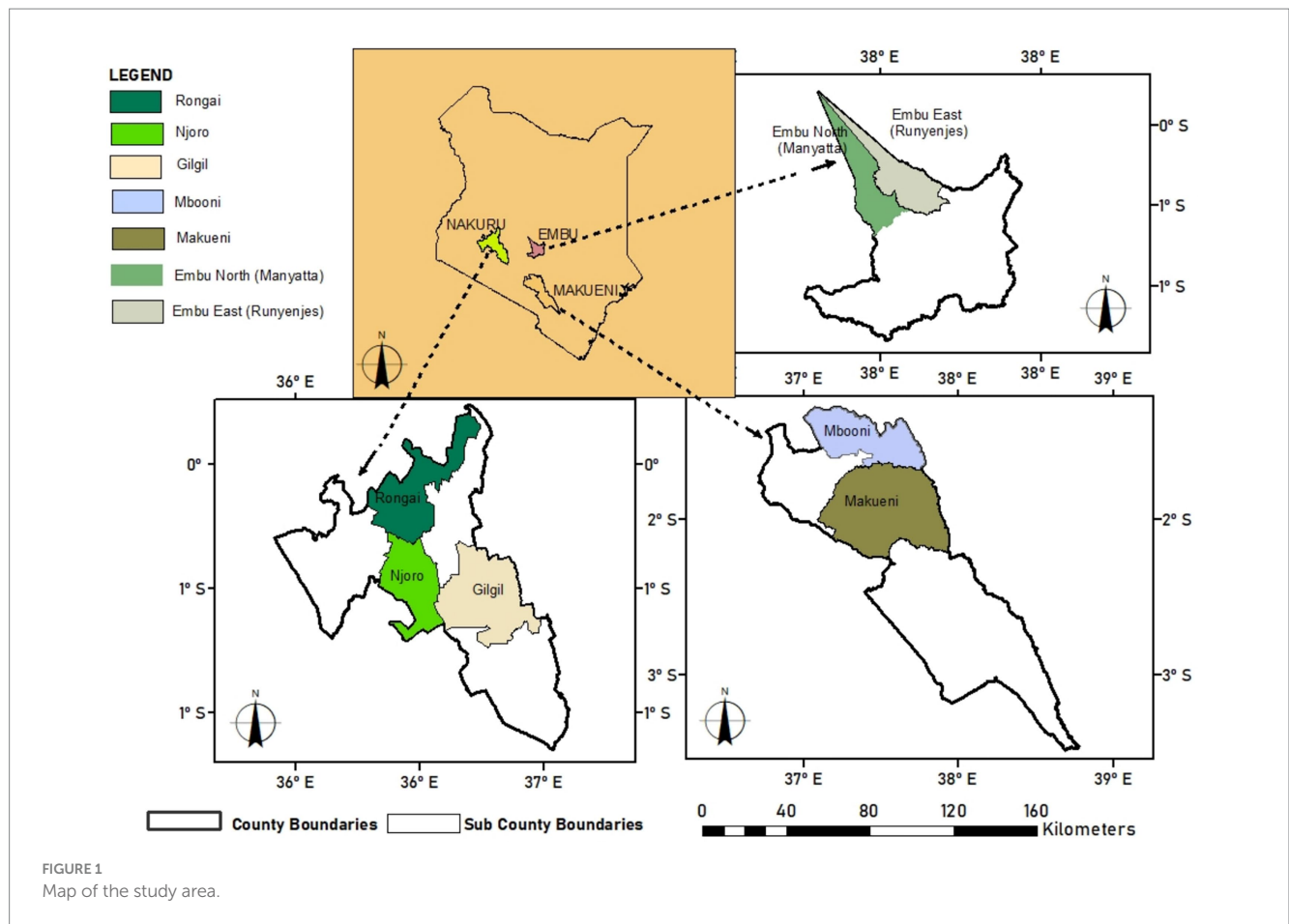
2.2.1 Research design

The study employed a quasi-experimental design to determine the effect of STIB on empowerment of male and female smallholder maize and bean farmers in Nakuru, Embu and Makueni counties in Kenya. The design allowed for the analysis of a pre-existing treatment group—smallholder farmers onboarded on HER+ initiative's activities and exposed to targeted innovative design of context-specific socio-technological innovation bundles. The beneficiary farmers (Ukama Ustawi farmers also referred to as UU—farmers) constituted the study's randomly assigned treatment group. The control group, also referred to as Non-UU farmers were randomly selected to ensure comparability while mitigating selection bias to enhance the robustness of the study's findings. HER+ and Ukama Ustawi (UU) are CGIAR initiatives designed to address challenges in the agri-food system by focusing on enhancing inclusivity, sustainability, and resilience. The initiatives jointly address the socioeconomic and gender challenges described in the study area through a socio-technical innovation bundling approach.

HER+ is keen on advancing gender-responsive approaches in agriculture, focusing on empowering smallholder farmers, particularly women. It aims to achieve this by addressing systemic barriers that hinder active participation in farming activities and decision-making.

TABLE 1 Description of variables for empowerment.

Variable	Description	Measurement	Expected sign
Dependent variable			
<i>Farmer empowerment index (FEI)</i>	Level of empowerment	Categorical	
Independent variables			
<i>STIB</i>	Used STIBs in the last 12 months	Binary	+
<i>Age</i>	The age of the farmer	Continuous	±
<i>MaritalStatus</i>	Marital status of the farmer	Binary	±
<i>GovtSupport</i>	Do you seek assistance from government when faced with significant farming challenges.	Binary	+
<i>CommunitySupport</i>	Farmer rely on community support to overcome climate change.	Binary	±
<i>Dependency</i>	Number of dependents in the household	Continuous	±
<i>AccessHealthServices</i>	Farmer has adequate access to health services	Binary	±
<i>UU_Participation</i>	Participation in UU activities	Binary	±
<i>LandTenure</i>	Type of land ownership	Binary	±
<i>Workload</i>	Farmers level of workload	Categorical	±
<i>MechanizedFarmOperations</i>	Farmer has access to mechanized farm machinery	Binary	±
<i>Off-farm income</i>	Farmer has off-farm income	Binary	±



It integrates socio-technical innovations in agroecological and climate-smart practices to ensure equitable benefits among farming communities. Ukama Ustawi (UU) is a regional CGIAR initiative focused on scaling sustainable agricultural practices through socio-technical innovation bundles. Together, these initiatives contribute to advancing sustainable agricultural development, working with farmers onboarded onto the project, referred to as UU farmers. The experience of non-beneficiary farmers, dubbed non-UU farmers, serves as a critical baseline for understanding the impact of STIBs on farmers’ empowerment.

2.2.2 Sampling design

The sample size for the treatment group (UU farmers) was determined using Kothari (2004) formula for known populations, accounting for a 95% confidence interval, 5% margin of error, and a design effect of 1.75 to adjust for clustering (see Supplementary Material S1 for detailed calculation). This yielded a sample of 371 UU farmers from a population of 450 beneficiaries. This sample size was distributed proportionately across the three project-implementing counties (Table 2).

The sample for the target group (UU farmers) was then matched with a control group identified as ‘non-UU farmers’ at a ratio of 1:1 at the aggregate level. This approach ensured an overall balance between the treatment and control groups, resulting in a total sample size of 742 respondents. This approach maintained the balance between the treated group and the control group to increase the statistical power of the study and to allow for the generalizability of the study’s findings.

TABLE 2 Sample distribution.

Type of farmers	Embu	Makueni	Nakuru	Total
UU farmer	114	111	146	371
Non-UU farmer	121	102	148	371
Total	235	213	294	742

2.3 Data and data collection

The data used in this study were collected by CIAT in October 2023 after obtaining ethical approval of the Alliance of Bioversity International and CIAT Institutional Review Board (IRB). The survey used a semi-structured questionnaire organized in 12 modules. The tool used collected socio-demographic and socio-economic information, including household demographic characteristics, land ownership, socio-technical innovation bundles, household income and resources, participation in initiative activities, and mechanization of farm operations. Data used for this study was retrieved from the respective modules.

2.4 Construction of empowerment index

Empowerment, particularly in the agricultural context, is a multifaceted concept. It encompasses dimensions including

decision-making power, resource ownership, and leadership (Kabeer, 2001). Using an index provides a metric for assessing the empowerment status of smallholder farmers. Construction of the Farmer Empowerment Index (FEI) follows Kabeer's (1999) framework, focusing on access to resources and agency, where resource ownership, group membership, leadership, access to information, education, and decision-making are the core variables. Using these variables ensures that the FEI represents the complex nature of empowerment.

To measure empowerment, an empowerment index is constructed using the variables resource ownership, group membership, leadership, education, and decision-making. The following steps were taken to develop an empowerment index (dependent variable): First, the variables used to construct the index were appropriately scaled for integration into an index (Table 3).

To aggregate the variables into a single empowerment score, Principal component analysis was subsequently used to identify latent empowerment dimensions retaining the first principal component (PC1) since the variables loaded strongly onto the one factor. A composite reliability test was then used to check the reliability of the index. A composite reliability test is better suited for indices derived from principal component analysis (PCA) with mixed variables as used in this study (continuous, binary, and ordinal). A composite reliability (Omega) score of 0.691 was obtained, demonstrating an acceptable internal consistency, nearing the 0.7 threshold for adequate reliability (McDonald's, 1999; Cho, 2016). The omega score of 0.691 remains within the adequate benchmark for exploratory science indices integrating diverse empowerment metrics, thus supporting the index robustness for regression analysis. It reflects a shared variance among variables in measuring latent empowerment.

Because empowerment progresses through recognizable phases (Huq, 2023), the empowerment index (ranging from 0 to 100) is categorized into three distinct levels of empowerment: "Not Empowered," "Partially Empowered," and "Empowered." The index is ordered to effectively capture transitional states that are critical in understanding the dynamics of empowerment. The cut-off points are as follows: Not Empowered (0–40), Partially Empowered (41–70), and Empowered (71–100). The cut-off points align with both theoretical frameworks and empirical precedents in empowerment measurement literature. The tripartite categorization reflects Kabeer's (1999) conceptualization of empowerment as a progressive process. "Not Empowered" (0–40) captures individuals with minimal or no empowerment, reflecting limited resource ownership, group

membership, decision-making, education and leadership opportunities (Alkire et al., 2013). This range aligns with the theoretical framework that defines disempowerment as the absence of agency and resource access (Kabeer, 1999). Partially Empowered (41–70) represents individuals with some degree of empowerment. This score demonstrates access to resources, group membership, participation in decision-making, leadership and education but not enough to achieve full empowerment, thus limiting individuals' ability to fully exercise agency (Kabeer, 1999). Empowered (71–100) reflects individuals who have achieved a high level of empowerment. This is characterized by strong agency, access to resources, and active participation in decision-making. This aligns with the theoretical definition of empowerment as the ability to make strategic life choices and influence one's environment (Alsop and Heinsohn, 2005). Similar threshold approaches have been employed in multidimensional poverty and empowerment indices (Alkire et al., 2013; Yount et al., 2019), where intermediate categories capture transitional states that are theoretically and empirically meaningful.

In this study, a farmer was categorized as a STIB user only if they simultaneously used all three components—social, technical, and technological innovations. A farmer who adopted any two or one component was categorized as a non-STIB user.

3 Results and discussion

3.1 Descriptive results

Table 4 presents the socio-demographic and socio-economic characteristics of the male and female smallholder maize and bean farmers who participated in the study. *T*-test results for continuous variables (age, dependency, off-farm Income) and chi-square tests for categorical variables (marital status, land tenure, access to healthcare services, mechanized farm operations, workload, UU participation, government support, community support, STIB) are presented.

Demographic results show that the average age of the farmers who participated in the study was 52 years old, with a significant majority (72%) reporting being married ($p = 0.000$). The respondents' marital status significantly differed by sex, with more male farmers (88%) reporting being married compared to female farmers (64%). Among the 28% unmarried participants, female farmers were the majority, with 36% being unmarried compared to only 12% male farmers. These findings are consistent with available literature, which states that in Sub-Saharan Africa, men spend more of their lives married than women (Shapiro and Gebreselassie, 2014; Nchanji, 2023a). The significant disparity in marital status, with more female farmers reporting being unmarried compared to male farmers, underscore a potential gender imbalance in resource ownership and control. Unmarried female farmers, particularly the widowed and those who are either divorced or separated, often face systemic barriers in their quest to access land, agricultural inputs and credit, unlike male farmers Shapiro and Gebreselassie, 2014. This directly impacts their empowerment outcomes in various domains, including income autonomy, asset ownership, and decision-making authority.

The use of socio-technical innovation bundles (STIBs) was widespread among surveyed farmers, with 62% adopting and using the innovation. The adoption and use of STIBs significantly differed by sex ($p = 0.000$). More female farmers reported using STIB (68%)

TABLE 3 Preprocess variables.

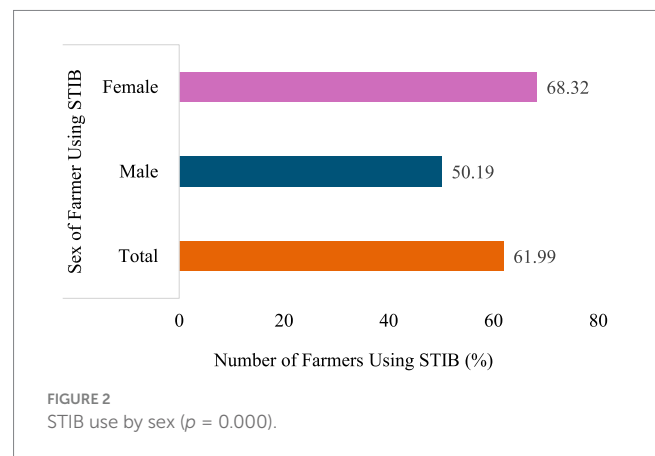
Variable	Type	Preprocessing steps
Resource ownership	Continuous (1–6)	Standardized using z-score for comparability.
Group-membership	Binary (0/1)	Kept as 0/1 (no transformation needed).
Leadership	Binary (0/1)	Kept as 0/1.
Decision making	Categorical	Convert to numerical scores (ordinal encoding).
Education	Categorical	Convert to numerical scores (ordinal encoding).

TABLE 4 Socio-demographic and contextual characteristics.

Variable	Total (N = 742)	Male (n = 259)	Female (n = 483)	p-value
Age	52.72	52.28	53.54	0.216
Marital status (%)				0.000
Married	72.37	88.03	63.98	
Not married	27.63	11.97	36.02	
Workload (%)				0.000
Much heavier	24.39	22.01	25.67	
Slightly heavier	28.71	22.01	32.30	
About the same	31.94	33.98	30.85	
Slightly lighter	13.75	19.31	10.77	
Much lighter	1.21	2.70	0.41	
Dependency	2	1	2	0.017
Off-farm income (%)	21.43	23.55	20.29	0.302
Land tenure	66.98	64.86	68.12	0.369
Access to healthcare services	81.67	77.99	83.64	0.058
Mechanized farm operations	43.53	36.29	47.41	0.004
UU participation	50.00	37.07	56.94	0.000
Government support	30.46	38.61	26.09	0.000
Community support	24.8	20.85	26.92	0.068

than their male counterparts (50%) (Figure 2). Similarly, farmers' participation in the HER+ project initiative (UU participation) differed significantly by sex ($p = 0.000$). The significantly higher participation of female farmers in the HER+ project activities at 57%, compared to only 37% male farmers, reiterated the initiatives' focus on gendered co-creation as a driver of empowerment. Unlike conventional innovation systems that often marginalize women farmers' voices, HER+ deliberately prioritized female farmers in co-developing STIBs to create an enabling platform that besides giving female farmers a voice, enables them actively shape innovations that address their needs, overcoming specific barriers including time poverty and limited land access. The significantly higher participation of female farmers suggests that the initiative's focus on gender-inclusive co-design processes may have resonated more strongly with female farmers, who are often marginalized in conventional innovation systems. These patterns suggest that gender-inclusive co-design processes may contribute to more equitable empowerment outcomes by enabling female farmers to actively participate in shaping innovations that address their specific needs and constraints, rather than merely receiving pre-designed technologies. This underscores STIB's broader relevance: systemic change requires not only measuring empowerment outcomes but intentionally restructuring who designs the innovations themselves.

The results further showed that engagement with mechanized farm operations significantly differed by gender ($p = 0.004$). Female farmers had a higher engagement with mechanized farm operations (47%) than men (36%). Nevertheless, they also reported experiencing a higher workload (58%) compared to males (44%), $p = 0.000$. Female farmers also reported a higher dependency ratio of 2 compared to men at 1, $p = 0.017$. The interplay of these outcomes likely drove female farmers' demand for labor-saving tools. Nonetheless, strained resources—exacerbated by limited government support (26%) for



female farmers compared to men (39%), $p = 0.000$ —may have possibly restricted female farmers to low-cost, partial mechanization, possibly handheld tools rather than transformative investments in fully mechanized tools (Daum et al., 2020). These findings reflect a coping strategy to manage female farmers' overlapping farm and household duties rather than a systemic shift in productivity. Traditional gender roles thus may confine women's mechanization efforts to tasks they are culturally or socially permitted to perform, whereas male farmers retain control over high-value machinery. Therefore, while female farmers' engagement with mechanized tools is higher compared to that of males, its effect on reducing labor burdens remains limited without addressing structural barriers (Baudron et al., 2019). These findings underscore the paradox of gender innovation adoption where, despite female farmers adopting technologies to cope with inequalities, systemic constraints tend to inhibit their potential to achieve transformative empowerment. The findings suggest the

importance of co-designed STIBs that integrate technological solutions with social innovations and technical support to address disempowerment among smallholder farmers particularly female farmers.

While this study’s cross-sectional design does not include pre-intervention baseline measurements, the control group (non-UU farmers) provides a proxy for understanding empowerment patterns under conventional agricultural conditions—representing the status quo in Kenyan smallholder agriculture where gender-targeted innovation co-design is often missing. The comparison between UU and non-UU farmers thus approximates differences in empowerment outcomes with versus without deliberate female engagement in STIB co-design processes.

Table 5 presents the results of the empowerment levels by farmer type: the treated group (UU farmers) and the control group (non-UU farmers) for both male and female farmers. The findings show significant differences in the empowerment levels between the UU farmers (treated) and non-UU farmers (control) for both sexes ($p = 0.000$). UU farmers, regardless of sex, have significantly higher levels of empowerment than non-UU farmers. The gender difference in empowerment levels is more notable among the non-UU farmers, with females lagging male farmers in empowerment. Among female farmers, 97.82% of UU farmers were reportedly empowered compared to 38.94 non-UU farmers. Unlike only 2.18% of UU farmers who were partially empowered, non-UU farmers comprised 31.73% of those partially empowered. None of the UU female farmers fell in the “not-empowered category,” while a sizeable percentage of female non-UU farmers, 29.33%, were in the “not-empowered” category.

Similarly, among male farmers, 97.92% of UU farmers were reportedly empowered, compared to only 60.12% of empowered non-UU farmers. While 29.45% of non-UU farmers reportedly fell in the partially empowered category, only 2.08% of the UU farmers were in the same category. No UU farmers were in the “Not empowered” category compared to 6.56% of the non-UU farmers in the same category. These findings indicate a significantly higher proportion of male and female UU farmers being empowered than their non-UU counterparts. The findings suggest that participation in HER+ initiatives activities linked to involving farmers in co-designing context-specific socio-technical innovation bundles encourages the adoption and use of context-specific STIB, which possibly helped raise the empowerment levels of both male and female UU farmers. The pronounced empowerment gap for female farmers, where a higher proportion of non-UU farmers remain either “not empowered” or “partially empowered” compared to their male counterparts, indicates that farmers’ use of co-designed STIB plays a critical role in enhancing the empowerment level of farmers, narrowing down the empowerment gap between male and female farmers. Moreover, farmer participation in the HER+ initiative’s activities exposed them to co-designed context-specific socio-technical innovation

bundles, potentially leading to increased use of context-specific STIB among UU farmers compared to non-UU farmers (Figure 3). The results testify to the critical role of co-designed socio-technical innovation bundles, developed based on farmers’ local context, in enhancing the empowerment level of both male and female farmers and narrowing the empowerment gap among smallholder farmers.

The increased use of STIBs, was significantly associated with a decline in the gender gaps in empowerment, with neither male nor female UU farmers being in the “Not empowered” category (Table 5).

The result thus suggests that STIBs potentially address farmers’ unique challenges, resulting in increased empowerment. The involvement of farmers, particularly female farmers, in the co-design of STIBs likely reduced the gender empowerment gap between male and female farmers, thus addressing the persistent lack of empowerment among female farmers.

Table 6 compares the empowerment levels of UU farmers (treated) and non-UU farmers (control) across key demographics (sex, age, marital status, education) and socio-economic factors (farm mechanization, off-farm income, and savings). Only 2.08% of male and 2.18% of female farmers were partially empowered. None of the UU farmers were in the ‘not empowered’ category. This pattern was consistent across the demographic and socio-economic factors influencing empowerment among UU farmers. The results show that empowerment levels are largely uniform among UU farmers, while among non-UU farmers, empowerment levels vary significantly based on demographic and socioeconomic factors. Participation in the HER+ activities encouraged farmers’ involvement in the co-design of STIB, encouraging the use of context-specific socio-technical innovation bundles, thus effectively mitigating demographic and socio-economic disparities in empowerment. The near-uniform empowerment among UU farmers suggests the strong impact of STIBs in creating an environment where variables such as gender, age, and financial resources do not limit a farmer’s ability to be empowered.

The results displayed disparities in empowerment across demographic and socio-economic factors among non-UU farmers. A clear gender gap was observed, with more male (60.12%) and female farmers (38.94%) being empowered ($p = 0.000$). The same pattern was evident for Age, where older farmers were more likely to be empowered ($p = 0.006$). Marital status and education also revealed striking differences ($p = 0.000$) and ($p = 0.016$), respectively. Married farmers and those with higher education were more likely to be empowered. Empowerment levels also differed significantly based on farmers’ access to mechanized farm operations, where farmers with access were more empowered ($p = 0.000$). The same was evident among farmers with savings ($p = 0.001$) and off-farm income (0.000). The stark contrast in empowerment distribution between UU and non UU farmers reflect the transformative role of co-designed STIBs in mitigating inherent demographic disparities among smallholder farmers. The results

TABLE 5 Empowerment category by project participation.

Empowerment category	Male (n = 259)			p-value	Female (n = 483)			p-value
	Total	UU farmer	Non-UU farmer		Total	UU farmer	Non-UU farmer	
Empowered	74.13	97.92	60.12	0.000	72.46	97.82	38.94	0.000
Partially empowered	19.31	2.08	29.45		14.91	2.18	31.73	
Not empowered	6.56	0	10.43		12.63	0	29.33	

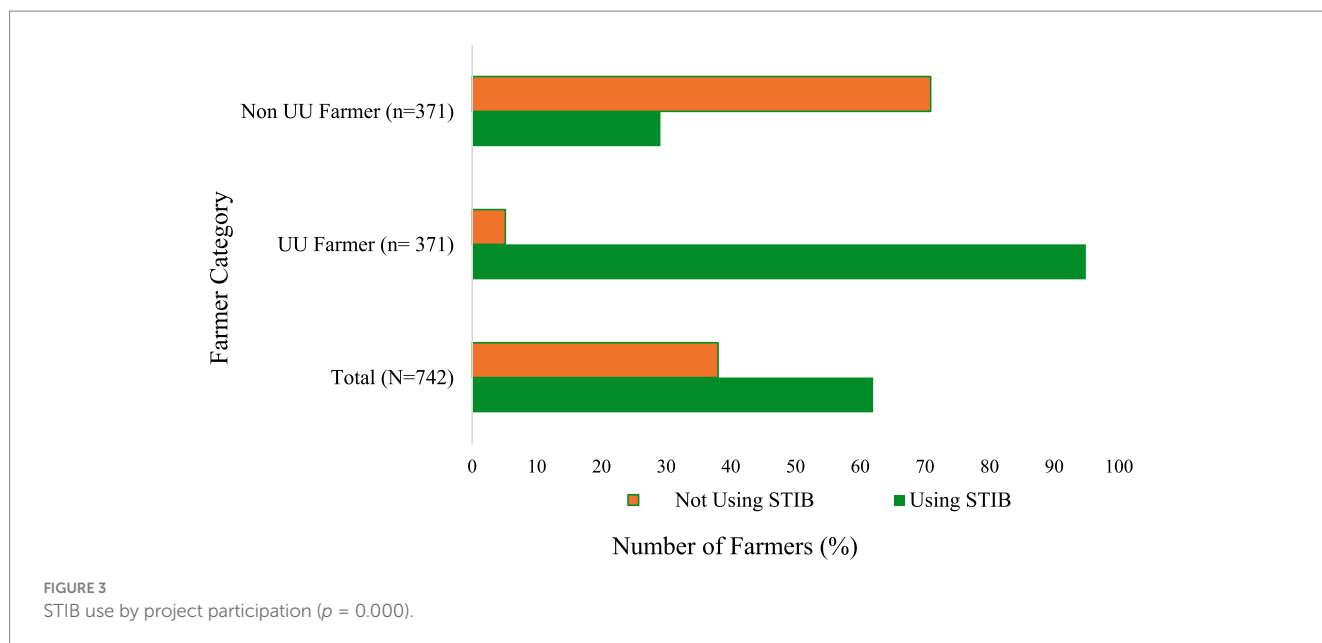


TABLE 6 Distribution of empowerment levels of UU vs. non-UU farmers across key demographic and socio-economic factors.

Key demographic and socio-economic factors	UU farmers (n = 371)			Non-UU farmers (n = 371)			
	Empowered	Partially empowered	p-value	Empowered	Partially empowered	Not empowered	p-value
Sex (%)			0.954				0.000
Male	97.92	2.08		60.12	29.45	10.43	
Female	97.82	2.18		38.94	31.73	29.33	
Age	53.29	48.63	0.306	53.81	48.78	53.72	0.006
Marital status (%)			0.375				0.000
Married	97.45	2.55		61.22	36.12	2.66	
Not married	98.97	1.03		16.67	17.59	65.74	
Years of education	9	11	0.381	9	9	7	0.016
Mechanization (%)	97.62	2.38	0.734	76.11	9.73	14.16	0.000
Savings	97.84	2.16	0.996	56.25	27.88	15.87	0.001
Off-farm income	96.77	3.23	0.412	80.3	15.15	4.55	0.000

suggest that among non UU farmers, empowerment levels were heavily stratified by age, sex, resource access and marital status. Only 38.94% of female non-UU farmers were empowered compared to 60.12% of the males ($p = 0.000$). This finding reveals entrenched inequalities in resource control and decision-making, hence the disparity in empowerment by sex. Empowered married non-UU farmers were 61.22%, while empowered unmarried non-UU farmers were only 16.67%, $p = 0.000$. This disparity reflects the influence of community and marital ties in land ownership. Similarly, empowered non-UU farmers with access to machinery were 76.11%, while those empowered and having savings comprised 56.25%, with these factors predicting empowerment strongly ($p = 0.000$), highlighting the influence of resource disparities in reinforcing stratification.

In contrast, UU farmers who participated in the co-design of STIBs through the HER+ initiative exhibited near-uniform empowerment levels across demographics. 97.82% female and 97.92% male farmers

reported being empowered ($p = 0.954$), suggesting that participatory STIBs co-designing disrupts gender barriers was associated with context-specific STIBs. Similarly, there was no significant variation in empowerment by age ($p = 0.306$) or marital status ($p = 0.375$), suggesting that STIBs expand capabilities independently of traditional social hierarchies. This divergence shows that co-designed STIBs redistribute agency by addressing structural inequalities.

The comparison of empowerment levels of UU farmers, who participated in HER+ initiative’s activities that involved farmers in the co-design of context-specific STIBs, and non-UU farmers reveal that co-designed STIBs effectively levels disparities among farmers, ensuring that farmers can achieve empowerment regardless of their demographic and socio-economic conditions. Without co-designed STIBs, conventional socio-economic and demographic inequalities tend to persist, substantially affecting empowerment levels among smallholder farmers. STIB thus potentially foster inclusive

agricultural development by reducing barriers to empowerment among vulnerable farming communities. The findings validate the argument that co-designed STIBs do not merely improve empowerment by expanding smallholder farmers' capabilities and opportunities redefining who can achieve empowerment. This, therefore, positions co-designed STIBs as a paradigm shift in the agri-food system moving beyond incremental gains to foster equitable, inclusive empowerment.

3.2 Econometric results

Ordered logistic regression model was used to evaluate the effect of co-designed STIBs on farmers' empowerment. Estimates of the ordered logistic regression coefficients of the factors influencing empowerment among male and female smallholder farmers in Nakuru, Embu and Makueni counties of Kenya are presented in Table 7. The results of the likelihood ratio chi-square test for the models' overall fit, 174.29 ($p = 0.000$) for men and 464.23 ($p = 0.000$) for women suggest that the coefficients of the variables used in the ordered logistic regression model were jointly significantly different from zero. Additionally, the model provides a reasonably good fit, accounting for approximately 46.85% of the variation in empowerment categories among male farmers and 61.73% among female farmers.

The findings reveal gender-specific pathways to empowerment among smallholder male and female farmers. Among male farmers, empowerment pathways centered around economic participation, while female farmers' pathways to empowerment shift towards

institutional support systems and health. The findings align with Kabeer (2011) assertion that institutional support is vital for ensuring access to resources among female farmers, thereby enhancing their economic roles and decision-making power. The overarching role of STIB in supporting smallholder farmers' empowerment in both pathways is evident, suggesting that STIBs are critical in addressing the distinct needs of male and female smallholder farmers, consequently reducing empowerment disparities.

Socio-technical innovation bundles were significantly associated with a significant effect on empowerment of male and female farmers, with a notably stronger effect on female farmers. A unit increase in the use of STIB results in a statistically significant increase in empowerment scores among male farmers ($\beta = 2.16, p = 0.000$) compared to female farmers ($\beta = 4.90, p = 0.000$). Farmers using STIB benefit from tailored solutions that directly address their unique challenges (Nchanji, 2023a). STIBs encourage targeted integration of technical, technological and social innovations providing context specific combinations of interventions that enable farmers to adapt to climatic shocks and enhance their productivity, consequently fostering greater autonomy. The use of STIBs suggests more pronounced effect on the empowerment of female farmers compared to male farmers. The differential effect of STIB observed among female ($\beta = 4.90, p = 0.000$) compared male farmers ($\beta = 2.16, p = 0.000$) demonstrate greater relative benefit for female farmers.

Female farmers characteristically experience limited decision-making power (Yount, 2017), access to resources and technical knowledge (Balasha et al., 2022). As a result, their ability to participate fully in agricultural activities is hampered.

TABLE 7 Empowerment determinants by sex.

Empowerment_category	Male			Female		
	Coeff	Std. Err.	p-value	Coeff	Std. Err.	p-value
STIB	2.1567	0.5310	0.000	4.9027	0.6454	0.000
Age	0.0342	0.0152	0.025	0.0059	0.0140	0.673
Marital status	4.7514	0.7657	0.000	4.8259	0.5813	0.000
Workload	-0.1377	0.1786	0.441	-0.1506	0.1716	0.380
LandTenure	1.0193	0.4423	0.021	0.9000	0.3795	0.018
AccessHealthServices	0.0530	0.4370	0.903	0.7751	0.3859	0.045
MechanizedFarmOperations	0.2240	0.4971	0.652	1.8317	0.4131	0.000
Dependency	0.2859	0.1907	0.134	-0.2139	0.1070	0.046
UU_Participation	4.9360	1.1957	0.000	2.7714	0.6138	0.000
GovtSupport	0.2395	0.4119	0.561	0.2027	0.3669	0.581
CommunitySupport	0.0824	0.5041	0.870	0.8871	0.3938	0.024
OffFarm_Income	1.0675	0.5285	0.043	1.1158	0.4903	0.023
/cut1	4.3568	1.3170		4.4114	1.2500	
/cut2	8.0422	1.4753		7.5607	1.3414	
Number of observations	259			483		
Likelihood ratio chi-square (LR chi2(12))	174.29			464.23		
p-value	0.000			0.000		
R ²	46.85			61.73		

/cut1 and /cut2 represent threshold parameters (cutpoints) in the ordered logistic regression model, indicating the boundaries between empowerment categories (Not Empowered, Partially Empowered, and Empowered).

Socio-technical innovation bundles showed potential for transformative impact, alleviating the challenges faced by smallholder farmers. STIBs provide holistic solutions integrating access to technologies, capacity building, and social support (Barrett et al., 2020; Nchanji et al., 2023b,c). These pathways of influence are multifaceted, enhancing farmers' decision-making capacity by promoting farmer participation in farmer groups, thus fostering collective actions and access to resources. Moreover, through technical training and knowledge sharing, STIBs equip farmers with the necessary skills to adapt and better use innovations to improve productivity and resilience. Social innovations that constitute STIB create enabling environments such as institutional support and policy frameworks that facilitate equitable access to opportunities, particularly for women, who are the most marginalized group. The pronounced influence of STIBs on female farmers' empowerment indicate the ability of STIBs to address structural barriers. This helps farmers, more so women, to overcome innovation trade-offs and foster greater inclusion, positioning them as key drivers of agricultural transformation (Barrett et al., 2020). Therefore, as STIBs reduce the effect of demographic, socio-economic, and gender disparities, the relative gains from STIBs become more transformative for female farmers compared to male farmers.

Age had a significant positive influence on empowerment of male farmers ($\beta = 0.034$, $p = 0.025$) but showed no significant influence on female farmers empowerment. As male farmers age, they solidify their influence on decision making, expand their networks, hold leadership positions, access more resources and accumulate experience (Taramuel-Taramuel et al., 2023). Over time, they are more adaptable to changes in agricultural practices and access to markets. By contrast, women farmers may not experience the same because they are faced with gender-specific barriers and cultural norms that limit their access to resources, decision-making power, and opportunities for leadership (Idu et al., 2023; Arintyas, 2024). The disparity reveals the influence of social and cultural norms on female farmers' roles, influence, and empowerment.

Smallholder farmers empowerment was significantly influenced by marital status for both male and female farmers ($p = 0.000$). The effect of marital status on empowerment was notably strong with coefficients of 4.751 for male farmers and 4.826 for female farmers, suggesting that being married possibly provides social and economic stability, resulting in enhanced access to resources and decision-making power. The findings echo the findings of Malabayabas et al. (2024), who also found that marital status correlates with better access to agricultural resources and social capital, which is critical for empowerment. Besides, married individuals benefit from pooled resources and collective decision making leading to increased agricultural productivity, hence high levels of empowerment (Kapelle et al., 2022).

Secure land tenure is critical for empowerment as demonstrated by the findings which revealed that it has a positive significant effect for both male ($\beta = 1.019$, $p = 0.021$) and female farmers ($\beta = 0.900$, $p = 0.018$). Access to secure land rights enhances the ability to adopt improved farming technologies, access resources and influence decisions (Lawry et al., 2017). Among female farmers, secure land tenure is essential in helping overcome traditional barriers to market participation, resource access and decision-making power thus contributing to greater autonomy and empowerment (Rizzo et al., 2024; Khouilla and Bastidon, 2024). Secure land tenure is critical in

promoting investment which in turn help improve the livelihood of smallholder farmers leading to transformative effect of both male and female farmers empowerment.

Access to health services had a significant impact on the empowerment of female farmers ($\beta = 0.775$, $p = 0.045$) but not for male farmers. For women, access to health services is possibly tied to improved well-being and labor productivity, which enhances their ability to participate in farming and community activities. Improved health can lead to greater involvement in decision-making processes and the adoption of sustainable farming practices reiterating the findings of Meizen-Dick et al. (2014), who emphasized that access to health services is particularly empowering for women. Access to health care not only improves physical capacity but also increases women's social capital and economic opportunities. For men, however, the results suggest that health services might not be a key determinant of empowerment, potentially because male farmers have different health-seeking behaviors compared to women. Male farmers often seek health services less frequently, which may make health services not to have the same effect on their empowerment as female farmers (Parent et al., 2018). Besides male farmers tend to have access to other resources which are conventionally stronger determinants of empowerment, and so health services might not play as central a role in influencing their overall empowerment.

Mechanization significantly influenced female farmers empowerment but not male farmers ($p = 0.000$). A unit increase in farm mechanization increased the odds of female farmers empowerment by 1.832 units. Farm mechanization plays a crucial role in reducing the labor burden for women, who traditionally engage in more labor-intensive farm tasks. By adopting mechanized equipment, female farmers can save time and energy, which can be redirected towards more productive activities such as market engagement or leadership roles within farming communities. This finding is consistent with Beuchelt and Badstue (2013) assertion that agricultural mechanization significantly reduces gender-based disparities in agricultural productivity by alleviating women's workload and increasing their control over agricultural activities. In contrast, men may already have better access to mechanized tools, which explains the less significant impact in their case.

Household dependency, the ratio of non-working individuals to economically active individuals in a household, negatively affected the empowerment of female farmers ($\beta = -0.214$, $p = 0.046$) but was not significant for male farmers. High dependency ratios often strain resources and reduce the ability of farmers, especially women, to invest in farming inputs or participate in community initiatives. This is consistent with the findings of Quisumbing and Maluccio (2003), who explained that higher dependency ratios disproportionately affect women, as they are often the primary caregivers and face greater time constraints, limiting their empowerment and participation in economic activities.

Participation in HER+ initiative's activities (UU participation) had a strong and significant impact on empowerment of both male ($\beta = 4.936$, $p = 0.000$) and female ($\beta = 2.771$, $p = 0.000$) farmers. HER+ initiatives activities engaged farmers in agricultural training, boosting their empowerment by enhancing their knowledge, providing access to resources, and fostering community support. The results reiterate that participation in project activities and community groups enhances farmers agency and decision making

(Meinzen-Dick et al., 2014). Among male and female farmers participation in project activities is critical in enhancing farmers skills and networks, necessary to improve their agricultural productivity and social standing.

Community support had a significant impact on the empowerment of female farmers ($\beta = 0.887, p = 0.024$) but not on male farmers ($\beta = 0.082, p = 0.870$), indicating the importance of social networks and community structures in empowering female farmers. Social capital is critical for the empowerment of female farmers. It helps address female farmers limited access to formal institutions such as credit markets or government programs (Machio et al., 2024). Women's groups, local organizations, and informal networks can provide essential support in terms of knowledge sharing, access to markets, and collective bargaining. This finding echoes the work of Agarwal (2018), who emphasized that women's participation in community-based organizations can significantly enhance their decision-making power and access to resources, particularly in agricultural settings.

Off-farm income had a significant positive effect on empowerment for both male ($\beta = 1.068, p = 0.043$) and female ($\beta = 1.116, p = 0.023$) farmers. Diversifying income sources beyond agriculture allows farmers to improve their financial stability and invest in their farming operations, which in turn enhances their decision-making power and social standing. Access to off-farm income can help mitigate the risks associated with agriculture and provide additional capital for farm inputs and innovations. The positive relationship between off-farm income and empowerment is reiterated by Das (2014) and Maligalig et al. (2019), who found that income diversification is a key factor in improving resilience and empowerment among smallholder farmers.

4 Conclusion

Smallholder farmer's empowerment is multidimensional, encompassing social and technical capacities. Socio-technical innovation bundling has emerged as a potential solution to enhance farmers' empowerment. This study set out to examine the effect of socio-technical innovation bundles on male and female farmers' empowerment. The findings reveal that STIBs play a critical role in enhancing farmers' social and technical capacities, significantly improving their empowerment levels and enabling them, particularly women, to achieve higher degrees of decision-making and resource access. As a result, farmers are enabled to act on their choices and influence their own circumstances. STIB's holistic approach to overcoming barriers in agriculture appeals to women farmers and enhances its suitability in addressing existing gender gaps. The findings contribute to the body of knowledge on the intersection of technology and social aspects in empowering smallholder farmers by offering actionable insights for stakeholders to design and implement gender-sensitive innovations to address existing gender disparities in empowerment in the agri-food systems.

The results suggest that STIBs improve farmers' decision-making capacity, fostering greater participation in agricultural activities. Therefore, STIBs are practical tools that can be incorporated into the agri-food system to address gender disparities. STIB's context-specific approach ensures equitable

empowerment outcomes. The implications of this study are crucial for policy and practice, highlighting the transformative potential of STIB in empowering smallholder farmers. The incorporation and scaling of STIBs in the agri-food system is thus a potential strategy that can be adopted to help realize sustainable and gender-sensitive agricultural production among smallholder maize and bean farmers. This study thus lays the foundation for future studies on interventions aiming to achieve equitable and sustainable agricultural development.

This study has limitations. The cross-sectional design limits causal inference and does not permit tracking empowerment trajectories over time. Ideally, longitudinal data measuring the same farmers before and after exposure to gender-inclusive STIB interventions would provide stronger evidence of impact. In the absence of such baseline data, non-UU farmers serve as a comparison group approximating conditions without gender-targeted interventions. However, this approach assumes pre-intervention comparability between groups—an assumption partially addressed through quasi-experimental sampling and regression controls.

The study employed quasi-experimental design which while appropriate for examining real-world program effects, has inherent limitations for causal inference. In this study UU farmers were recruited by HER+ through systematic targeting rather than random assignment, which may have introduced selection bias despite the random control selection and covariate adjustments. Therefore, the findings demonstrate strong associations between STIB participation and empowerment rather than definitive causal proof. These associations remain substantively important for understanding gender-inclusive innovation outcomes in actual implementation contexts and provide a foundation for future causal studies. Therefore, future research employing panel data or baseline-endline designs would strengthen causal claims regarding the effects of gender-inclusive STIB co-design on empowerment.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by Institutional Review Board (IRB) of the Alliance of Bioversity International and CIAT. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required from the participants or the participants' legal guardians/next of kin because The IRB of the Alliance of Bioversity International and CIAT determined that the study was exempt from full ethical review based on minimal risk to participants. The approved protocol involved the use of anonymized survey data and verbal informed consent procedures, which were deemed sufficient for ethical compliance under the exemption criteria. Therefore, written informed consent was not required. This study was reviewed and approved by the Institutional Review Board (IRB) of the Alliance of Bioversity International and CIAT, Reference number: 2023-IRB50.

Author contributions

VN: Formal analysis, Writing – review & editing, Methodology, Writing – original draft, Conceptualization. OA: Writing – review & editing, Supervision, Writing – original draft, Methodology, Conceptualization. CL: Writing – original draft, Conceptualization, Writing – review & editing, Validation, Methodology, Data curation. EN: Funding acquisition, Writing – review & editing, Supervision, Writing – original draft, Validation, Conceptualization, Investigation.

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Conflict of interest

The author(s) declared that this work 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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