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Uptake determinants of climate-smart agricultural practice for greening smallholder groundnut value chain: Evidence from Malawi

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A R T I C L E I N F O

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A B S T R A C T

Crop value chain greening projects can increase sustainability amidst the numerous difficulties facing agroecosystems due to degradation caused by overuse and climate change. Over the last few decades, external aid/support has been the main driver of food value chain greening efforts. One such initiative is the Sustainable Agriculture Production and Marketing for Rural Transformation (SAPMaRT) project, implemented to green Malawi's groundnut value chain. There is limited evidence on determinants of project participation and uptake of innovative practices among groundnut smallholders in Malawi. What determines agricultural project participation and the uptake level and intensity of promoted greening practices? We collected data from 244 households that participated in two SAPMaRT project districts, Kasungu and Mzimba. The binary probit and poisson regression models were used to assess the factors influencing project participation and groundnut greening practices (GPs) uptake. We found project participation's positive and significant effect on GPs' uptake level and intensity. Education level, household size, climate awareness, and extension positively influenced project participation. Project participation, education level, age, and extension positively influenced the uptake level of GPs. However, the age of the household head was a negative determinant of the uptake level of GPs. The key determinants of uptake intensity were household head project participation, education level, land size, and extension. Our findings suggested that funded project participation enhances the uptake of agricultural interventions among smallholders.

1. Introduction

Climate change and soil fertility decline are major problems facing smallholders, leading to low agricultural productivity and severe hunger (Teshome et al., 2021; Mairura et al., 2022; Asule et al., 2024). Increases in temperature, prolonged droughts, floods, and invasive pests in sub-Saharan African (SSA) countries are the major climate change events that aggravates food insecurity and poverty levels (Burck et al., 2019). Nutrient mining over time has led to low land productive capacity (Ansari, 2022). These problems are intense in most developing countries, including Malawi, where agroecosystems are predominantly rain-fed and managed by smallholder farmers (Madsen et al., 2021).

Over the last decades, climate-related disasters have increased in Malawi, increasing food insecurity and poverty (World Bank Group, 2022). The average annual temperature has increased by 0.2 °C; however, information on rainfall variations is limited (World Bank Group, 2022). Malawi is experiencing a decline in rainfall coupled with erratic and unpredictable patterns (International Water and Sanitation Centre (IRC), (2021). The planting season has been shifting, and the country has experienced shorter seasons (Vizy et al., 2015). In recent years, tropical cyclones and droughts have intensified extreme weather events in Malawi(Baquie and Fuje, 2020). These factors and extreme poverty levels have manifested a continued decline in the country's food productivity.

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Climate-resilient crops can enhance agricultural sustainability to curb climate change and environmental degradation (Simtowe et al., 2012; Govind et al., 2021). Climate-resilient crops can thrive under low and unreliable rains. Promoting climate-resilient crops in Malawi could overcome the continued crop failures and low productivity caused by erratic rains and landscape degradation. Groundnut (*Arachis hypogaea*), a climate-resilient crop, is one of Malawi's most important legumes that significantly contribute to food security and income (UNDP, 2023). Despite the importance of climate-resilient crops, soil infertility, climate change, aflatoxin contamination, low use of productivity-enhancing technologies, and dysfunctional markets affect the performance of groundnut farm systems (Anitha et al., 2019). Under optimal management approaches, groundnut productivity in Malawi may reach potential yields of 2500 kg ha^{-1}; however, it only produces actual yields of between 322 and 1057 kg ha^{-1}. Promoting a sustainable value chain in Malawi is essential for enhanced food security and income among smallholders.

The greening approach, including the incorporation of climate change response strategies into the groundnut value chain (Teklewold et al., 2013; Konja, 2021), is essential for enhancing sustainability in the groundnut cropping system (Madsen et al., 2021). Value chain greening in the groundnut cropping system delves into improving economic gains and social benefits through implementing environmentally friendly practices (Sekaran et al., 2021). Therefore, the value chain greening approach is essential in promoting food system sustainability. The greening of the value chain occurs at different stages, including input acquisition, production, harvesting, post-harvesting, processing, aggregation, and marketing (AGRA and UNDP, 2020). A holistic approach is accentuated to ensure sustained growth from input acquisition to marketing. Due to its susceptibility to climate variability and declining soil fertility, Malawi's groundnut value chain stands to gain greatly from the greening method (Aberman and Roopnaraine, 2020).

We used the case study of The Sustainable Agriculture Production and Marketing for Rural Transformation (SAPMaRT), a 2-year program funded by Global Environmental Facility through UNDP and AGRA in 2020, to determine key factors that lead to smallholder participation in promoting and using sustainability practices. The promoted GPs are similar to climate-smart agriculture and sustainable agricultural practices promoted across different crops in sub-Saharan Africa (Simtowe et al., 2012; Bouwman et al., 2021). However, information on GPs uptake or project participation in Malawi remains scanty and based on a few technologies (Amadu et al., 2021). This study aims to (i) assess the determinants of project participation in Malawi and (ii) evaluate the determinants of uptake level and intensity of climate-smart agricultural practices in Malawi.

This paper adds three unique contributions to literature. First, it establishes the determinants of participation in greening projects using a groundnut value chain greening case study as the evidence points. Second, it identifies the uptake levels of groundnut greening practices under funded project participation, thus enhancing understanding of the practices that smallholders prefer under-aided programmes that they could not implement without the financing. Thirdly, it enhances evidence regarding the factors influencing smallholders' level and intensity of GP uptake and how incorporating these factors into policy formulation may increase the value chain's sustainability in Malawi and other countries.

2. Review of empirical studies

Previous research in SSA has revealed that the uptake of innovative practices could be determined by farmer, farm, and institutional factors (Simtowe et al., 2012; Musafiri et al., 2022c; Ngetich et al., 2022). This paper focuses on the factors influencing Malawian smallholders' adoption of groundnut greening techniques. Soil fertility decline and climate variability are major drawbacks hindering enhanced agricultural productivity in most developing countries (Maharjan and Joshi, 2013; Teshome et al., 2021). Smallholders may choose to implement one or several GPs to combat climate variability and declining soil fertility effects. Smallholders uptake a practice if they believe the advantages outweigh the drawbacks in line with the utility maximization theory. Adopting one practice can lead to the adoption of others (Musafiri et al., 2022b). This study shows the socioeconomic, institutional, and biophysical factors influencing smallholders' project participation, uptake level, and intensity.

We had three hypotheses. First, involvement in the SAPMaRT project may be influenced by socioeconomic, institutional, and biophysical characteristics, such as experience, age, education, household size, acreage, extension access, and climate change awareness (Masud et al., 2017; Udimal et al., 2017; Amadu et al., 2021). Second, GPs uptake level can be predicted by the SAPMaRT project participation level as well as socioeconomic, institutional, and biophysical factors (Melesse, 2018; Musafiri et al., 2022b; Khatibi et al., 2021). Finally, the socioeconomic, institutional, and biophysical factors—education, family size, land, extension access, and climate change awareness—as well as the SAPMaRT project participation may account for the intensity of GPs uptake (Ehiakpor et al., 2021; Martey and Kuwornu, 2021).

Project participation influences the uptake level and intensity, which could be supported by the fact that the project acts as an empowerment platform for smallholders (Snapp et al., 2019). Through the project, the smallholder farmers learned the applicability of various GPs. Furthermore, the projects supply smallholders with GPs and offer coordinated training (Amadu et al., 2020; Okumu et al., 2023), which increases the probability of GPs uptake level and intensity. Farmers can experiment and adopt greening measures with the help of projects like SAPMART, which serve as proof points and give the necessary information.

3. Materials and methods

3.1. The SAPMaRT project and study area

The SAPMaRT project was implemented in Kasungu and Mzimba districts in Malawi's Central and Northern regions. The population in Kasungu is 842,953 people, and the population density is 107 people per square kilometre (National Statistical Office, 2018). The population in Mzimba is 936,250 people, and the population density is 90 people per square kilometre (National Statistical Office, 2018). The regions experience sub-humid to semi-arid climatic conditions. The districts are vulnerable to climate change due to erratic and unreliable rainfall and prolonged dry spells during cropping. The project site experiences annual rainfall ranging from 800 mm to 1500 mm. The area has an annual average temperature of 19 °C–23 °C. Predominant soil types are Acrisols and Arenosols. Crop farming is a major economic activity. The predominant crop grown in the area is Groundnut (*Arachis hypogaea* L.) (Nzima et al., 2014). Smallholders dominate the sector, producing 80 % of all the food consumed locally (David-Benz et al., 2022). Population pressure and climate change exert pressure on smallholder farming systems. The SAPMaRT project promoted the uptake of eleven GPs, namely double-row planting, inoculants, Aflasafe ™, crop rotation, cover cropping, drought-resilient varieties, agroforestry, organic inputs, conservation tillage, and mulching for enhanced sustainability of the groundnut value chain. The project stakeholders developed an elaborate training pathway using village-based Advisors (VBAs). Additionally, the dissemination of the GPs was anchored on practical and interpersonal approaches, including workshops, farmer field schools, farmer field days, and farmers' demonstration plots.

3.2. Project partners

The SAPMaRT project relied on multistakeholder platforms to implement the project activities. The main stakeholders were AGRA, United Nations Development Programme (UNDP) African Fertilizer and Agribusiness Partnership (AFAP), Milele Agro-Processing Malawi

Limited, Fortune Gardens Investments, Agro-Input Suppliers Limited, local administration, Ministry of Agriculture and extension systems. The AFAP was in charge of the overall project coordination and capacity building. AGRA and UNDP, served as the project's pillars by assisting the stakeholders in creating value chains that are robust and sustainable. The AFAP was responsible for the coordination of project partners. Private actors, including Milele Agro-Processing Malawi Limited, Fortune Gardens Investments, and Agro-Input Suppliers Limited (AISL), were responsible for developing and disseminating the GPs. For instance, the AISL developed and jointly distributed greening practices, including inoculants, Aflasafe ™, and solubilizers. The project promoted the GPs among smallholders using a coordinated extension system. The AGRA recruited and trained the Village Based Advisors (VBAs).

3.3. Conceptual framework and determinants identification

The framework begins with SAPMaRT project participation among smallholders in Malawi (Fig. 1). Various greening technologies were promoted, including Aflasafe™, inoculants, double-row planting, crop rotation, and organic inputs. The greening practices are aimed at addressing the three pillars of sustainability: economic, social, and environmental feasibility. The green groundnut value chain refers to optimizing economic and social factors in an environmentally sustainable manner. This calls for proactively changing every step of the value chain and its associated activities to make sustainable use of natural resources to reduce harmful environmental effects and benefit communities and the natural world (Hilmi, 2016). Moreover, the practices, either in isolation or collectively, have been developed, tried, tested, and proven vital in enhancing productivity and sustainability. Therefore, the project approach is an important entry point for practically strengthening the uptake of the practices. The project employs an elaborate extension system (sources and methods) to promote the diffusion of innovations.

The success of GPs uptake results from the decentralized dissemination using the VBA model. Following the successful dissemination of the GPs, smallholders decide whether to implement them or not. Smallholders uptake a new practice based on expected utility. The diffusion of innovations is the foundation for the penetration of greening practices (GPs) in the population (Rogers, 1962). The uptake of GPs is crucial in enhancing the production process' sustainability (environmentally friendly, economically beneficial, and socially acceptable). Green technologies are vital in fostering environmental benefits (improving soil fertility and retention while lowering land degradation and pest & disease infestation), economic gains (increased yields), and social gains (gender-sensitive practices). The improved land capacity produces higher yields. The realized yields are proportional to returns. Smallholder groundnut farmers with higher yields could realize better returns or profits (Alwang et al., 2019). Therefore, increased yields lead to higher market participation (the ratio of market yields to the total yields). The increased market participation results in higher income for the smallholders.

The uptake of labour-saving practices fosters gender mainstreaming. Most of the smallholders are employed in the value chain. *Ceteris paribas*, increasing supply counter the demand for the product, thus fetching lower prices. This leads to low/ affordable groundnut prices in the overall markets. As a result, most of the community members can afford food, thus food security: increased food availability and accessibility resulting in reduced malnutrition among the population. Integrating economic, environmental, and social gains fosters sustainability.

3.4. Data collection and description

Data from two SAPMaRT project districts (Kasungu and Mzimba) were gathered for this study. We used a household-level questionnaire administered to household heads on socioeconomic, institutional, biophysical, climate awareness, and climate change adaptation. First, we

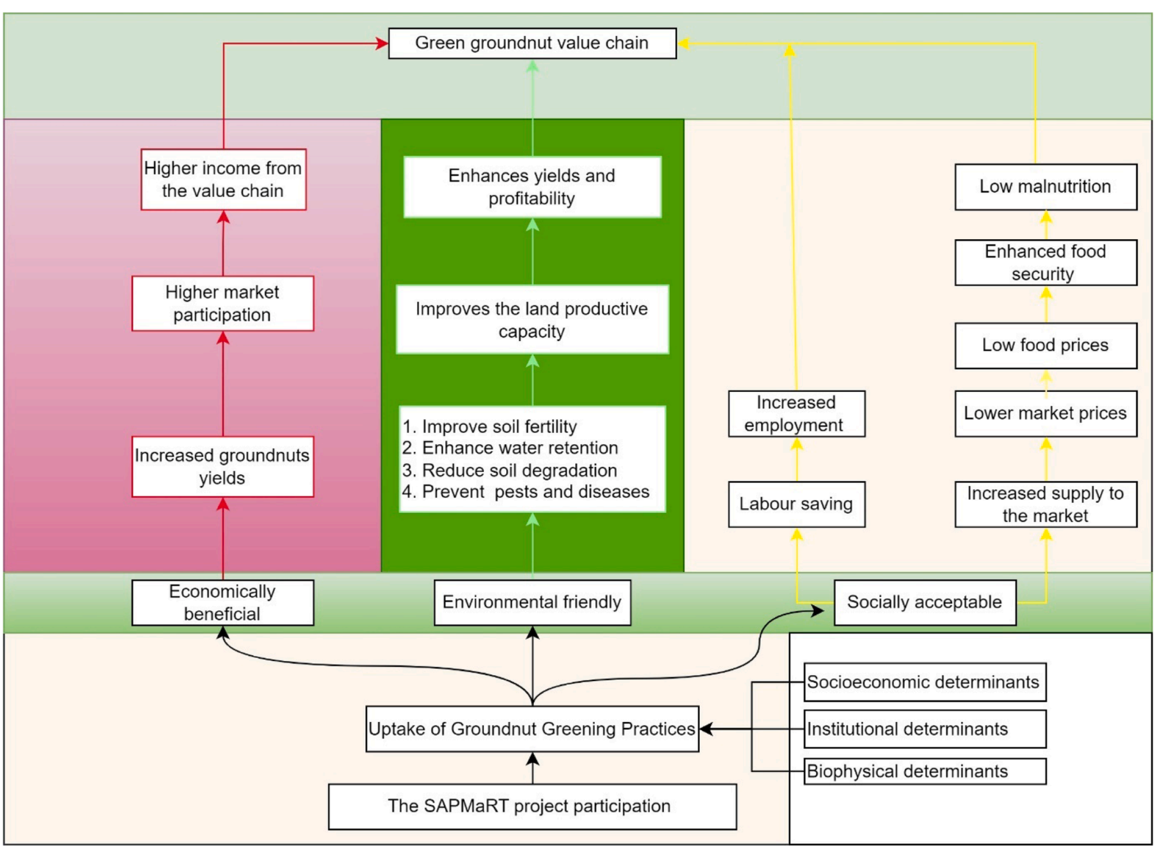

Fig. 1. The pathway of greening groundnut value chain. Motivated by Alwang et al. (2019).

trained enumerators from the local administrative area for data collection. Therefore, they were fluent in both the local dialect and the national language. The trained enumerators took part in piloting the research tool. We randomly sampled 244 smallholders, including 125 participants and 119 non-participants. We used an Open Data Kit (ODK) mobile app for data collection. Digital tablet data collection techniques helped to minimize data entry errors. The questionnaire had the following key sections: demographic (socioeconomic, institutional & biophysical), extension access, climate change awareness, and climate change adaptation. The demographic components captured different determinants. The second section highlighted the extension dissemination to smallholders, including extension access. Smallholders were asked if they knew about climate change during their conversation with the enumerators. The respondents were asked to enumerate contributors and consequences of climate change. Further, the respondents (smallholder farmers) identified responses and coping mechanisms in their groundnut fields.

3.5. Analytical approach

We analyzed the data in STATA version 15. The data were first cleaned, coded, and checked for consistency. First, we performed descriptive statistics such as frequency (percentage) and mean (standard error of the mean). Second, we tested for association between groups (Participants and non-participants) using a *t*-test. Finally, we performed binary and poisson regression to establish the determinants of project participation, GPs uptake level, and intensity.

We determined the reliability of the preference-extension methods using Cronbach's alpha test (Cronbach, 1951). In this study, the preference for the extension method had four constructs. The study revealed Cronbach's alpha coefficient of 0.83, which was greater than 0.7, thus making it reliable for measuring preference. Following Musafiri et al. (2022a), we used the Weighted Average Index (WAI) to rank the preference for extension methods and GPs among smallholders in Malawi.

We used binary probit regression to evaluate the factors influencing SAPMaRT project participation and GPs uptake level, similar to Pilarova et al. (2022). We tested whether regression analysis was justifiable using independent variables correlation and multicollinearity tests. The finding showed that the correlation coefficients were below 0.3, the variance inflation factor was below 2, and the tolerance was above 0.5. The results suggested that the variables were not correlated, and the binary probit regression was applicable (Othuon et al., 2021). The model estimates the predictors of a dummy dependent variable Tosteson et al. (1989), in this study the dummy variables are project participation, and uptake level. The binary probit model is described in Eq. (1).

$$ln\frac{p}{1-p} = B_0 + B_1X_1 + B_2X_2 + \ldots + B_nX_n \tag{1}$$

Where $ln\frac{p}{1-p}$ is the odd ratio, p is the probability of project participation/ uptake of at least one GP, i-p is the probability of the household not participating in the project or not implementing any GP, B_0 is the intercept, B1, B2 … and Bn are regression coefficients while X1, X2 and … and Xn are the independent variables.

Uptake intensity describes the number of GPs, an individual farmer implements. The number of GPs implemented by an individual smallholder farmer can be considered a count variable. Therefore, a Poisson regression model can be used to assess the determinants of uptake intensity (Musafiri et al., 2022a). However, the count variable should follow a Poisson distribution. More so, the data have equi-dispe rsion, as Greene (1997) described. We tested for over-dispersion using Deviance and Pearson goodness-of-fit tests. The Deviance and Pearson goodness-of-fit were not statistically significant at 5 %. Therefore, the findings suggested that the data were not over-dispersed, justifying using the Poisson regression model. The Poisson regression model is described in Eq. (2).

$$Prob\ (Y_i = Y_i|X_i) = f\left(x_i^{se}, x_i^{in}, x_i^{bio}\right) \tag{2}$$

Where Y_i is the GPs uptake intensity, x_i^{se} is the socioeconomic factors, x_i^{in} is the institutional factors and x_i^{bio} the biophysical determinants. Finally, we estimated the marginal effect of probit and Poisson regression to estimate the change in the dependent variable caused by a unit change in the independent variable.

4. Results and discussion

4.1. Smallholders profile in Malawi

Of the 244 sampled groundnut smallholder farmers, 125 (51.2 %) participated in the SaPMAT project under AFAP (Table 1). The findings suggested that the study collected data from approximately 50 % of project participants and non-participants. Most project participants (77.6 %) received formal education compared to non-participants (66.4 %). The findings revealed that participants were 3.1 years older than the non-participants, significant at $p < 0.05$. Regarding climate change awareness and access to extension agents, participants dominated at 99.2 % and 100 % compared to the non-participants, who had 86.6 % and 42.0 %, respectively, at a 1 % significance level.

4.2. Groundnut smallholders' perceptions of climate change

The study showed that 227 (93 %) smallholders were aware of climate change (Table 2). The results indicated that most groundnut growers were dealing with the unpredictable effects of global warming. Our findings on awareness of climate change were more than 60 % to 74 %, as indicated by earlier studies conducted in Malawi (Chisale et al., 2022). The heightened understanding of smallholders regarding climate change and its effects on their livelihoods may be ascribed to the efforts of several stakeholders in raising awareness, as suggested by Glynn et al. (2019).

Smallholder groundnut farmers believed that burning charcoal (19 %) and deforestation (72 %) were the main contributors to climate change (Table 2). These results suggested that human activity is one of the leading causes of climate change. According to Kerr et al. (2018), deforestation is the primary cause of climate change, which aligns with our findings.

Smallholders perceive climate change as leading to unreliable rains, low productivity, and droughts (Table 3). Our findings corroborated with various studies in SSA, including Kahsay et al. (2016), Mairura et al. (2021), which established that the main effects of climate change were changes in precipitation leading to erratic and unreliable rains, droughts, and low yields. We found that changes in groundnut grain yields (28 %) and frequent drought (26 %) were the expected effects of climate change (Table 3).

4.3. Extension service

Out of the sampled 244 groundnut smallholders, most of them (71 %) accessed extension services (Table 1). All the project participants had access to extension services, while only 42 % of the non-participants accessed extension services. Ragasa and Niu (2017) found that Malawi's extension access was 50 %.The access extension significantly varied between the participants and non-participants (Fig. 2). Significantly (X^2=68.18, $p < 0{,}001$), more participants (47.2 %) accessed extension through Community Agribusiness Advisors (CAAs) than non-participants (0.8 %) at 1 % level of significance. More participants (97.6 %) than non-participants (9.2 %) accessed extension services through private sectors at a 1 % significance level. The findings show the value of project participation in accessing agricultural advisory services. Similar to our study results, Zakaria et al. (2020) found that project participation improves access to agricultural extension services.

Table 1
Descriptive characteristics of the sampled smallholders in Malawi.

Variable	Pooled (n = 244)		Non-participants (n = 119)		Participants (n = 125)		Diff
	Mean	SE	Mean	SE	Mean	SE	
Gender (1=male)	0.545	0.032	0.538	0.046	0.552	0.045	−0.014
Household head education level (1=formal)	0.721	−0.112	0.664	0.0434	0.776	0.0374	−0.112**
Age of household (years)	42.0	−3.086	40.4	1.0616	43.5	0.9272	−3.086**
Experience of household head (years)	7.439	0.385	6.874	0.48087	7.976	0.59291	−1.102
Household head size (members)	−0.411	0.401	5.109	0.3724	5.520	0.1644	−0.411
Land size (acres)	1.694	0.097	1.588	0.1338	1.795	0.1403	−0.207
Renting (1=yes)	0.250	0.028	0.235	0.0390	0.264	0.0395	−0.029
Climate aware (1=yes)	0.930	0.016	0.866	0.0314	0.992	0.008	−0.126***
Access to extension (1=yes)	0.717	0.029	0.420	0.0454	1.00	0.00	−0.580***

** and *** significant at 5 % and 1 %, respectively.

Table 2
Groundnut smallholders perceptions of climate change causes in Malawi.

Cause of climate change	Frequency	Percent (%)
Climate change awareness		
Aware (1=yes)	227	93.03
Causes of climate change		
Deforestation (1=yes)	194	79.51
Charcoal burning (1=yes)	46	18.85
Poor farming methods (1=yes)	22	9.02
Industrialization (1=yes)	13	5.33
Unaware (1=yes)	13	5.33
Pollution (1=yes)	10	4.10
Overpopulation (1=yes)	9	3.69
Bush fires(1=yes)	8	3.28
Global warming and GHG emissions (1=yes)	10	4.10
God and Calamities (1=yes)	9	3.69

Table 3
Groundnut smallholders' perceptions of the effects of climate change in Malawi.

Effects of climate change	Frequency	Percent (%)
Change in rain patterns and amount (1=yes)	135	55.33
Decreased groundnut grain yields (1=yes)	70	28.69
Frequent drought (1=yes)	63	25.82
Increased soil erosion (1=yes)	20	8.2
Increased natural calamities (1=yes)	14	5.74
New pests and diseases (1=yes)	14	5.74
Increased temperature (1=yes)	10	4.1
Loss of habitat (1=yes)	10	4.1
None (1=yes)	6	2.46

The groundnut smallholders accessed agricultural advisory services through workshops, farmers' field schools, farmers' field days, and demonstration farmers' plots (Fig. 3). Participants had significantly higher access to agricultural advisory services through the four methods than non-participants at a 1 % significance level. The findings suggested that projected participation improved groundnut access to agricultural training across various methods. Given the access to extension sources and methods for participants, this could significantly influence technology uptake (Wossen et al., 2017).

4.4. The uptake level and intensity of groundnut greening technologies

The uptake of the eleven groundnut greening technologies ranged from 0.8 % to 55.3 % (Table 4). Most of the smallholders implemented crop rotation (55 %), double-row planting (53 %), and inoculants (43 %). However, the most preferred technologies were inoculants, double-row planting, Aflasafe ™, crop rotation, and drought-resilient varieties (Table 5). The high uptake and preference of the technologies showed that smallholders appreciate the climate change problems and must confront them. We found slightly low uptake levels (uptake rate of each practice) of drought-resilient varieties (21 %), agroforestry (17 %), and Aflasafe™ (15 %). However, the uptake level for organic inputs, conservation tillage, cover crops, and mulching was low. Despite the low to moderate uptake of specific practices, the uptake of at least one technology was high (94 %). The findings suggested that groundnut smallholders implemented at least one of the eleven practices in their farms. Our results agreed with Kpadonou et al. (2017), who found a greater adoption level of at least one climate-smart agricultural practice in the West African Sahel.

Of the 244 sampled groundnut smallholders, 14 (5.7 %) did not implement a single greening technology (Table 5). Of most sampled groundnut smallholders, 99 (40.6 %) implemented only one practice. Notably, 53.7 % of the smallholders were simultaneously implementing atleast two greening practices. These findings suggested that smallholders used the greening technologies jointly and not in isolation. Our results underscored the smallholder's implementation of a bundle of greening technologies. This could be attributed to the synergetic benefits of the technologies. Teklewold et al. (2013) found that several productive, sustainable agriculture techniques in Ethiopia that are in line with our findings.

4.5. Project participation and uptake of groundnut greening technologies

Education level, household size, climate change awareness, and access to extension positively and significantly influenced participation of smallholder groundnut farmers in the project. Household head project participation, education level, age and access to extension services positively and significantly influenced the uptake level of GPs. However, age in groundnut production was a negative determinant of the uptake level of GPs.The key determinants of uptake intensity were household head project participation, education level, land size and access to extension services.

The project participation positively and significantly influenced the GPs uptake level and intensity (Table 6). The findings suggested that project participants had a higher propensity to implement at least one and more GPs. Project participation could influence GPs' information access. Further, project participation enhances smallholders' knowledge of implementing target practices. Therefore, the increased uptake level and intensity of GPs with project participation could be endorsed to increase access to extension services (Fig. 2). More so, projects act as empowerment programs for farmers. The findings agreed with Snapp et al. (2019), who found that farmer-participatory research increases the adoption of sustainable practices in Malawi. Similarly, Okumu et al. (2023) found that project participation enhances agricultural innovation awareness, adoption, and general improvement of the farming sector.

The propensity of project participation and uptake level and intensity of GPs was higher among educated farmers (Table 6). Education is vital in project participation. A higher information level and understanding could have influenced smallholders with formal education to be ready for change through the uptake of innovations for enhanced sustainability. The farmers with formal education seemed to attribute

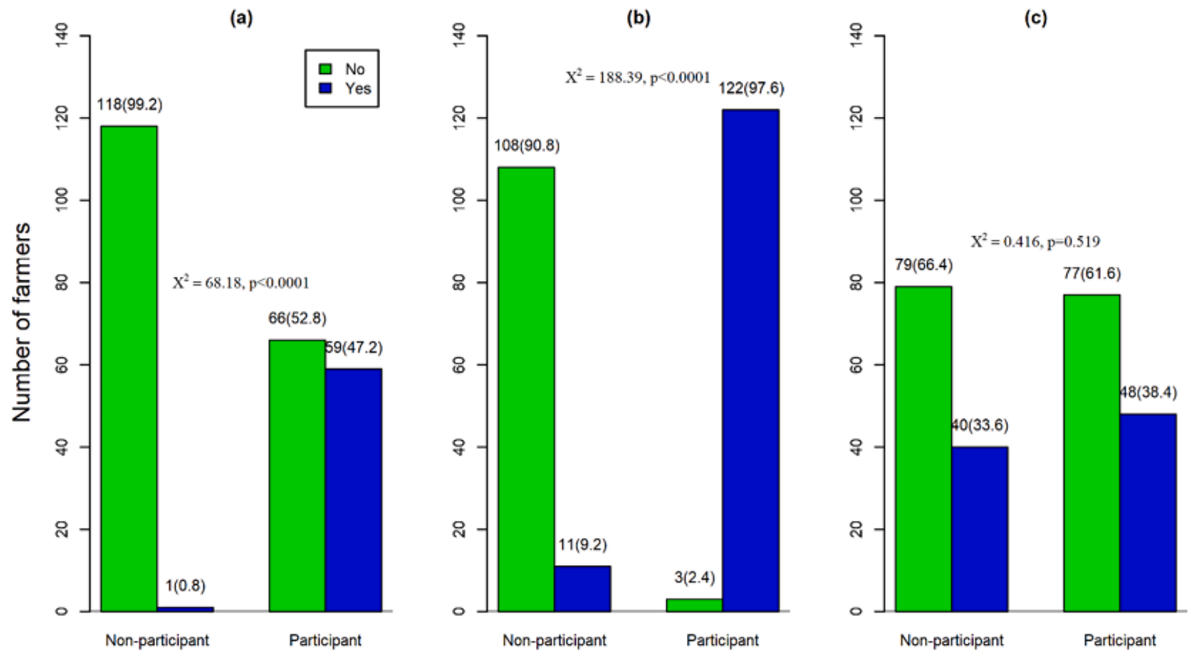

Fig. 2. Extension sources among project non-participants and participants in Malawi: (a) Community Agribusiness Advisors (CAAs), (b) private sectors, and (c) public sector.

the challenges to climate change and choose a greening pathway. More so, educated farmers seemed to comprehend technical procedures better than those with lower levels of education. In agreement with our findings, Etwire et al. (2013) revealed that knowledgeable farmers seemed to source and contextualize information, thus enhancing project participation and uptake of agricultural innovations.

Against our hypothesis, household head age positively influenced the uptake level of GPs (Table 6). Age could influence smallholder information access and resources for the uptake of technologies. Ceteris Paribas, the older farmers have more farming experience and resources than their young counterparts. Our findings agreed with Melesse (2018), who revealed that older farmers could adopt innovations due to the proximity to resources compared to their younger counterparts. Varma (2019) found that age was a positive determinant of adopting India's System of Rice Intensification technologies. Contrary to our findings, Udimal et al. (2017) found that age negatively affected the adoption of improved Rice Varieties in Ghana. They attributed it to the risk aversion nature of older farmers compared to their younger counterparts. In agreement with our findings, Asule et al. (2024) found that age was a positive and significant determinant of manure, crop residue, and intercropping in Kenya.

Contrary to our hypothesis, experience negatively predicted the uptake level of GPs (Table 6). Experience is essential in helping smallholders switch from traditional to innovative practices (Ainembabazi and Mugisha, 2014). Since most disseminated technologies are highly related and mimic traditional methods, experienced farmers seemed to adopt new technologies. However, limited information on new technologies could limit their use among experienced smallholders. Therefore, the negative prediction of the experience on the uptake of GPs could be attributed to limited information access to newly promoted practices. Further, the negative prediction could be attributed to unobserved factors such as the disadoption of the technologies (Ainembabazi and Mugisha, 2014).

Household size increased the likelihood of participating in agricultural projects (Table 6). The findings suggested that smallholders with larger families were more likely to participate in projects. The positive predictability of household size on project participation could be attributed to information diversification. Each adult household could act as a source of agricultural information. Similar to our results, Etwire et al. (2013) found that family size positively influenced smallholders' participation in mentorship projects in Ghana due to greater information sources. However, our findings were inconsistent with Jamilu et al. (2015), who established that household size negatively influences smallholders' participation in the IFAD project.

Smallholders with larger farm holdings were likelier to implement a bundle of GPs (Table 6). The findings suggested that an increase in farm size improved uptake intensity. Smallholders with larger farm sizes could try different technologies at their farms to assess performance. Additionally, larger farm sizes help realize the economics of scale in agricultural production. Therefore, smallholders with larger farm sizes could test various technologies at different plots. Our findings were consistent with Ehiakpor et al. (2021), Musafiri et al. (2022a), who established that farm size was a positive determinant of adoption intensity. Additionally, Kolapo et al. (2022) found that land size was a significant determinant of adopting multiple practices in Nigeria.

Climate awareness positively predicted groundnut smallholders' project participation (Table 6). The findings implied that groundnut farmers who were aware of climate change were more likely to participate in projects. Smallholders' awareness of climate change could also effectively affect the agricultural sector. Therefore, any information source, including projects, is their essential empowerment avenue to cope with the climate change shocks. There is a strong linkage between climate change awareness and participation in projects oriented to climate change adaptation and mitigation (Khatibi et al., 2021). Climate change awareness is the primary stage in appreciating coping options including participation in innovative projects (Masud et al., 2017).

Extension access positively predicted project participation, GPs uptake level, and intensity (Table 6). The findings suggested that smallholders with extension access are likelier to participate in projects and implement one or a bundle of GPs. Extension provides an essential platform for bridging the knowledge gap among smallholders. More so, the technologies can be practically presented to smallholders, thus enhancing the ease of use. Since information is vital to agricultural success, extension is the primary information source among smallholders. Therefore, smallholders with extension access could join projects where most technology information is generated and disseminated,

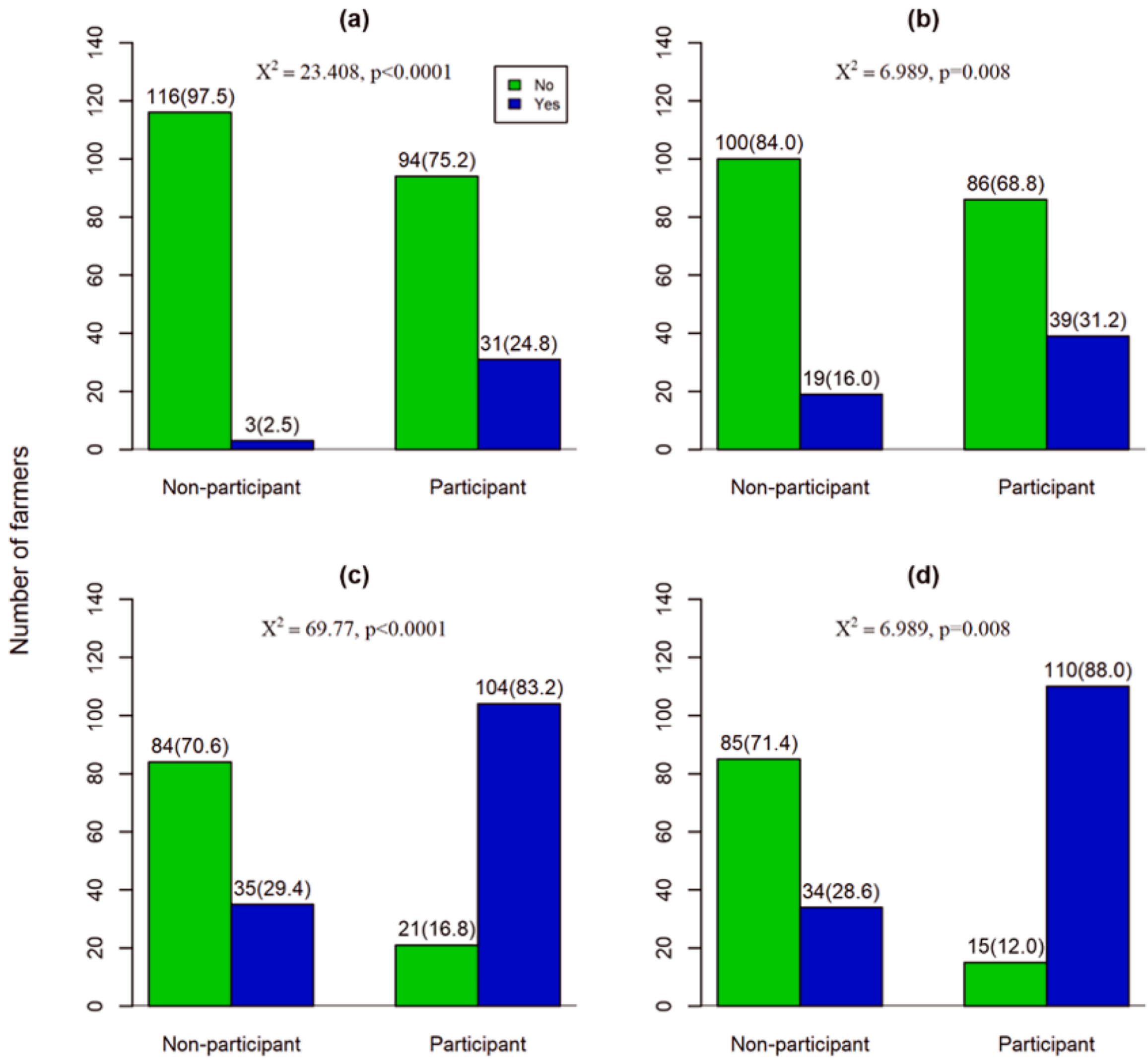

Fig. 3. Extension methods among project non-participants and participants in Malawi: (a) workshops, (b) farmer field schools, (c) farmers field days, and (d) demonstration farm plots.

Table 4
Uptake level of groundnut greening technologies in Malawi.

Greening Technology	Pooled		Non-participants		Participants	
	Frequency	Percent (%)	Frequency	Percent (%)	Frequency	Percent (%)
Mulching	2	0.82	2	1.68	0	0.00
Cover crops	3	1.23	1	0.84	2	1.60
Conservation tillage	5	2.05	4	3.36	1	0.80
Organic inputs	6	2.46	1	0.84	5	4.00
Aflasafe™	36	14.75	0	0.00	36	28.80
Agroforestry	42	17.21	5	4.20	37	29.60
Drought resilient varieties	52	21.31	9	7.56	43	34.40
Inoculant	104	42.62	22	18.49	82	65.60
Double row planting	129	52.87	34	28.57	95	76.00
Crop rotation	135	55.33	62	52.10	73	58.40
At least one practice	230	94.26	105	88.24	125	100

thus increasing uptake and intensity. Smallholders participate in extension to enhance productivity (Mamun-Ur-Rashid et al., 2017), achieved through innovative practices. In agreement with our results, Mohammed and Abdulai (2022) revealed that coupling innovative practices with extension programs enables farmers to comprehend and explore the full potential of the practices.

5. Conclusion and recommendations

We have evaluated the determinants of agricultural project participation and the uptake level and intensity of the GPs in Malawi. Greening the crop value chain approach is essential for enhancing agricultural sustainability (economic, social, and environmental). Agricultural projects, such as the SAPMaRT project, are key in improving the uptake of greening technologies. However, there is scanty evidence on the

Table 5
Uptake intensity of groundnut greening technologies.

Intensity	**Pooled**		**Non-participants**		**Participants**	
	Frequency	**%**	**Frequency**	**%**	**Frequency**	**%**
0	14	5.74	14	11.76	0	0.00
1	99	40.57	78	65.55	21	16.80
2	36	14.75	19	15.10	17	13.60
3	54	22.13	7	5.88	47	37.60
4	21	8.61	1	0.84	20	16.00
5	13	5.33	0	0	13	10.40
6	5	2.05	0	0	5	4.00
7	2	0.82	0	0	2	1.60
Total	**244**	**100**	**119**	**100**	**125**	**100**

Table 6
Factors Influencing the uptake level and intensity of groundnut greening technologies in Malawi.

Variable	Project participation		Uptake level		Uptake intensity	
	Odd Ratio	Marginal effect	Odd Ratio	Marginal effect	Coefficient	Marginal effects
Project participation (1=yes)	–	–	**1.322*****	**0.125****	**0.621*****	**0.935*****
			(0.401)	**(0.045)**	**(0.098)**	**(0.175)**
Gender (1=male)	0.144	0.043	−0.278	−0.014	−0.076	−0.150
	(0.228)	(0.068)	(0.426)	(0.019)	(0.090)	(0.179)
Education level (1=formal)	**0.447***	**0.142***	**0.182***	**0.157***	**0.191***	**0.362***
	(0.268)	**(0.090)**	**(0.067)**	**(0.008)**	**(0.115)**	**(0.208)**
Age HH (years)	−0.670	−0.199	**0.054***	**0.001***	0.139	0.274
	(0.473)	(0.138)	**(0.0310)**	**(0.001)**	(0.189)	(0.371)
Experience (years)	0.111	0.033	**−0.090****	**−0.004***	0.012	0.023
	(0.071)	(0.021)	**(0.040)**	**(0.002)**	(0.011)	(0.022)
HH size (members)	**0.137*****	**0.040*****	−0.001	−0.001	0.007	0.014
	(0.037)	**(0.009)**	(0.041)	(0.003)	(0.008)	(0.015)
Land size (acres)	−0.042	−0.012	0.121	0.007	**0.064****	**0.126****
	(0.072)	(0.021)	(0.167)	(0.008)	**(0.027)**	**(0.052)**
Renting (1=yes)	0.132	0.038	0.304	0.001	0.114	0.232
	(0.279)	(0.078)	(0.459)	(0.019)	(0.103)	(0.215)
Climate aware (1=yes)	**2.090****	**0.693*****	0.731	0.035	0.246	0.437
	(0.909)	**(0.168)**	(0.482)	(0.048)	(0.233)	(0.371)
Access to extension (1=yes)	**2.852****	**1.233****	**1.852*****	**0.233****	**0.824*****	**1.397*****
	(0.681)	**(0.562)**	**(0.501)**	**(0.068)**	**(0.131)**	**(0.183)**
Constant	−0.747		−1.398		−0.999	
	(1.847)		(1.028)		(0.702)	
Observations	244		244		244	
LR chi2	35.62		33.25		81.34	
prob>chi2	<0.0001		<0.0001		<0.0001	
Pseudo R^2	0.3706		0.341		0.4966	
Log-likelihood	−86.551		−32.157		−380.280	

determinants of agricultural project participation, uptake level, and intensity of greening practices in Malawi.

Using a case study of a greening project, SAPMaRT, we evaluated the determinants of project participation, uptake level, and intensity of GPs. The study was conducted on Malawi's sub-humid and semi-arid agroecologies, which are environmental conditions prone to climate change. We used binary probit and Poisson regression functions to evaluate the determinants of participation, uptake level and intensity among smallholder groundnut farmers in Malawi. The findings showed that participants had a 100 % uptake level compared to non-participants, who had 84 % significance at a 1 % significance level. We found project participation to positively and significantly affect GPs' uptake level and intensity. Education level, household size, climate awareness, and access to extension positively and significantly influenced project participation. Project participation, education level, age, and access to extension services positively and significantly influenced the uptake level of GPs. However, age in groundnut production was a negative determinant of the uptake level of GPs. The key determinants of uptake intensity were household head project participation, education level, land size, and access to extension services.

For improved climate change adaptation and food security, we advise project stakeholders to support the development of value chains of climate-resilient crops like groundnuts and the implementation of green practices. Access to extension services through pro-farmer strategies should be strengthened to increase project participation and the uptake of recommended practices. Stakeholder involvement in promoting the post-project adoption of the encouraged greening techniques must be taken into consideration by policymakers. More research is required to determine how involvement in projects and the implementation of various greening techniques affect the well-being of smallholders.

The study contributes to the literature on greening crop value chains by evaluating the uptake of innovative approaches between project participants and participants. More so, the study employed the concept of project funding in assessing uptake. Funding is vital in spurring rural development, where financial constraint is a major drawback.

Consent to participate

The participants were informed of the purpose of the study, and the participation was voluntary. Informed consent was first obtained from the smallholder farmers who participated in the study. The participants were assured of anonymity and confidentiality of their personal information.

Consent to publish

Not applicable.

Funding

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Ethics approval

The need for ethical approval was deemed unnecessary, according to Jaramogi Oginga Odinga University of Science and Technology ethics committee regulations.

Code availability

The STATA commands available from the corresponding author upon reasonable request.

CRediT authorship contribution statement

Assan Ng'ombe: Writing – review & editing, Supervision, Resources, Conceptualization. **Mupangi Sithole:** Writing – review & editing, Writing – original draft, Resources, Methodology, Conceptualization. **Collins Muimi Musafiri:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation. **Milka Kiboi:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Data curation. **Tomas Sales:** Writing – review & editing, Writing – original draft, Funding acquisition, Conceptualization. **Mcloud Kayira:** Writing – review & editing, Resources, Project administration, Data curation. **Felix Kipchirchir Ngetich:** Writing – review & editing, Writing – original draft, Supervision, Resources, Methodology, Investigation, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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