frontiers | Frontiers in Sustainable Food Systems

TYPE Original Research
PUBLISHED 11 June 2025
DOI 10.3389/fsufs.2025.1607687

OPEN ACCESS

EDITED BY
Liming Ye,
Ghent University, Belgium

REVIEWED BY
Sushil Kumar,
Chaudhary Charan Singh Haryana Agricultural University, India
Neetu Sharma,
SKUAST-JAMMU, India
Kim Kayunze,
Sokoine University of Agriculture, Tanzania

*CORRESPONDENCE
Busisiwe Vilakazi
✉ 219058079@stu.ukzn.ac.za

RECEIVED 07 April 2025
ACCEPTED 13 May 2025
PUBLISHED 11 June 2025

CITATION
Vilakazi B, Mafongoya PL, Odindo AO and Phophi MM (2025) Socioeconomic factors influencing smallholder farmers' willingness to cultivate neglected legumes and their selection of suitable planting dates. *Front. Sustain. Food Syst.* 9:1607687. doi: 10.3389/fsufs.2025.1607687

Socioeconomic factors influencing smallholder farmers' willingness to cultivate neglected legumes and their selection of suitable planting dates

Busisiwe Vilakazi[1,2]*, Paramu L. Mafongoya[1], Alfred O. Odindo[1] and Mutondwa M. Phophi[3,4]

[1]Department of Crop Science, School of Agricultural, Earth, and Environmental Sciences, College of Agriculture, Engineering, and Science, University of KwaZulu-Natal, Pietermaritzburg, South Africa, [2]School of Agricultural Sciences, University of Mpumalanga, Mbombela, South Africa, [3]Department of Crop Sciences, Faculty of Natural and Agricultural Sciences, North-West University, Mmabatho, South Africa, [4]Food Security and Safety Niche Area, Faculty of Natural and Agricultural Sciences, North-West University, Mmabatho, South Africa

Neglected legumes are fundamental to global food systems, contributing to agricultural sustainability, enhancing food security, and strengthening the resilience of smallholder farming systems. However, they remain underutilized and have historically received limited attention in terms of cultivation, research, and market development, despite their significant nutritional, agronomic, and environmental potential. This study assessed socioeconomic factors influencing farmers' willingness to cultivate neglected legumes and their selection of suitable planting dates in Bergville, South Africa. A simple random sampling procedure was employed to collect data from 150 farmers specializing exclusively in crop production. An action research design was implemented, comprising structured training sessions on neglected legumes and trial demonstrations. Data were collected through a structured survey questionnaire, focus group discussions, and key informant interviews. Descriptive statistics were used for analysis, and a multivariate probit model was employed to determine the socioeconomic factors influencing farmers' willingness to cultivate neglected legumes including Bambara groundnut (*Vigna subterranea*), cowpea (*Vigna unguiculata*), pigeon pea (*Cajanus cajan*), and common bean (*Phaseolus vulgaris*) and their selection of suitable planting dates. Findings confirmed that the majority of smallholder farmers primarily focus on vegetable cultivation, followed by cereals, while a smaller proportion engage in legume farming. The results also revealed that limited knowledge and resources, along with the lack of training programs and extension services specifically targeting neglected legumes, are significant barriers hindering their adoption and cultivation in the region. Furthermore, the study showed that training on legumes, marital status, farm size, market access, and water sources for irrigation were significant socioeconomic factors influencing farmers' willingness to cultivate neglected legumes, while household size, legume training, and water sources for irrigation had a significant effect on farmers' selection of suitable planting dates. These findings underscore the need for targeted interventions, including tailored training programs, improved access to resources, and enhanced extension services, to overcome these barriers and promote the adoption of neglected legumes into smallholder farmers' cropping systems.

KEYWORDS

legumes adoption, sustainable agriculture, farming systems, training programs, multivariate probit regression model, socioeconomic factors

1 Introduction

In the context of escalating global challenges such as climate change and population growth, the development and maintenance of resilient cropping systems are critical for ensuring the long-term sustainability of smallholder agriculture, enhancing food security, and improving rural livelihoods (Wijerathna-Yapa and Pathirana, 2022; Danquah et al., 2025). According to Dixon et al. (2020), cropping systems constitute the foundation of smallholder agricultural production, playing a pivotal role in food security, income generation, and environmental sustainability. These systems encompass the selection, spatial arrangement, and temporal rotation of crops within a given agricultural landscape, thereby ensuring a stable and diverse supply of food for household consumption and market sales (Nkansah-Dwamena, 2024). For smallholder farmers, well-structured cropping systems are essential in meeting dietary needs by providing access to various nutrient-dense crops, thereby contributing to food security at both the household and community levels (Pradhan et al., 2021; Mrabet, 2023). These systems are integral to sustaining rural livelihoods, as smallholder farmers often depend on their agricultural output as their primary source of income. The adoption of diversified cropping strategies enables farmers to mitigate risks associated with market volatility, pest infestations, and climate variability, thereby strengthening their economic resilience (Rosa-Schleich, 2023; Mihrete and Mihretu, 2025). Moreover, sustainable cropping systems contribute to environmental health by enhancing soil fertility, reducing erosion, and promoting biodiversity (Saliu et al., 2023). In particular, the integration of neglected legumes into cropping systems has been shown to improve soil nutrient balance and support ecological sustainability (Kebede, 2020). Given these multifaceted benefits, the promotion of resilient and diversified cropping systems is essential for advancing smallholder agriculture in the face of increasing global challenges.

The term "neglected legumes" refers to legume species that have been underutilized or overlooked in mainstream agricultural systems, despite their significant potential to contribute to food security, nutrition, and sustainable agricultural practices. According to the FAO (2017), neglected legumes are primarily grown in subsistence farming systems and are often overshadowed by more commercially viable crops. These species, also known as orphan crops, have historically received limited attention in terms of cultivation, research, and market development, despite their considerable nutritional, agronomic, and environmental benefits (Abberton et al., 2022; Odeku et al., 2024). These legumes are often indigenous or regionally cultivated but have not achieved widespread commercial recognition compared to major legumes such as soybeans or peanuts. As noted by DALRRD (2020), data on the area and production of neglected legumes in Bergville, South Africa, remain limited. However, soybeans continue to be a significant legume crop in the region, with approximately 9,929 hectares under cultivation and a total production of 52,990 metric tons. Dry beans follow with a production volume of 900 tons, accounting for only 1.3% of the national output.

However, the neglected legumes offer a range of agronomic and nutritional benefits, making them valuable components of sustainable agricultural systems, particularly within smallholder farming systems. Neglected legumes, including cowpea (*Vigna unguiculata*), pigeon pea (*Cajanus cajan*), Bambara groundnut (*Vigna subterranea*), tepary bean (*Phaseolus acutifolius*), marama bean (*Tylosema esculentum*), rice bean (*Vigna umbellata*), and moth bean (*Vigna aconitifolia*), are highly nutritious (Vilakazi et al., 2025). They are rich in protein, dietary fibre, and essential micronutrients such as iron, zinc, and folate, making them crucial for addressing malnutrition and food insecurity, particularly in regions where access to animal-based proteins is limited (Li et al., 2020; Vilakazi et al., 2025). Their diverse nutritional profile positions them as an important source of plant-based nutrition for populations facing dietary deficiencies. Neglected legumes further contribute significantly to soil health and environmental sustainability (Samal et al., 2023). Their ability to fix atmospheric nitrogen enhances soil fertility, reducing the dependence on synthetic fertilizers and promoting sustainable soil management. These legumes exhibit resilience to pests, diseases, and drought, making them well-suited for cultivation in regions characterized by erratic rainfall and prolonged dry spells (Hossain et al., 2021; Sharma et al., 2024). Their capacity to withstand both biotic and abiotic stresses enhances their reliability in ensuring stable yields under challenging environmental conditions. These multiple benefits of neglected legumes underscore their potential in enhancing agricultural sustainability, improving food security, and strengthening the resilience of smallholder farming systems. Given their adaptability to resource-constrained environments and their role in climate resilience, increased research, policy support, and market development efforts are essential to promote their wider adoption and integration into global food systems. Despite the increasing recognition of the potential benefits of neglected legumes, a significant research gap persists regarding socioeconomic factors influencing farmers' willingness to cultivate neglected legumes and their selection of suitable planting dates.

Existing research on legume integration has predominantly focused on technical aspects, including crop productivity, soil fertility enhancement, and resistance to pests and drought. Studies have documented the agronomic performance of neglected legumes such as cowpea, pigeon pea, and Bambara groundnut, highlighting their potential contributions to sustainable agriculture. However, these studies often overlook the critical role of socioeconomic factors in shaping adoption decisions and influencing the successful cultivation of these crops into existing cropping systems. In South Africa, particularly in Bergville, KwaZulu-Natal Province, smallholder farmers face various resource constraints and agroecological challenges that significantly influence their crop choices and management practices. Therefore, this study aims to address this research gap by assessing the socioeconomic factors that influence farmers' willingness to cultivate neglected legumes and their selection of suitable planting dates in Bergville. Additionally, this research provides a more comprehensive understanding of the barriers affecting the uptake of neglected legume crops. This approach not only broadens the scope of research on neglected legume cultivation but

also supports the development of targeted interventions and policies to promote the sustainable adoption of these crops in smallholder farming systems. Bridging the gap between technical recommendations and the realities of smallholder agriculture is essential to ensuring that the benefits of neglected legumes are fully realized in practice, thereby enhancing agricultural sustainability, food security, and rural livelihoods.

2 Materials and methods

2.1 Description of the study area

The study area, Bergville (28° 43′49.74"S, 29° 21′4.20"E), is located in the northern part of KwaZulu-Natal Province, South Africa (Figure 1). It falls within the Okhahlamba Local Municipality, which is part of the uThukela District. The region experiences a temperate climate, characterized by cool, dry winters with occasional frost and warm, wet summers. Annual precipitation ranges between 700 mm and 1,200 mm, with winter minimum temperatures of 2–5°C and summer maximum temperatures of 25–30°C. The altitude ranges from 1,200 to 1,800 meters above sea level. Bergville was selected as the study area due to its agro-ecological significance, which is both ecologically diverse and agriculturally important. Its climatic variability, combined with semi-arid conditions, makes the region a valuable location for studying agricultural and ecological dynamics. Rainfall and temperature fluctuations in the region have a significant impact on local livelihoods and biodiversity.

2.2 Research design

This study employed an action research design to assess farmer's knowledge on neglected legumes cultivation and integration into smallholder agricultural systems. The research employed structured training sessions and implementation of field trial demonstrations. Action research, as defined by Stringer and Aragón (2020), is a collaborative and cyclical methodology that involves researchers and stakeholders, including farmers, extension officers, and community members, working together to identify problems, implement solutions, and evaluate outcomes. This participatory approach enables the generation of context-specific knowledge through continuous reflection and adaptation, making it particularly effective for addressing complex, real-world agricultural challenges in dynamic local settings.

2.2.1 Structured training sessions

A participatory approach was utilized to design and implement practical training sessions, ensuring relevance to local agroecological conditions and smallholder farmers' needs. The training was conducted in Bergville and included selected participants from five villages: Mlimeleni, Ezimbovini, KwanoKopela, Eqeleni, and Busingatha. These villages were selected based on agroecological variation, socio-economic diversity, and the presence of resource-constrained smallholder farmers engaged in diverse farming practices prior to engagement with the Farmers' Support Group. The program focused on enhancing farmers' knowledge of neglected legumes, emphasizing their potential benefits and the adoption of

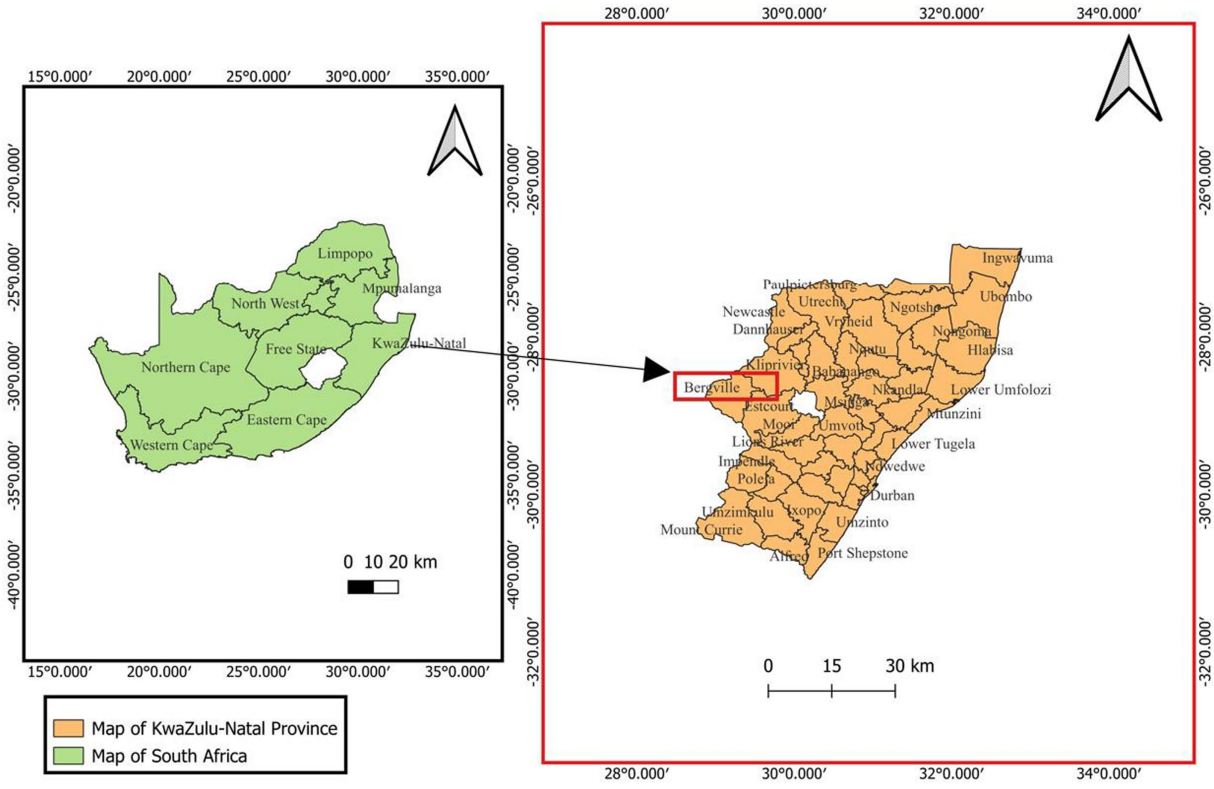

FIGURE 1
Location of Bergville in KwaZulu Natal Province, South Africa.

drought-tolerant cultivars. Key agronomic practices, including site selection, land preparation, planting, demonstration of proper plant spacing and intercropping strategies, integrated pest and disease management through intercropping, and crop rotation, were covered. Training encompassed harvesting, post-harvest handling, storage techniques to maintain quality and reduce post-harvest losses, neglected legumes value addition, product development, introduction to legume-based products such as flour, snacks, and animal feed, and market opportunities to promote sustainable production and economic viability.

2.2.2 Field trials demonstrations

Following the training sessions on the cultivation of neglected legumes, a field trial site was selected in Mlimeleni, an area characterized by a high population of smallholder farmers actively engaged in crop production. The land was prepared, and the neglected legumes including pigeon pea, Bambara groundnut and cowpea were planted alongside common bean, which is widely cultivated by farmers in the region. The legumes were planted across three various planting dates (November, December, and January) to demonstrate the agronomic performance and optimal planting dates for maximizing the productivity of neglected legumes in rainfed farming systems. These legumes were also cultivated under both sole cropping and intercropping with maize to demonstrate the stability and agronomic benefits of diversified cropping systems. All participating smallholder farmers were actively involved throughout the cultivation cycle to facilitate knowledge transfer and enhance their understanding of the adaptability and agronomic potential of neglected legumes under rainfed conditions. Given that smallholder farmers in this marginalized environment often face limited access to essential agricultural resources, including capital, irrigation infrastructure, and inputs such as fertilizers and pesticides, the trials were conducted without the application of external agricultural inputs. This approach aimed to demonstrate the resilience and sustainability of neglected legumes as climate-smart crops capable of thriving under suboptimal environmental conditions. The demonstration trials highlighted the ability of neglected legumes to enhance soil fertility through biological nitrogen fixation, thereby reducing dependence on synthetic fertilizers and promoting sustainable soil management. Furthermore, their cultivation contributes to improved biodiversity and agroecosystem resilience. The trials also demonstrated that these neglected legumes exhibit substantial resistance to pests and diseases, reinforcing their potential as viable alternatives for smallholder farmers seeking to improve food security, soil health, and environmental sustainability within resource-constrained farming systems.

2.3 Research philosophical orientation

The research was conducted based on a preliminary survey conducted to assess the status of crop diversification among smallholder farmers in the region.

2.3.1 Ontological assumption

Socioeconomic factors play a pivotal role in shaping the adoption of crop diversification, particularly the cultivation of neglected legumes and their integration into smallholder farming systems. Constraints such as limited land availability, water scarcity, restricted market access, and varying levels of education significantly influence farmers' ability to diversify their crop choices. Demographic and experiential factors, including marital status, household size, farming experience, and perceived benefits of crop diversification, further impact diversification decisions. Limited awareness or technical knowledge also serves as a barrier to diversification. Moreover, older farmers are less inclined to adopt diversified cropping systems due to factors such as risk aversion, adherence to traditional farming practices, physical limitations, and a lower propensity to embrace innovative agricultural techniques.

2.3.2 Epistemological assumptions

Farmers who perceive the potential benefits of legume crop diversification are more likely to adopt diverse cropping practices. Consequently, the cultivation of neglected legumes and their integration into smallholder farming systems can be achieved through targeted interventions designed to enhance farmers' knowledge of diversification strategies. The implementation of farmer training workshops and the promotion of participatory learning approaches can serve as effective mechanisms for knowledge transfer, ultimately fostering the wider adoption of legume crop diversification.

2.3.3 Axiological assumptions

Knowledge transfer and demonstration trials are expected to influence smallholder farmers' willingness to cultivate neglected legumes into cropping systems, providing a true reflection of the transformative experiences anticipated from this research.

Based on the synthesis of these assumptions, this study adopts a transformative paradigm. According to Dhanaraj et al. (2024), research grounded in the transformative paradigm aims to empower individuals to initiate change and take action to transform society. Education has been shown to effectively alter farmers' beliefs and behaviors, leading to long-lasting impacts. This research seeks to shift farmers' perspectives on neglected legumes, promoting the adoption of climate-resilient cropping strategies, with the goal of enhancing food security, income stability, and rural livelihoods.

2.4 Research approach

Following the structured training sessions on neglected legumes and trial demonstrations, a mixed-methods approach was employed to ensure a comprehensive analysis of farmers' cultivation and the adoption of neglected legumes into cropping systems. This approach incorporated surveys, key informant interviews, and focus group discussions.

2.5 Sampling procedure and sample size

The study adopted a quantitative research approach and employed a descriptive survey research design. According to Bless et al. (2006), descriptive and quantitative research methods are critical for examining beliefs, attitudes, and emerging patterns within a given population. The study's target population included all farmers who were affiliates of the Farmers' Support Group (FSG) at the time of the research, with eligibility limited to smallholder

farmers specializing in crop production. The FSG's criteria were to register all resource-constrained smallholder farmers in the region with diverse farming practices and socio-economic backgrounds, ensuring inclusivity and support for a broad range of agricultural activities. A two-stage sampling procedure was employed to select respondents for the study. In the first stage, purposive sampling was employed to select smallholder crop farmers from the Farmers' Support Group. In the second stage, a simple random sampling method was used to select participants from this group, ensuring adequate representation and preserving the diversity among the smallholder crop farmers. The target population comprised 240 smallholder farmers. The sample size was determined according to Yamane (1973), ensuring an unbiased and statistically representative selection of participants. This method accounts for population size and desired precision to enhance the reliability of findings. Applying a 95% confidence level and a 5% margin of error, the computed sample size comprised 150 randomly selected smallholder farmers from five villages (Mlimeleni, Ezimbovini, KwanoKopela, Eqeleni, and Busingatha) in Bergville.

The following calculation demonstrates the method used to determine the appropriate sample size.

$$n = \frac{N}{1+Ne^2} = n = \frac{240}{1+240(0.05)^2} = 150$$

Where n = sample size (150); N = population size of smallholder farmers (240); e = desired margin of error (0.05).

2.6 Data collection and analysis

2.6.1 Baseline survey

A structured questionnaire was developed as the primary survey instrument to elicit data for the study. Prior to the data collection process, four enumerators were trained to assist with data collection. In-formed consent was obtained from all participating farmers, and participation was voluntary. Data were collected through face-to-face interviews using structured questionnaires, adhering to all protocols and ethical principles outlined in the Declaration of Helsinki. The questionnaire was face and content validated by field experts in the field of agronomy to ensure relevance and applicability prior to data collection. This evaluation assessed its structure and relevance and examined whether the included variables were reasonable and clear. In addition, a reliability assessment was conducted through a pre-test to determine the instrument's stability and consistency in measuring the intended variables. The pre-test method was applied to 10 smallholder farmers from a village not included in the study. A reliability coefficient of r = 0.85 was obtained, which, according to established standards in the literature, indicates that the questionnaire was reliable (Mulaudzi et al., 2024). The survey instrument comprised sections aligned with specific study objectives, assessing socioeconomic factors influencing farmers' willingness to cultivate neglected legumes and their selection of suitable planting dates. To enhance clarity and cultural appropriateness, interviews were conducted in isiZulu, the native language of the respondents, ensuring effective communication and improving the reliability of responses. A total of 150 questionnaires were successfully administered across the five villages, with all participants being local smallholder farmers actively engaged in crop production.

2.6.2 Key informant interviews

In each of the five villages, five key informants were selected based on their roles and expertise within the community. These informants included agricultural extension officers, schoolteachers, community members, healthcare workers, and smallholder farmers. The local chief was also interviewed due to their leadership position and in-depth knowledge of the community's social, cultural, and agricultural dynamics. Community leaders, many of whom were smallholder farmers, were included to provide additional perspectives on the integration of neglected legumes. The inclusion of this diverse group of informants ensured a comprehensive understanding of local farming practices, awareness of neglected legumes, and the challenges and opportunities associated with their adoption. The insights gained from these interviews were crucial in informing the subsequent stages of the research, particularly regarding local agricultural practices, challenges, and opportunities.

2.6.3 Focus group discussions

To gain in-depth insights into the perspectives of smallholder farmers, focus group discussions (FGDs) were utilized as a key qualitative data collection method. Each FGD consisted of 10 participants, ensuring balanced representation in terms of gender and age. Participants ranged in age from ≤ 25 to 66 years. The participants were randomly selected from the villages to minimize selection bias and ensure diverse viewpoints reflective of the broader farming community. The discussions were guided by a set of open-ended questions, designed to elicit detailed and nuanced responses from participants. This approach allowed smallholder farmers to share their experiences, opinions, and challenges in an unrestricted and interactive manner. Efforts were made to create a comfortable and inclusive environment that encouraged open dialogue. While ensuring equal participation among participants presented challenges, specific measures were implemented to address this. Enumerators were trained to actively engage quieter participants, redirect dominating conversations, and ensure that each individual had the opportunity to respond to every question posed. This strategy aimed to reduce imbalances in participation and enhance the comprehensiveness of the data collected.

The survey data were imported from an Excel file into IBM SPSS (Statistical Package for the Social Sciences) software, version 30, for analysis. A systematic review of variable names was conducted to ensure clarity and consistency in coding. During the data cleaning process, missing values were identified and addressed using multiple imputation, which accounts for uncertainty by creating several imputed datasets and combining the results for robust estimation. Outliers were detected through box plots and z-scores and were excluded to maintain the dataset's integrity. Categorical variables were recoded for uniformity, with numerical codes assigned where applicable to facilitate statistical analysis. Following data preparation, descriptive statistical analyses were performed using SPSS, providing frequency distributions, percentages, means, and standard deviations for both continuous and categorical variables in alignment with the study's research objectives. Results were presented using tables, pie charts, and bar graphs to enhance clarity and interpretability. Additionally, a multivariate probit regression model was employed to

examine the socio-economic factors influencing smallholder farmers' willingness to cultivate neglected legumes and their selection of various suitable planting dates.

2.7 Model specification

2.7.1 Multivariate probit model (MVP)

The study also utilized a multivariate probit model approach to examine the socio-economic determinants of farmers' willingness to cultivate neglected legumes and their selection of various suitable planting dates. In contrast to other dichotomous models, the MVP model effectively accounts for unobservable factors that influence smallholder farmers cultivation of neglected legumes and planting dates by permitting correlation across error terms of latent equations. The identified correlations allow for error terms that indicate positive correlation (complementarity) and negative correlation (substitutability) on legumes cultivation and planting dates. In this study, the MVP model consists of four binary choice equations for neglected legumes (pigeon pea, cowpea, Bambara groundnut and common bean) and three binary choice equations for suitable planting dates (November, December, and January).

Hence, the study model is specified as:

$$P^{*}_{im} = \beta_{im} + x_{im} + \varepsilon_{im} \left(m = 1,2,3\ldots\right) \quad (1)$$

P_{im} {1 if $P^{*}_{im} > 0$ and 0 otherwise}

The above equation is formulated under the assumption that a rational i-th farm household possesses a latent variable P^{*}_{im} which captures unobserved factors influencing the m-th neglected legumes selection and planting dates (m = 4 neglected legumes selection in the first model and planting dates in the second model). X_{im} consists of exogenous variables that determine neglected legumes selection as well as planting dates, including smallholder farmers' socioeconomic attributes as detailed in Figure 2 and Table 1. The coefficients βm quantify the effects of these explanatory variables on neglected legumes selection and planting dates. The error terms ε_{im} follow a multivariate normal distribution, each with a mean of zero and a variance–covariance matrix characterized by values of 1 along the diagonal and nonzero correlations among off-diagonal elements.

2.8 Ethical consideration

Ethical clearance for this study was obtained from the University of KwaZulu-Natal Ethics Committee, facilitated by the School of Agricultural, Earth, and Environmental Sciences, under reference number HSSREC/00008179/2025. During the administration of the questionnaires, the researcher sought informed consent from the participants, ensuring confidentiality throughout the process. The questionnaires were distributed at times and locations that were convenient for the participants. Before completing the questionnaires, participants were fully informed about the scope of the study, and their anonymity was preserved by not disclosing any personal identities. The study was conducted with a strong emphasis on participant welfare, ensuring that no harm was inflicted during the process. Furthermore, all participants were acknowledged and thanked for their valuable time and contribution to the completion of the questionnaires.

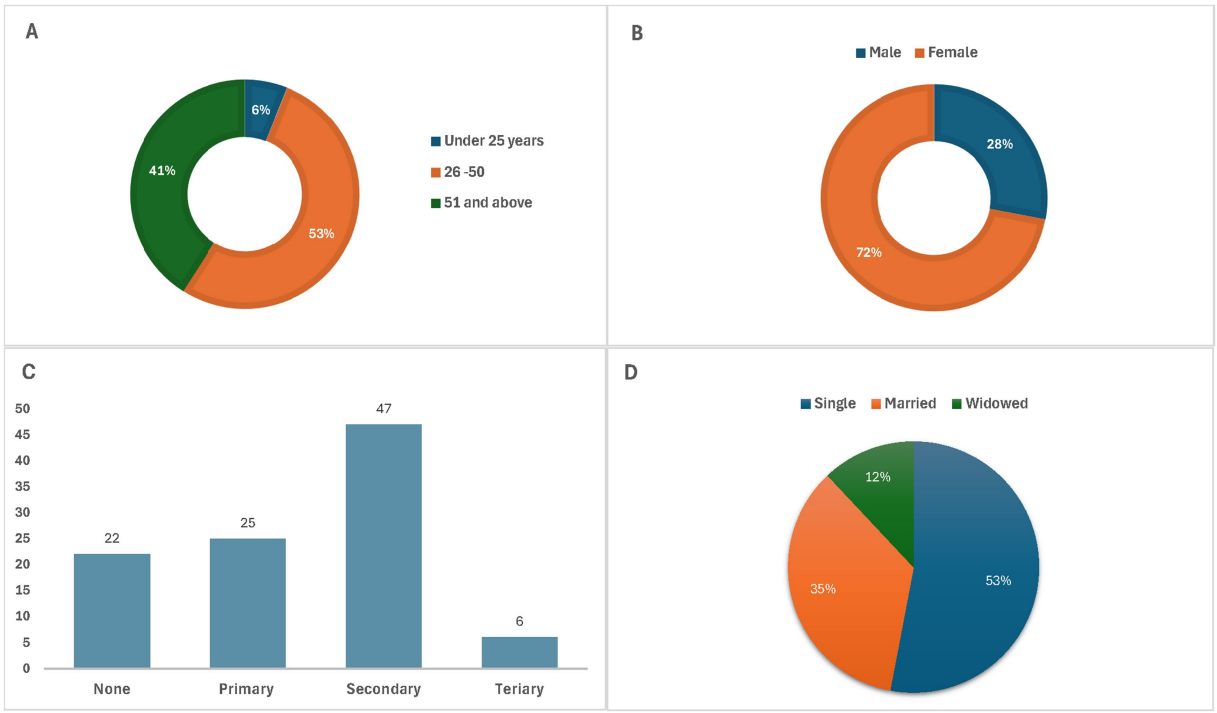

FIGURE 2
Socioeconomic characteristics of smallholder farmers. **(A)** Age of respondents. **(B)** Gender of respondents. **(C)** Respondents' education level. **(D)** Marital status of respondents.

10.3389/fsufs.2025.1607687

3 Results

3.1 Socioeconomic characteristics of smallholder farmers in the study area

The data illustrated in Figure 2 provide a comprehensive overview of the socioeconomic profile of smallholder farmers within the study area. A majority of the respondents (53%) were aged between 26 and 50 years, followed by 41% who were 51 years and above, while only 6% were aged 25 years or younger (Figure 2A). The results also showed that 72% of smallholder farmers were female, while males accounted for 28% (Figure 2B). Regarding educational attainment, 47% of respondents had completed secondary education, 25% had primary education, and 22% had no formal education. In contrast, only 6% had attained tertiary education (Figure 2C). Marital status indicated that a significant proportion (53%) of farmers were unmarried, while 35% were married and 12% were widowed (Figure 2D). As shown in Table 1, slightly more than half (51.4%) of the farmers lived in households with 6–10 members, while 31.3% had one to five members. Only 17.3% lived in households with 11 or more members. Furthermore, the findings revealed that the primary source of income for most farmers (70.7%) was welfare grants. Other sources of income included irrigated crop farming (28.7%), rainfed crop farming (13.3%), livestock sales (16.7%), remittances (20%), and temporary employment (16%). Additionally, 10% of farmers relied on other income-generating activities, such as sewing and handicrafts.

Table 1 further indicated that 66.7% of farmers primarily sourced their food from supermarkets, while 32.7% produced their own food, and only 0.7% depended on food schemes or aid programs. In terms of farming experience, the majority (85.3%) had between one and 10 years of experience, 10.7% had between 11 and 20 years, while 2% had between 21 and 30 years, and another 2% had over 30 years of experience. Land ownership showed that 92.7% of respondents owned less than two hectares of land, 6.7% owned between three and five hectares, and only 0.7% owned more than six hectares. Moreover, the findings indicated that a substantial majority of farmers (79%) had not received any prior training on neglected legumes, with only 20.7% having participated in such training before the study commenced. In terms of water sources for agricultural activities, 65.3% of farmers utilized a combination of rainfall and irrigation, while 25% relied exclusively on rainfall, and 9.3% depended solely on irrigation. With respect to seed sourcing, most farmers (71.3%) acquired seeds from supermarkets, whereas 21.3% preserved seeds from previous harvests for future use. A small proportion (7.3%) sourced seeds from institutions such as the Department of Agriculture and the Farmers Support Group. Lastly, market access remained a significant challenge, with 80.7% of farmers reporting no access to markets, while only 19.3% had market access.

TABLE 1 Distribution of the socio-economic characteristics of smallholder farmers *contd.*

Socio-economic variables	Frequency (%)
Household size	
1–5 people	47 (31.3)
6–10 people	77 (51.4)
11 and above	26 (17.3)
***Source of income**	
Temporal employment	24 (16.0)
Welfare grant	106 (70.7)
Remittances	30 (20.0)
Crop sales - irrigated	43 (28.7)
Crop sales - rainfed	20 (13.3)
Livestock sales	25 (16.7)
Other	15 (10.0)
Source of food	
Own production	49 (32.7)
Purchased	100 (66.7)
Food aid	01(0.7)
Years of farming experience	
1–10 years	128 (85.3)
11–20 years	16(10.7)
21–30 years	3 (2.0)
31 and above	3 (2.0)
Farm size (hectares)	
≤ 2	139 (92.7)
3–5 ha	10 (6.7)
6 and above	1 (0.7)
Training on legumes	
Yes	31 (20.7)
No	119 (79.)
Sources of water for irrigation	
Irrigation	14 (9,3)
Rainfall	38 (25.3)
Both	98 (65.3)
Sources of seeds	
Own production	32 (21.3)
Supermarkets	107 (71.3)
Other	11 (7.3)
Market access	
Yes	29 (19.3)
No	121 (80.7)

*Multiple choice response.

3.2 Overview of cropping practices in the surveyed region

Figure 3 provides a detailed analysis of the agricultural practices employed by smallholder farmers within the study area. A significant proportion (87%) cultivate vegetables, followed by 55% who grow cereals, while only 43% cultivate legumes (Figure 3A). Regarding cropping systems, 48% of respondents practice intercropping, 35% engage in monoculture, and 15% implement crop rotation. In contrast, only 1.3% practice relay cropping (Figure 3B). The frequency of legume cultivation varied among farmers. The majority (49%) reported never cultivating legumes, while 20% rarely grew them, and

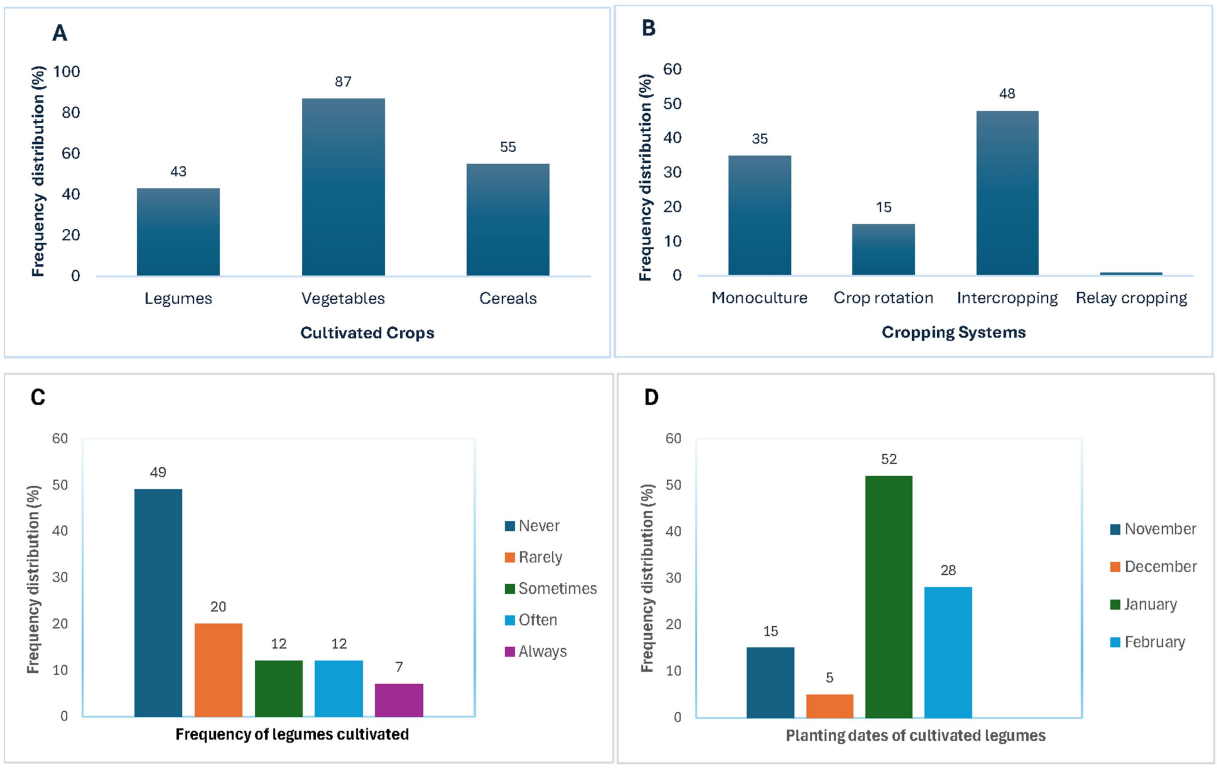

FIGURE 3
Overview of cropping practices in the surveyed region. **(A)** Crops cultivated by smallholder farmers. **(B)** Dominant cropping systems. **(C)** Frequency of legumes cultivation. **(D)** Planting dates of cultivated legumes.

12% cultivated legumes sometimes or often. Only 7% grew legumes every season (Figure 3C). Additionally, the findings revealed that 52% of farmers cultivated legumes in January, 28% in February, and 15% in November. A small proportion (5%) planted legumes in December (Figure 3D).

To verify the types of crops cultivated in the region, both key informants and focus groups reported the following:

> "Crop production in the study area is primarily focused on vegetable cultivation, followed by cereals, while a smaller proportion of farmers engage in legume farming. The predominant legumes grown include sugar bean *(Phaseolus vulgaris)*, kidney bean *(Phaseolus vulgaris)*, and cowpea *(Vigna unguiculata)*. Vegetable cultivation encompasses a wide range of crops, including spinach *(Spinacia oleracea)*, beetroot *(Beta vulgaris)*, onion *(Allium cepa)*, carrot *(Daucus carota)*, green pepper *(Capsicum annuum)*, sweet potato *(Ipomoea batatas)*, potato *(Solanum tuberosum)*, chili pepper (*Capsicum* spp.), eggplant *(Solanum melongena)*, and cabbage *(Brassica oleracea)*. The primary cereals cultivated in the region are maize *(Zea mays)* and wheat *(Triticum aestivum)*."

Regarding planting dates, focus group discussions stated:

> "Majority of farmers cultivate legumes in January, as this period experiences reduced rainfall. In contrast, excessive rainfall in December often leads to pod abortion and seed rot, making it less favorable for legume cultivation."

The focus group discussions further indicated:

> "Although nearly half of the farmers practice intercropping, primarily integrating maize *(Zea mays)* with pumpkins (*Cucurbita* spp.) *or* sugar beans *(Phaseolus vulgaris)*, a significant proportion continue to rely on monoculture. The persistence of monoculture is attributed to several factors, including limited land availability, reliance on rainfall as the primary water source for irrigation, financial constraints that hinder seed acquisition, and a shortage of labour. The challenge is exacerbated by minimal youth participation in agriculture, as younger individuals often perceive farming as an occupation primarily suited for older generations."

3.3 Training participation and knowledge of legumes in the surveyed region

A majority of smallholder farmers (79.3%) had never participated in legume training, while just 20.7% had attended such training (Table 2). An assessment of farmers' knowledge about legumes in the region revealed that a large proportion (85.3%) were unfamiliar with legume cultivars, with only 14.7% having any knowledge. Similarly, knowledge about legume production was scarce, as only 7.3% of farmers had relevant expertise, while 92.7% lacked understanding of legume cultivation. When it came to legume adaptability, only 5.3% of farmers were knowledgeable, leaving 94.7% unaware of this aspect. Additionally, understanding of the legume market was limited, with 94.7% of farmers having no

TABLE 2 Training participation and knowledge of legumes in the surveyed region.

Tested knowledge of legumes in the region	Frequency (%)	Frequency (%)
	Yes	No
a. Have you been trained on legumes before?	31 (20.7)	119 (79.3)
b. Do you have knowledge of legume cultivars?	22 (14.7)	128 (85.3)
c. Do you have knowledge of legume production?	11 (7.3)	139 (92.7)
d. Do you have knowledge of legume adaptability?	8 (5.3)	142 (94.7)
e. Do you have knowledge of legume market?	8 (5.3)	142 (94.7)

knowledge of market trends and only 5.3% possessing any insights into market dynamics.

To corroborate the challenges related to the lack of training and awareness regarding neglected legumes, as highlighted by the quantitative study, both key informants and focus group discussions emphasized the following:

> "Respondents identified a gap in knowledge and resources, which hinders the adoption and cultivation of underutilized crops. The lack of training programs and extension services specifically targeting neglected legumes was noted as a significant barrier, limiting farmers' ability to diversify their crop production. Additionally, the absence of awareness campaigns and technical support further exacerbates the issue, as many farmers are unfamiliar with the potential benefits and cultivation practices associated with neglected legumes. Consequently, these challenges contribute to the low uptake and limited cultivation of neglected legumes in the region."

One of the key informants stated:

> "The low intake of legumes in local diets is primarily attributed to their high cost in supermarkets, which limits their accessibility to many consumers. Additionally, farmers in the region tend to produce legumes in small quantities, which further exacerbates the issue by preventing the establishment of reliable local markets. The limited scale of production restricts the availability of legumes in both retail and wholesale markets, making them less competitive compared to other staple crops. Consequently, the low market supply, coupled with high prices, creates a significant barrier to increasing legume consumption. This cycle is reinforced by the lack of market infrastructure and proper supply chains, which could otherwise facilitate the distribution of legumes at more affordable prices. Therefore, addressing both production challenges and market access is critical to improving legume consumption in the region."

3.4 Pre-training knowledge levels of smallholder farmers on the benefits of neglected legumes

The results in Table 3 revealed that the majority (73.3%) of farmers had extensive knowledge of neglected legumes' richness in proteins, carbohydrates, fibre, minerals, vitamins, and micronutrients, while 26.7% had limited knowledge. In contrast, 76% of respondents were unaware that neglected legumes can help lower the risk of heart disease, diabetes, cancer, and obesity, while only 24% recognized this potential benefit. Regarding legumes' ability to improve soil fertility and reduce the need for nitrogen fertilizers through biological nitrogen fixation, only 35.3% of farmers had knowledge, whereas 64.7% were unaware of it. Additionally, 73.3% of farmers did not know that legumes can help break the cycle of pests and diseases, while 26.7% were aware of this benefit. More than three-quarters (78%) of respondents had limited or no knowledge of legumes' ability to conserve soil water, while only 22% were aware of this function. Only a small minority (5.3%) of respondents understood legumes' role in promoting ecosystem stability in marginal environments, whereas a significant majority (94.7%) lacked knowledge in this area.

3.4.1 Post-training knowledge levels of smallholder farmers on the benefits of neglected legumes

The results in Figure 4 illustrate the knowledge levels of smallholder farmers regarding the benefits of neglected legumes following the training provided by the study. A significant proportion (81%) demonstrated strong knowledge, defined as the ability to identify at least four legume cultivars and five functions of legumes. Additionally, 15% exhibited weak knowledge, characterized by the ability to name at least two legume cultivars and two functions. In contrast, only a small minority (4%) showed no knowledge, as they were unable to identify any legume cultivars or functions of neglected legumes.

3.5 Farmers' participation in neglected legume training, adoption willingness, and post-training cropping system integration

The results presented in Figure 5 indicated that a significant proportion (92%) of respondents participated in the training on neglected legumes conducted in this study, while 8% did not participate (Figure 5A). Following the training and trial demonstrations, the majority of farmers (96%) expressed a willingness to integrate legumes into their cropping systems, whereas 4% remained reluctant to adopt neglected legumes (Figure 5B). Additionally, farmers who previously practiced monoculture showed interest in adopting intercropping. Consequently, 89% transitioned to an intercropping system, while a minority (11%) preferred to continue with monoculture (Figure 5C).

3.6 Socio-economic factors influencing farmers' willingness to cultivate neglected legumes

The results in Table 4 present the socioeconomic factors influencing smallholder farmers' willingness to cultivate neglected

TABLE 3 Pre-training knowledge levels of smallholder farmers on the benefits of neglected legumes.

Tested knowledge on neglected legumes benefits	Frequency (%) Yes	Frequency (%) No
a. Neglected legumes are rich in proteins, carbohydrates, fibre, minerals, vitamins, and micronutrients.	110 (73.3)	40 (26.7)
b. Neglected legumes lower the risk of heart disease, diabetes, cancer, and obesity.	36 (24.0)	114 (76.0)
c. Neglected legumes improve soil fertility and reduce the need for nitrogen fertilizers through biological nitrogen fixation.	53 (35.3)	97 (64.7)
d. Neglected legumes break the cycle of pests and diseases.	40 (26.7)	110 (73.3)
e. Neglected legumes conserve soil water.	33 (22.0)	117 (78.0)
f. Neglected legumes promote ecosystem stability in marginal environments.	8 (5,3)	142 (94.7)

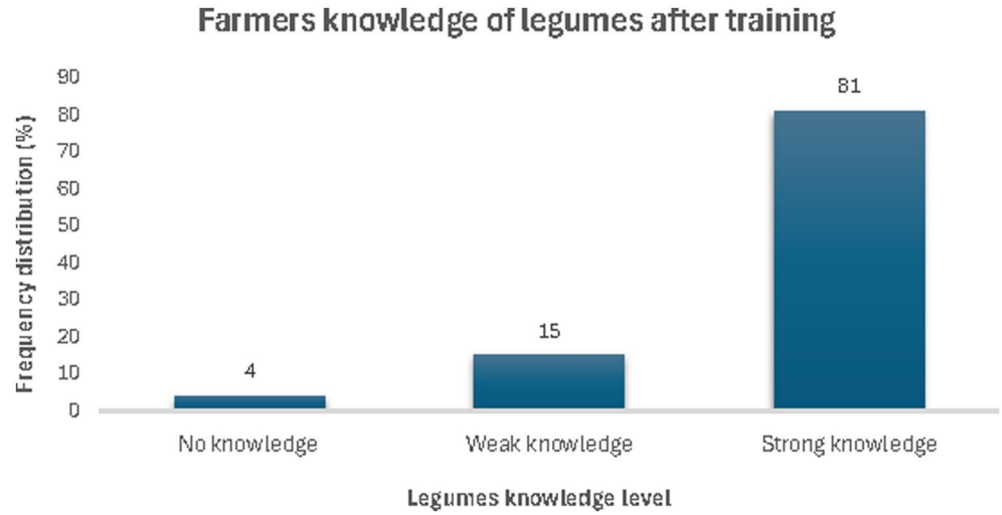

FIGURE 4
Post-training knowledge levels of smallholder farmers on the benefits of neglected legumes.

legumes in Bergville, as analyzed using a multivariate probit regression model. The Wald test [chi2 (44) = 40.27, Prob > chi2 = (0.632)] was insignificant at $p > 0.05$. The insignificant ($p > 0.05$) socioeconomic factors included age, gender, household size, farming experience, and sources of seeds. However, training on legumes ($p < 0.1$) had a significant positive influence on pigeon pea cultivation. Additionally, both marital status ($p < 0.1$) and legume training ($p < 0.05$) significantly influenced farmers' willingness to cultivate cowpea. Furthermore, farm size ($p < 0.1$), market access ($p < 0.1$), and sources of water for irrigation ($p < 0.05$) were positively associated with farmers' willingness to cultivate common bean. Among the examined factors, only sources of water for irrigation ($p < 0.1$), were significantly related to the selection of Bambara groundnut.

3.7 Socio-economic determinants influencing farmers' selection of optimal planting dates

The results in Table 5 present the socioeconomic determinants influencing smallholder farmers' selection of optimal planting dates, using a multivariate probit regression model. The Wald test [chi2 (33) = 31.65, Prob > chi2 = (0. 534)] was not significant ($p > 0.05$), indicating that the overall model fit was not statistically significant. Among the socioeconomic determinants, age, gender, marital status, farming experience, and seed sources were not significant ($p > 0.05$). However, farm size ($p < 0.1$) and legume training ($p < 0.1$) significantly influenced the selection of a November planting date. Similarly, household size ($p < 0.05$) and legume training ($p < 0.1$) had a significant effect on selecting a December planting date. Additionally, water sources for irrigation ($p < 0.1$) and legume training ($p < 0.1$) were positively associated with the selection of January planting date.

4 Discussion

4.1 Socioeconomic characteristics of smallholder farmers in the study area

The study findings indicated that only 6% of smallholder farmers were aged 25 years or younger, while 41% were aged 51 years or older. These results suggested limited engagement of youth in agriculture, potentially due to the perception that farming is predominantly an occupation for older generations (Geza et al., 2021). These findings align with those of Sithole and Olorunfemi (2024), who reported that young people are not actively engaging in agricultural-related activities. According to Chipfupa and Tagwi (2021), the declining participation of youth in agriculture has become a significant concern,

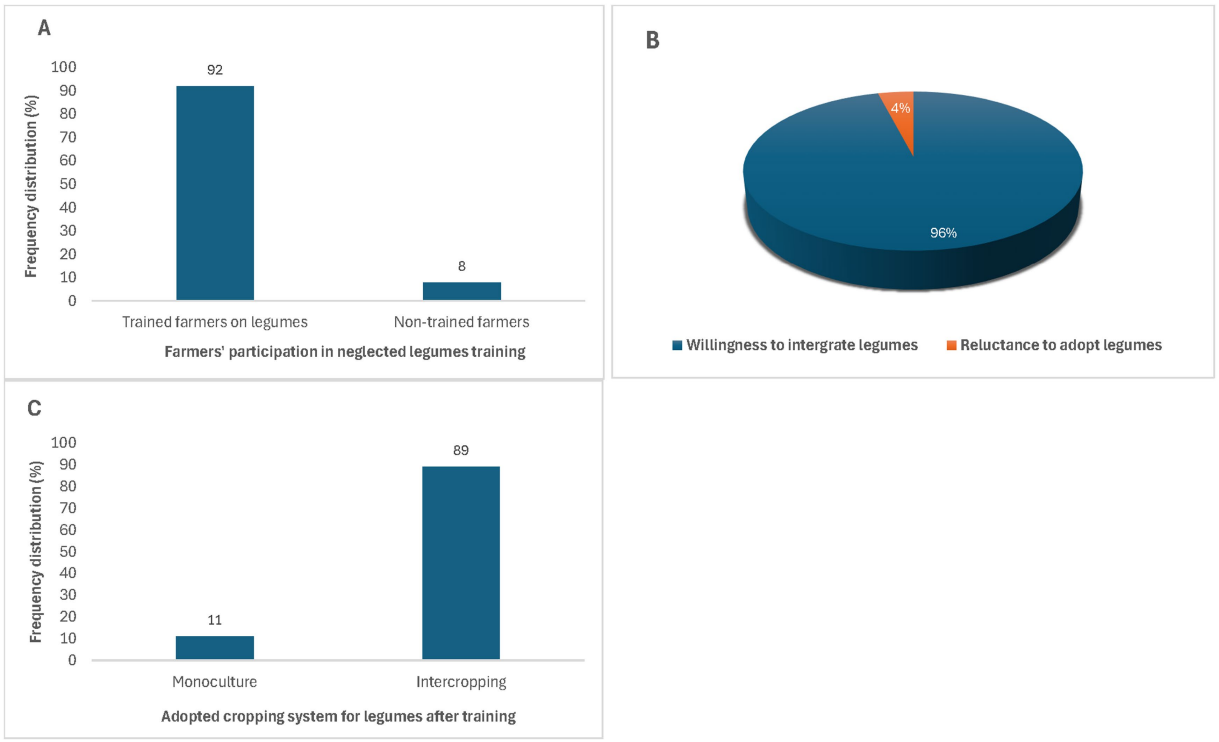

FIGURE 5
(A) Farmers' participation in neglected legume training. **(B)** Willingness to integrate legumes into the cropping system. **(C)** Adopted cropping system for legumes post-training.

with empirical evidence suggesting that young individuals perceive the sector as a low-productivity and last-resort livelihood. This could be attributed to various socioeconomic factors, including restricted access to agricultural resources, concerns regarding financial viability, and the perceived attractiveness of urban employment opportunities. However, this demographic imbalance may hinder the integration of neglected legumes into cropping systems, as younger farmers are generally more inclined to adopt innovative agricultural practices and technologies. While the involvement of older farmers contributes to short-term agricultural productivity, concerns persist regarding the long-term sustainability of the sector if younger generations continue to disengage. As highlighted by Osabohien et al. (2021) and Terefe (2025), youth participation in agriculture is essential for ensuring sustainable socioeconomic development.

The study further revealed that women constitute a substantial proportion (72%) of smallholder cropping systems, underscoring their crucial role in agricultural production. This finding is consistent with previous research, which has demonstrated that women contribute significantly to crop production, surpassing men (Glazebrook et al., 2020; Mukaila et al., 2021). This reinforces the critical role of women in ensuring food security in the Global South, despite persistent structural inequalities that hinder their productivity and economic empowerment. Furthermore, the results revealed that a minority (6%) of farmers had attained tertiary education, while the majority lacked formal education. This disparity presents a significant concern, as higher education levels are generally associated with improved comprehension of agronomic practices and a greater propensity for adopting innovative cropping strategies. The findings suggest that farmers without formal education may encounter challenges in accessing and interpreting scientific research, agricultural extension services, and market trends related to neglected legumes. Consequently, these farmers tend to rely on traditional farming methods and may demonstrate hesitancy in adopting novel crops due to apprehensions about failure, unfamiliarity, or entrenched misconceptions. These findings align with those of Ge et al. (2023), who identified limited education and restricted access to agricultural information as key barriers to crop diversification, particularly among female farmers. Bridging these educational gaps through targeted extension services, knowledge dissemination, and capacity-building initiatives could enhance the adoption of neglected legumes and foster more resilient and sustainable agricultural systems.

The high proportion of unmarried farmers (53%) presented significant implications for smallholder farmers' capacity to cultivate or adopt neglected legumes. Marital status plays a crucial role in determining access to labor, decision-making autonomy, and financial stability, all of which are essential for agricultural innovation and diversification. As noted by Ge et al. (2023), restricted decision-making power among female farmers often leads to reluctance in adopting new crops. This suggests that unmarried farmers, particularly women, may encounter additional barriers to integrating neglected legumes into their farming systems due to structural constraints in resource access and limited autonomy in agricultural decision-making. Moreover, women often face significant barriers to securing land ownership. The findings confirmed that 92.7% of respondents owned less than two hectares of land, highlighting the

10.3389/fsufs.2025.1607687

TABLE 4 Socio-economic factors influencing farmers' willingness to cultivate neglected legumes.

Characteristics	Pigeon pea		Cowpea		Bambara groundnut		Common bean	
	Coeff.	Std. Err	Coeff.	Std. Err	Coeff.	Std. Err	Coeff.	Std. Err
Age	0.346	0.086	0.064	0.085	0.034	0.087	0.082	0.093
Gender	0.109	0.247	−0.183	0.239	0.033	0.245	0.084	0.263
Marital status	−0.166	0.137	−0.249	0.140*	0.458	0.143	−0.006	0.149
Household size	0.335	0.030	−0.009	0.029	0.003	0.230	0.010	0.033
Farming experience	0.072	0.094	−0.010	0.093	0.070	0.099	−0.047	0.093
Farm size	−0.160	0.280	−0.343	0.311	0.323	0.428	−0.507*	0.302
Training on legumes	0.479*	0.289	−0.589	0.276**	−0.159	0.275	−0.124	0.295
Source of seeds	0.186	0.218	−0.244	0.217	−0.242	0.233	−0.073	0.228
Market access	−0.352	0.281	−0.151	0.282	0.226	0.301	−0.465*	0.291
Sources of water for irrigation	−0.174	0.333	−0.120	0.166	0.192	0.270*	0.295**	0.173
Constant	−0.060	0.764	1.754	0.788	−0.281	0.864	0.282	0.847
N	150							
Wald chi2 (44)	40.27							
Log- likelihood	−353.155							
Prob > chi2	0.632							

*, **, and *** signify statistical significance at $p < 0.1$, $p < 0.05$, and $p < 0.01$ levels, respectively.

TABLE 5 Socio-economic determinants influencing farmers' selection of optimal planting dates.

Characteristics	November		December		January	
	Coeff.	Std. Err	Coeff.	Std. Err	Coeff.	Std. Err
Age	−0.124	0.089	0.132	0.086	0.028	0.089
Gender	0.188	0.251	−0.109	0.238	0.172	0.269
Marital status	−0.162	0.135	−0.060	0.133	−0.033	0.140
Household size	0.011	0.031	−0.019**	0.029	−0.031	0.030
Farming experience	0.088	0.095	0.078	0.088	−0.001	0.095
Farm size	−0563*	0.311	−0.599	0.420	−0.034	0.293
Training on legumes	−388*	0.275	0.403*	0.268	0.379	0.326*
Source of seeds	−0.326	0.230	0.134	0.217	−0.005	0.233
Market access	0.142	0.293	0.129	0.279	−0.265	0.294
Sources of water for irrigation	0.145	0.174	−0.229	0.170	0.293**	0.173**
Constant	1.661	0.836	0.620	0.823	−0.005	0.841
N	150					
Wald chi2 (33)	31.65					
Log- likelihood	−261.935					
Prob > chi2	0.534					

*, **, and *** signify statistical significance at $p < 0.1$, $p < 0.05$, and $p < 0.01$ levels, respectively.

structural challenges women encounter in acquiring agricultural resources. Limited land ownership among farmers, particularly women, significantly affects crop diversity, as reported by Schling and Pazos (2024). Addressing these land-related constraints through policies that promote equitable land access, tenure security, and targeted support for neglected legumes cultivation could facilitate the integration of legumes into smallholder cropping systems, ultimately enhancing soil health and improving farmer livelihoods.

Most households comprised 6–10 members, suggesting that most farmers have relatively large families. This finding indicates that family size may influence the adoption of neglected legumes in the region, as it determines the availability of labor, as noted by Foguesatto et al. (2020). Furthermore, the findings revealed that the primary source of income for most farmers (70.7%) was social welfare grants. These results align with those of Mkuhlani et al. (2020), who reported that most resource-constrained farmers,

including social welfare-dependent and struggling subsistence farmers, are unemployed. Consequently, they are unable to invest in farming and face food insecurity. Due to financial constraints, they rely on limited inputs, such as minimal fertilizer application, leading to reduced productivity (Nyambo et al., 2022; Touch et al., 2024). This was confirmed by the study findings, which indicated that 66.7% of farmers primarily sourced their food from supermarkets, while others depended on food schemes or aid programs due to low yields, soil degradation, and other factors. However, integrating legumes into their farming systems could enhance soil fertility, reduce dependency on external inputs, and improve food security by providing a cost-effective and nutrient-rich crop option.

The findings also revealed that market access remains a significant challenge, with 80.7% of farmers lacking access to formal markets. This limitation may be attributed to farmers' reliance on informal markets for selling their surpluses due to inadequate linkages with formal market structures. Similar findings were reported by Hlatshwayo et al. (2021). These results underscore the need to reassess policies and institutional frameworks that support smallholder participation in formal markets. Strengthening market access could promote neglected legume cultivation in the region by enhancing profitability and incentivizing adoption. In addition, despite 85.3% of farmers demonstrating extensive farming experience, the results revealed that 79% had never received training on neglected legumes. This indicates that the low adoption of underutilized crops, such as neglected legumes, may be primarily attributed to insufficient technical knowledge, limited extension support, and inadequate awareness of their agronomic and nutritional benefits. Strengthening farmer education through targeted training and extension services is essential to promote the adoption and integration of these crops into farming systems, thereby enhancing food security and contributing to long-term agricultural sustainability. The study results also revealed that 9.3% of farmers relied exclusively on irrigation as the primary source of water for farming, while a significant proportion depended on rainfall. This indicates the prevalence of water scarcity in smallholder farming systems, which limits crop diversity and reduces yields (Ricciardi et al., 2020). Therefore, the adoption of drought-tolerant crops, such as neglected legumes, into their cropping systems would enhance resilience to water stress and contribute to higher yields, thereby promoting agricultural sustainability in the face of climate variability.

4.2 Overview of cropping practices in the surveyed region

The results revealed that a significant proportion (87%) primarily focused on vegetable cultivation, followed by cereals, while a smaller proportion of farmers engage in legume farming. This suggests that smallholder farmers prioritize vegetable cultivation due to its economic viability, short production cycles, and high market demand. Cereals are grown for food security, while legumes are cultivated in smaller proportions due to lower profitability and longer growth durations. The balance between these crop categories reflects a strategic adaptation to market dynamics, food needs, and agronomic constraints. Similar findings were reported by Ojiewo et al. (2015) and Mkhize et al. (2022), who highlighted that vegetable production and consumption serve as a potent mechanism for disadvantaged smallholder farmers to obtain essential nutrients in their diets while generating much-needed income through trade. This underscores the need to improve market access for neglected legumes, which play a crucial role in diversifying farm incomes, and improving dietary nutrition. Strengthening legume value chains through better infrastructure, policy support, and farmer incentives could enhance their adoption, contributing to both economic resilience and sustainable agricultural systems.

In addition, the study findings revealed that nearly half of the farmers practice intercropping, while a significant proportion continue to rely on monoculture. The limited cultivation of neglected legumes has contributed to the dominance of a monoculture vegetable cropping system, as noted by Mkhize et al. (2022). However, this practice presents significant agronomic and ecological challenges, as continuous monocropping depletes soil nutrients, reduces overall crop productivity, and affects long-term agricultural sustainability (Belete and Yadete, 2023). Therefore, the findings suggest that the current monocropping system of vegetables and maize in the study area requires modification, as it leads to declining soil fertility, reduced yields, and unsustainable food and nutrition security. Furthermore, the lack of crop diversification exacerbates the risk of micronutrient deficiencies, negatively impacting dietary quality and resilience to climate variability. To promote agricultural sustainability and improve farmers' livelihoods, the integration of neglected legumes into cropping systems through intercropping and crop rotation should be promoted.

Furthermore, the small proportion of farmers cultivating legumes indicated that January is the most suitable planting period due to reduced rainfall during this time. In contrast, excessive rainfall in December often leads to pod abortion and seed rot, making this period less favorable for legume cultivation in the region. This finding suggests that farmers primarily rely on their experiential knowledge to determine optimal planting dates. However, results from neglected legumes trial demonstrations revealed that rainfall patterns in the region are increasingly erratic. Some of the neglected legume varieties introduced in the study exhibited stable performance throughout November, December, and January, challenging traditional perceptions of planting suitability. These findings highlight the need for evidence-based agronomic recommendations to help farmers adapt to changing climatic conditions and maximize neglected legumes productivity. Strengthening extension services and promoting climate-resilient, neglected legume varieties could enhance adoption rates, improve farm productivity, and contribute to diversified and sustainable cropping systems.

4.3 Training participation and knowledge of legumes in the surveyed region

The results of the study revealed that only 20.7% of farmers had participated in legume training prior to the study. This suggests that the limited production of neglected legumes in the region could be attributed to the shortage of targeted training programs and extension services focused on these crops. As a result, the lack of specialized training hinders farmers' knowledge of best agronomic practices and the potential benefits of integrating neglected legumes into existing cropping systems. This was further confirmed by an assessment of farmers' knowledge of legumes in the surveyed region, which showed that 85.3–94.7% of farmers lacked awareness of neglected legume cultivars, production techniques, adaptability, and market opportunities. These

findings align with those of Harouna et al. (2019), who highlighted that limited resources are not the only constraint affecting diversified cropping systems; rather, a lack of knowledge and awareness also presents a significant barrier. Consequently, these challenges contribute to the low adoption and limited cultivation of neglected legumes in the region. These findings underscore the urgent need for targeted capacity-building initiatives, including smallholder farmers training and knowledge dissemination programs. This concurs with the findings of Rutto (2016), who emphasized the importance of training programs that are inclusive of elderly and illiterate farmers. Such programs will enhance farmers' understanding of neglected legumes, improve their adoption, and ultimately promote food security in smallholder farming systems.

4.4 Pre- and post-training knowledge levels of smallholder farmers on the benefits of neglected legumes

Prior to the study training, the findings revealed that most farmers had extensive knowledge of the nutritional richness of neglected legumes, including their high content of proteins, carbohydrates, fibre, minerals, vitamins, and micronutrients. This awareness may be attributed to information disseminated by health facilities, which emphasized the dietary importance of these foods in addressing malnutrition and highlighted the role of legumes as an alternative protein source to meat, as noted in face-to-face interviews. In contrast, between 76 and 94% of respondents were unaware of the additional benefits of neglected legumes, including their potential to reduce the risk of heart disease, diabetes, cancer, and obesity; enhance soil fertility through biological nitrogen fixation; break pest and disease cycles; conserve soil moisture; and promote ecosystem stability in marginal environments. However, following the training provided in the study, a significant proportion (81%) of farmers demonstrated a strong understanding of neglected legumes. These findings validate the effectiveness of the training, highlighting its potential to enhance farmers' knowledge and improve the adoption of neglected legumes, thereby contributing to both nutritional security and sustainable agricultural practices. Furthermore, these findings corroborate the findings of Pui et al. (2022) and Odeku et al. (2024), who reported that a lack of awareness and knowledge regarding the nutritional and health benefits associated with consuming a diverse range of neglected legumes has contributed to limited demand, subsequently limiting their cultivation and distribution.

4.5 Farmers' participation in neglected legume training, adoption willingness, and post-training cropping system integration

The findings of the study revealed that a significant proportion (92%) of respondents participated in the training on neglected legumes conducted as part of this research. Following the training and trial demonstrations, most farmers (96%) expressed a willingness to integrate legumes into their cropping systems. Smallholder farmers who previously practiced monoculture showed increased interest in adopting intercropping. This suggests that targeted training and practical demonstrations play a crucial role in enhancing farmers' awareness and adoption of neglected legumes' integration. The findings highlight the potential for knowledge-based interventions to influence cropping decisions, improve crop diversification, and promote sustainable agricultural practices, as stated by Gayathri and Manimozhi (2024). Furthermore, increased adoption of intercropping with legumes could contribute to soil fertility enhancement, pest and disease management, and improved resilience to climate variability in the study area. This agrees with the findings of Kumawat et al. (2022) and Akchaya et al. (2025), who also reported the role of legume intercropping in sustainable farming systems. The findings underscore the need for continued extension support and policy initiatives to facilitate the large-scale adoption of neglected legumes.

4.6 Socio-economic factors influencing farmers' willingness to cultivate neglected legumes

The findings on the socioeconomic factors influencing smallholder farmers' willingness to cultivate neglected legumes, analyzed through a multivariate probit regression model, revealed that training on legumes is a statistically significant determinant. Particularly, participation in training was positively correlated with the adoption of pigeon pea ($\beta = 0.479$, $p < 0.1$) and cowpea ($\beta = 0.276$, $p < 0.05$). These results suggest that farmers who received training were more inclined to adopt these neglected legumes, underscoring the crucial role of knowledge dissemination in raising awareness, improving agronomic practices, and promoting their cultivation. These findings are consistent with those of Mkhize et al. (2023), who introduced innovative cultivation and consumption methods to enhance farmers' knowledge and acceptance of cowpea and jugo beans. Their study demonstrated that educational interventions led to a statistically significant increase in both the acceptability and cultivation of these legumes. These findings highlight the vital role of knowledge dissemination in facilitating the reintegration of neglected legume species into local cropping systems, thereby contributing to food security, dietary diversity, and sustainable agricultural practices (Ratnayake et al., 2023).

Moreover, a positive and statistically significant relationship ($\beta = 0.140$, $p < 0.1$) was observed between marital status and cowpea adoption, indicating that farmers' marital status influences their likelihood of adopting cowpea. This suggests that married farmers may have greater access to resources, labor, or decision-making support, which could enhance their willingness to cultivate neglected legumes. Similar findings have been reported by Lana (2025) where marital status was identified as a key socioeconomic factor influencing the adoption of improved agricultural technologies and crop diversification strategies. In addition, farm size ($\beta = -0.507$, $p < 0.1$) and market access ($\beta = -0.465$, $p < 0.1$) were negatively associated with farmers' willingness to cultivate common bean, indicating that larger farm sizes and limited market access may reduce the likelihood of adopting common bean cultivation.

Conversely, access to irrigation water sources was positively correlated with the adoption of both common bean ($\beta = 0.295$, $p < 0.05$) and Bambara groundnut ($\beta = 0.270$, $p < 0.1$), suggesting that farmers with better access to irrigation are more likely to cultivate these crops. This finding underscores the importance of water availability in promoting the adoption of water-intensive crops such as common bean, emphasizing the need for improved irrigation

infrastructure and enhanced market access to support smallholder farmers in diversifying their crop production systems. In contrast, the positive correlation with Bambara groundnut adoption may be attributed to its drought resistance, as demonstrated by trials conducted in the study. This resilience makes Bambara groundnut a viable option for farmers with limited access to irrigation, further highlighting the potential of drought-tolerant crops in enhancing agricultural resilience in water-scarce regions (Feldman et al., 2019; Pui et al., 2022).

4.7 Socio-economic determinants influencing farmers' selection of optimal planting dates

The study results revealed that socioeconomic determinants, including farm size ($\beta = -0.563$, $p < 0.1$) and legume training ($\beta = -0.388$, $p < 0.1$), were negatively and significantly correlated with the selection of a November planting date. This suggests that smallholder farmers and those who received legume training were less likely to plant in November. The negative correlation with farm size may indicate that smallholder farmers prefer alternative planting periods to optimize resource use, mitigate climatic risks, or align with labor availability. Likewise, the negative association with legume training suggests that trained farmers may adopt improved agronomic practices or recommended planting schedules that deviate from a November planting date.

However, legume training was positively and significantly correlated with the selection of both a December ($\beta = 0.403$, $p < 0.1$) and January ($\beta = 0.326$, $p < 0.1$) planting date, whereas household size ($\beta = -0.019$, $p < 0.05$) exhibited a negative correlation with the selection of a November planting date. This suggests that farmers who received legume training were more likely to delay planting until December or January, potentially to align with recommended agronomic practices, o or mitigate risks associated with early-season climatic variability. Conversely, the negative correlation between household size and the selection of a November planting date implies that larger households were less inclined to plant in November, possibly due to competing labor demands for other agricultural activities or resource constraints. These findings underscore the critical role of agricultural training in shaping planting decisions.

Furthermore, access to water sources for irrigation ($\beta = 0.173$, $p < 0.1$) was positively and significantly associated with the selection of a January planting date. This association may be attributed to the improved performance of the neglected legumes introduced in the study under rainfed conditions, highlighting the need to adopt climate-smart, resilient crops such as neglected legumes in regions where water scarcity persists. Moreover, the availability of irrigation water provides farmers with greater flexibility in their planting decisions, enabling them to extend the growing season and mitigate risks associated with unpredictable rainfall patterns. These findings underscore the critical role of irrigation access in promoting the cultivation of neglected legumes and highlight the need for targeted interventions to improve water management strategies, thereby enhancing the productivity and sustainability of legume-based farming systems. These results are consistent with the findings of Mhembwe et al. (2019).

5 Conclusions, recommendations, and research directions

This study assessed the socioeconomic factors influencing farmers' willingness to cultivate neglected legumes and their selection of suitable planting dates in South Africa, using KwaZulu-Natal Province as a case study. The findings indicate the crucial role of socioeconomic factors in shaping adoption decisions and cultivation of these crops into existing cropping systems. Consistent with previous research, the study confirms that limited access to land, water availability, market access, and marital status influence farmers' willingness to cultivate neglected legumes. Household size, participation in legume-related training, and access to irrigation water influence the selection of suitable planting dates. The findings further revealed that the limited cultivation and adoption of neglected legumes were not primarily due to resource constraints but rather a lack of awareness and knowledge regarding their nutritional and health benefits. This lack of awareness has contributed to low demand, subsequently limiting the cultivation and distribution of neglected legumes. To address these challenges, the study recommends targeted capacity-building initiatives, including smallholder farmer training and knowledge dissemination programs. These initiatives will enhance farmers' understanding of neglected legumes, encourage their adoption, and ultimately promote food security in smallholder farming systems. The effectiveness of such interventions was demonstrated through training and trial demonstrations conducted in this study, where a significant proportion of farmers expressed a willingness to cultivate neglected legumes into their cropping systems. Furthermore, farmers who previously practiced monoculture showed increased interest in adopting intercropping, highlighting the potential for knowledge-based interventions to influence cropping decisions.

Despite the promising results of this study, it is essential to acknowledge that, like other research studies, this article has limitations. The study specifically focused on smallholder crop farmers in Bergville. This may introduce some bias, as the sample comprised crop farmers affiliated with the Farmers Support Group in the region. However, this study attempted to mitigate bias by using a multistage sampling strategy to ensure representation of diverse demographic groups, particularly resource-constrained farmers actively engaged in various farming practices. Moreover, the study employed techniques to enhance data accuracy and reliability, including the use of multiple question formats to capture comprehensive information and minimize response errors. Despite these limitations, the study contributes to a more profound understanding of how socioeconomic factors including farm size, training on legumes, marital status, household size, water sources for irrigation, and market access influence smallholder farmers' willingness to cultivate neglected legumes and their selection of suitable planting dates.

Further research should explore the long-term impact of knowledge-based interventions on the sustained adoption of neglected legumes in smallholder farming systems. In addition, future studies should also investigate the role of policy support, market incentives, and climate resilience in promoting their integration. Research into the genetic improvement of these legumes to enhance yield potential, adaptability, and nutritional value could further increase their appeal to both farmers and consumers. Addressing these research gaps will contribute to more resilient and diversified cropping systems,

ultimately enhancing food and nutritional security while increasing smallholder farmers' adaptability to climate variability and market dynamics.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by University of KwaZulu-Natal Ethics Committee, under certificate reference number HSSREC/00008179/2025. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

BV: Methodology, Software, Investigation, Conceptualization, Writing – original draft, Visualization, Data curation, Formal analysis, Project administration. PM: Methodology, Supervision, Writing – review & editing, Data curation, Conceptualization, Resources, Funding acquisition, Project administration, Visualization, Validation. AO: Supervision, Visualization, Conceptualization, Methodology, Writing – review & editing, Validation, Data curation. MP: Writing – review & editing, Validation, Supervision, Data curation, Visualization, Conceptualization, Methodology.

Funding

The author(s) declare that financial support was received for the research and/or publication of this article. This research was funded by South Africa's National Research Foundation (NRF) grant number (86893), the South African National Seed Organization (SANSOR), and NGAP University of Mpumalanga (B670).

Acknowledgments

The authors wish to acknowledge the South Africa's National Research Foundation (NRF) grant number (86893), the South African National Seed Organization (SANSOR), University of KwaZulu-Natal, the University of Mpumalanga, and the Farmers Support Group for their invaluable support and for cultivating an environment conducive to the successful completion of this research. The authors also extend their sincere appreciation to Oluwasogo Olorunfemi from the University of Mpumalanga for his assistance with the analysis, and to the smallholder crop farmers in Bergville for their generous contribution of time and participation in this study.

Conflict of interest

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

Generative AI statement

The authors declare that no Gen AI was used in the creation of this manuscript.

Publisher's note

References

Abberton, M., Paliwal, R., Faloye, B., Marimagne, T., Moriam, A., and Oyatomi, O. (2022). Indigenous African orphan legumes: potential for food and nutrition security in SSA. *Front. Sust. Food Syst.* 6:708124. doi: 10.3389/fsufs.2022.708124

Akchaya, K., Parasuraman, P., Pandian, K., Vijayakumar, S., Thirukumaran, K., Mustaffa, M. R. A. F., et al. (2025). Boosting resource use efficiency, soil fertility, food security, ecosystem services, and climate resilience with legume intercropping: a review. *Front. Sust. Food Syst.* 9:1527256. doi: 10.3389/fsufs.2025.1527256

Belete, T., and Yadete, E. (2023). Effect of mono cropping on soil health and fertility management for sustainable agriculture practices: a review. *Plant Sci.* 11, 192–197. doi: 10.11648/j.jps.20231106.13

Bless, C., Higson-Smith, C., and Kagee, A. (2006). Fundamentals of social research methods: An African perspective. Cape Town: Juta and Company Ltd.

Chipfupa, U., and Tagwi, A. (2021). Youth's participation in agriculture: a fallacy or achievable possibility? Evidence from rural South Africa. *S. Afr. J. Econ. Manag. Sci.* 24, 1–12. doi: 10.4102/sajems.v24i1.4004

DALRRD (2020). Dry bean value chain profile 2020. Pretoria: Directorate Marketing.

Danquah, E. O., Frimpong, F., Addo-Danso, A., Amankwaa-Yeboah, P., Yeboah, S., Danquah, F. O., et al. (2025). Climate-smart cropping systems for resilient food production in sub-Saharan Africa in the face of changing climate: a review. *Circ. Agric. Syst.* 5:16. doi: 10.48130/cas-0024-0016

Dhanaraj, A., Girdhar, S., and Prakash, P. (2024). Transformative education: a strategical tool for empowering social change and sustainable future in the Indian context. *Library Progress Sci. Inf. Technol. Comput.* 44:3.

Dixon, J., Garrity, D. P., Boffa, J., Williams, T. O., Amede, T., Auricht, C., et al. (2020). "Farming systems and food security in Africa" in Priorities for science and policy under global change. eds. J. Dixon, D. Garrity and J.-M. Boffa (London: Routledge).

FAO (2017). The state of food and agriculture: leveraging food systems for inclusive rural transformation. Rome: Food and Agriculture Organization of the United Nations.

Feldman, A., Ho, W. K., Massawe, F., and Mayes, S. (2019). Bambara groundnut is a climate-resilient crop: how could a drought-tolerant and nutritious legume improve community resilience in the face of climate change? *Sust. Solut. Food Secur. Combating Clim. Change Adapt.* 11, 151–167. doi: 10.1007/978-3-319-77878-5_8

Foguesatto, C. R., Borges, J. A. R., and Machado, J. A. D. (2020). A review and some reflections on farmers' adoption of sustainable agricultural practices worldwide. *Sci. Total Environ.* 729:138831. doi: 10.1016/j.scitotenv.2020.138831

Gayathri, M., and Manimozhi, K. (2024). Bridging the knowledge gap: enhancing awareness among farmers about millet cultivation. *Curr. Agric. Res. J.* 12, 286–293. doi: 10.12944/CARJ.12.1.23

Ge, Y., Fan, L., Li, Y., Guo, J., and Niu, H. (2023). Gender differences in smallholder farmers' adoption of crop diversification: evidence from Shaanxi plain, China. *Clim. Risk Manage.* 39:100482. doi: 10.1016/j.crm.2023.100482

Geza, W., Ngidi, M., Ojo, T., Adetoro, A. A., Slotow, R., and Mabhaudhi, T. (2021). Youth participation in agriculture: a scoping review. *Sustain. For.* 13:9120. doi: 10.3390/su13169120

Glazebrook, T., Noll, S., and Opoku, E. (2020). Gender matters: climate change, gender bias, and women's farming in the global south and north. *Agriculture* 10:267. doi: 10.3390/agriculture10070267

Harouna, D. V., Venkataramana, P. B., Matemu, A. O., and Ndakidemi, P. A. (2019). Wild Vigna legumes: farmers' perceptions, preferences, and prospective uses for human exploitation. *Agronomy* 9:284. doi: 10.3390/agronomy9060284

Hlatshwayo, S. I., Ngidi, M., Ojo, T., Modi, A. T., Mabhaudhi, T., and Slotow, R. (2021). A typology of the level of market participation among smallholder farmers in South Africa: Limpopo and Mpumalanga provinces. *Sustain. For.* 13:7699. doi: 10.3390/su13147699

Hossain, A., Islam, M. T., Maitra, S., Majumder, D., Garai, S., Mondal, M., et al. (2021). Neglected and underutilized crop species: are they future smart crops in fighting poverty, hunger and malnutrition under changing climate? *Neglected Underutilized Crops-Nutr. Secur. Sust.* 1, 1–50. doi: 10.1007/978-981-16-3876-3_1

Kebede, E. (2020). Grain legumes production and productivity in Ethiopian smallholder agricultural system, contribution to livelihoods and the way forward. *Cogent Food Agric.* 6:1722353. doi: 10.1080/23311932.2020.1722353

Kumawat, A., Bamboriya, S. D., Meena, R. S., Yadav, D., Kumar, A., Kumar, S., et al. (2022). "Legume-based inter-cropping to achieve the crop, soil, and environmental health security" in Advances in legumes for sustainable intensification (Cambridge, MA: Academic Press), 307–328.

Lana, M. (2025). Exploring gender dynamics in climate-smart agriculture adoption: A study in semi-arid Dodoma, Tanzania. AGRIS – International System for Agricultural Science and Technology.

Li, X., Yadav, R., and Siddique, K. H. (2020). Neglected and underutilized crop species: the key to improving dietary diversity and fighting hunger and malnutrition in Asia and the Pacific. *Front. Nutr.* 7:593711. doi: 10.3389/fnut.2020.593711

Mhembwe, S., Chiunya, N., and Dube, E. (2019). The contribution of small-scale rural irrigation schemes towards food security of smallholder farmers in Zimbabwe. *Jàmbá* 11, 1–11. doi: 10.4102/jamba.v11i1.674

Mihrete, T. B., and Mihretu, F. B. (2025). Crop diversification for ensuring sustainable agriculture, risk management and food security. *Global Chall.* 9:2400267. doi: 10.1002/gch2.202400267

Mkhize, X., Napier, C., Oldewage-Theron, W., and Duffy, K. (2023). Educating urban farmers in Kwazulu-Natal, South Africa on new innovative ways of reintroducing cowpea (Imbumba) and jugo beans (Izindlubo) to remodel their production and consumption patterns. *Indilinga Afr. J. Ind. Knowledge Syst.* 22, 90–108.

Mkhize, X., Oldewage-Theron, W., Napier, C., Duffy, K., and Mthembu, B. E. (2022). Introducing grain legumes for crop diversification and sustainable food production systems amongst urban small-holder farmers: a food and nutrition security project in KwaZulu-Natal, South Africa. *Agroecol. Sustain. Food Syst.* 46, 791–814. doi: 10.1080/21683565.2022.2070814

Mkuhlani, S., Crespo, O., Rusere, F., Zhou, L., and Francis, J. (2020). Classification of small-scale farmers for improved rainfall variability management in South Africa. *Agroecol. Sustain. Food Syst.* 44, 7–29. doi: 10.1080/21683565.2018.1537325

Mrabet, R. (2023). "Sustainable agriculture for food and nutritional security" in Sustainable agriculture and the environment. ed. National Research Council, Board on Science, Technology for International Development, Committee on Sustainable Agriculture, & the Environment in the Humid Tropics (New York, NY: Academic Press), 25–90.

Mukaila, R., Falola, A., and Omotesho, O. A. (2021). Food security status: Its drivers and coping strategies among vegetable farming households. *Cercetări Agronomice in Moldova* 53, 414–425. doi: 10.46909/cerce-2020-035

Mulaudzi, A. I., Olorunfemi, O. D., and Agholor, A. I. (2024). Social media utilization level among south African smallholder farmers: a case study of Mopani District, Limpopo Province. *Cogent Soc. Sci.* 10:2356722. doi: 10.1080/23311886.2024.2356722

Nkansah-Dwamena, E. (2024). Why small-scale circular agriculture is central to food security and environmental sustainability in sub-saharan Africa? The case of Ghana. *Circ. Econ. Sustain.* 4, 995–1019. doi: 10.1007/s43615-023-00320-y

Nyambo, P., Nyambo, P., Mavunganidze, Z., and Nyambo, V. (2022). "Sub-Saharan Africa smallholder farmers agricultural productivity: risks and challenges" in Food security for African smallholder farmers. eds. H. A. Mupambwa, A. D. Nciizah and P. Nyambo (Springer Nature Singapore: Singapore), 47–58.

Odeku, O. A., Ogunniyi, Q. A., Ogbole, O. O., and Fettke, J. (2024). Forgotten gems: exploring the untapped benefits of underutilized legumes in agriculture, nutrition, and environmental sustainability. *Plan. Theory* 13:1208. doi: 10.3390/plants13091208

Ojiewo, C., Keatinge, D. J., Hughes, J., Tenkouano, A., Nair, R., Varshney, R., et al. (2015). The role of vegetables and legumes in assuring food, nutrition, and income security for vulnerable groups in sub-Saharan Africa. *World Med. Health Policy* 7, 187–210. doi: 10.1002/wmh3.148

Osabohien, R., Wiredu, A. N., Nguezet, P. M. D., Mignouna, D. B., Abdoulaye, T., Manyong, V., et al. (2021). Youth participation in agriculture and poverty reduction in Nigeria. *Sustain. For.* 13:7795. doi: 10.3390/su13147795

Pradhan, A., DJ, N., Panda, A. K., Wagh, R. D., Maske, M. R., and RV, B. (2021). Farming system for nutrition-a pathway to dietary diversity: evidence from India. *PLoS One* 16:e0248698. doi: 10.1371/journal.pone.0248698

Pui, L. P., Tan, W. C., Kong, I., and Tan, C. H. (2022). Drought-tolerant Bambara groundnuts as future food: a comprehensive review of its properties and applications in food. *Br. Food J.* 124, 3680–3694. doi: 10.1108/BFJ-04-2021-0436

Ratnayake, S., Reid, M., Hunter, D., Larder, N., Silva, R., Kadupitiya, H., et al. (2023). "Exploring social-ecological systems for mainstreaming neglected and underutilised plant foods: local solutions to food security challenges in Sri Lanka" in Neglected plant foods of South Asia: Exploring and valorizing nature to feed hunger. eds. T. Ismail, S. Akhtar and C. E. Lazarte (Cham: Springer International Publishing), 171–225.

Ricciardi, V., Wane, A., Sidhu, B. S., Godde, C., Solomon, D., McCullough, E., et al. (2020). A scoping review of research funding for small-scale farmers in water scarce regions. *Nat. Sust.* 3, 836–844. doi: 10.1038/s41893-020-00623-0

Rosa-Schleich, J. (2023). Diversified farming systems–an evaluation of ecological benefits, economic costs & risks farmers face. AGRIS – International System for Agricultural Science and Technology.

Rutto, S. K. (2016). Factors influencing involvement of legume farmers in agricultural training programs in Makueni County, Kenya (Doctoral dissertation). Nairobi: University Of Nairobi.

Saliu, F., Luqman, M., and Alkhaz'leh, H. S. (2023). A review on the impact of sustainable agriculture practices on crop yields and soil health. *Int. J. Res. Adv. Agric. Sci.* 2, 1–13.

Samal, I., Bhoi, T. K., Raj, M. N., Majhi, P. K., Murmu, S., Pradhan, A. K., et al. (2023). Underutilized legumes: nutrient status and advanced breeding approaches for qualitative and quantitative enhancement. *Front. Nutr.* 10:1110750. doi: 10.3389/fnut.2023.1110750

Schling, M., and Pazos, N. (2024). Effective land ownership, female empowerment, and food security: evidence from Peru. *World Dev.* 181:106680. doi: 10.1016/j.worlddev.2024.106680

Sharma, P., Tailor, A., Joshi, A., and Bhoi, T. K. (2024). "Genetic diversity of grain legumes for food and nutritional security" in Sustainable utilization and conservation of plant genetic diversity. eds. J. M. Al-Khayri, S. M. Jain and S. Penna (Springer Nature Singapore: Singapore), 63–105.

Sithole, A., and Olorunfemi, O. D. (2024). Sustainable agricultural practices in sub-Saharan Africa: a review of adoption trends, impacts, and challenges among smallholder farmers. *Sustain. For.* 16:766. doi: 10.3390/su16229766

Stringer, E. T., and Aragón, A. O. (2020). Action research. London: Sage publications.

Terefe, D. (2025). Enhancing youth engagement in agriculture for a sustainable future in Ethiopia: Challenges and policy solutions in focus.

Touch, V., Tan, D. K., Cook, B. R., Li Liu, D., Cross, R., Tran, T. A., et al. (2024). Smallholder farmers' challenges and opportunities: implications for agricultural production, environment and food security. *J. Environ. Manag.* 370:122536. doi: 10.1016/j.jenvman.2024.122536

Vilakazi, B., Mafongoya, P. L., Odindo, A. O., and Phophi, M. M. (2025). The role of neglected grain legumes in food and nutrition security and human health. *Sustain. For.* 17:350. doi: 10.3390/su17010350

Wijerathna-Yapa, A., and Pathirana, R. (2022). Sustainable agro-food systems for addressing climate change and food security. *Agriculture* 12:1554. doi: 10.3390/agriculture12101554

Yamane, T. (1973). Statistics: An introductory analysis. New York, NY: Harper and Row.