frontiers | Frontiers in Sustainable Food Systems

TYPE Original Research
PUBLISHED 25 April 2025
DOI 10.3389/fsufs.2025.1471333

OPEN ACCESS

EDITED BY
Rishi Raj,
Indian Agricultural Research Institute (ICAR), India

REVIEWED BY
Adeola Oluwabunmi Adeagbo,
University of Ibadan, Nigeria
Mario Anaya,
Universidad Católica Sedes Sapientiae, Peru

*CORRESPONDENCE
Frank Chidawanyika
✉ fchidawanyika@icipe.org

RECEIVED 27 July 2024
ACCEPTED 09 April 2025
PUBLISHED 25 April 2025

CITATION
Okoma RN, Omuse ER, Mutyambai DM, Beesigamukama D, Murongo MF, Subramanian S and Chidawanyika F (2025) An assessment of vegetable production constraints, trait preferences and willingness to adopt sustainable intensification options in Kenya and Uganda.
Front. Sustain. Food Syst. 9:1471333.
doi: 10.3389/fsufs.2025.1471333

An assessment of vegetable production constraints, trait preferences and willingness to adopt sustainable intensification options in Kenya and Uganda

Rose N. Okoma[1,2], Evanson R. Omuse[1,3], Daniel M. Mutyambai[1,4], Dennis Beesigamukama[1], Marius F. Murongo[2], Sevgan Subramanian[1] and Frank Chidawanyika[1,5]*

[1]International Centre of Insect Physiology and Ecology (ICIPE), Nairobi, Kenya, [2]Faculty of Agriculture, Uganda Martyrs University, Kampala, Uganda, [3]Department of Zoology and Entomology, University of Pretoria, Pretoria, South Africa, [4]Department of Life Sciences, South Eastern Kenya University, Kitui, Kenya, [5]Department of Zoology and Entomology, University of the Free State, Bloemfontein, South Africa

Global food production systems are under pressure due to population increase, limited farmland, biotic and abiotic constrains, and ongoing climate change. Sustainable intensification is needed to increase agricultural productivity with minimal adverse environmental and social impacts. Vegetable-integrated push pull (VIPP) technology coupled with black soldier fly (BSF) frass offer such opportunities to smallholder farmers. However, farmers' vegetable preferences and willingness to adopt these innovations remain unknown and are variable across various geographic scales. Focus group discussions (FGDs) and in-person interviews with smallholder farmers were conducted to assess vegetable production constraints and select vegetables to be integrated into VIPP coupled with BSF frass biofertilizer in Kenya and Uganda. Twenty-six FGDs followed by in-person interviews were conducted from July to November 2023 with 227 and 106 farmers from Kenya and Uganda, respectively. A total of 23 vegetable types were identified. The most considered discerning parameters and traits included household consumption, income generation, nutritional value, extended harvesting, drought tolerance and resistance to diseases and insect pests. The major constraints were the high cost of agrochemicals and fertilizers and poor seed quality in Kenya while diseases, pests, drought and poor rainfall, low soil fertility, too much rainfall and floods, high cost of agrochemicals and fertilizers, lack of seeds and poor seed quality were pressing constraints among farmers in Uganda. More than 83% of farmers showed readiness to adopt a combination of VIPP+BSF. Kales, spinach, cabbage, *Amaranthus*, African nightshade and tomatoes were preferred in central Kenya whereas cowpeas, kales, African nightshade, *Amaranthus*, pumpkin leaves and spider plants in western Kenya were preferred as vegetables to be included in VIPP and BSF frass innovations. Ugandan farmers considered eggplants, *Amaranthus*, garden eggs, cabbage, kales and tomatoes the most popular vegetables to be incorporated in VIPP and BSF frass innovations. Our results provide a baseline for vegetables to be integrated into VIPP with BSF frass biofertilizer for validation with farmers. The study also underlies how farmer crop preferences vary according to site and the need for participatory selection to increase the chances of adoption of agricultural interventions.

KEYWORDS

black soldier fly, circular bioeconomy, co-creation, food security, nutrition-sensitive agriculture, organic frass fertilizer, push-pull technology

1 Introduction

Global population increase, limited land for agriculture, and ongoing climate change require sustainable methods for food production to boost productivity without further environmental degradation (United Nations, 2021; Kumar et al., 2022). In sub-Saharan Africa (SSA), agriculture is predominantly rain-fed, which accounts for 97% of total farmland, making crop production and food security highly vulnerable to seasonal variations in precipitation and temperature stress (Kotir, 2011). In SSA, land degradation through soil erosion and nutrient depletion has so far affected 65% of the total land area (Tefera et al., 2024). Other challenges that further impede agricultural productivity include poor health, limited land tenure and ownership, crop diseases and pests, costly inputs with limited outputs, limited agricultural information, limited credit and market access, lack of appropriate technologies, inadequate policies, and policy inconsistencies, which result in smallholder farmer neglect (Shimeles et al., 2018; Bjornlund et al., 2020). There is therefore a need for sustainable agricultural practices to mitigate these challenges and promote food security (Struik, 2017).

Sustainable intensification (SI) is one of the innovative approaches to producing more food and associated economic returns on existing farmland with positive impacts on the environment. It entails agricultural practices that promote resilience to biotic and abiotic stress, reduce reliance on external inputs such as agrochemicals, and promote biodiversity and ecosystem services (Pretty and Bharucha, 2014). Sustainable intensification is highly applicable in SSA because the region's ever-growing population leaves very little land for agricultural expansion without further environmental degradation (Struik, 2017). One such SI is push-pull technology (PPT), which is a cropping system integrating pest, weed and soil management practices in cereal–livestock farming systems (Cook et al., 2007). To suppress pests, the PPT intercrops legumes of the *Desmodium* spp. with cereals such as maize (*Zea mays* L.) or sorghum (*Sorghum bicolor* L.) to repel ("push") pests while surrounded by grasses such as Napier grass (*Pennisetum purperum* Schumach.) or *Brachiaria* spp. which attract ("pull") the pests from the crop (Khan et al., 2011; Chidawanyika et al., 2014). The root exudates of *Desmodium* plants suppress parasitic weeds of the genus *Striga* that are key cereal production constraints in Africa (Khan et al., 2011). Additionally, *Desmodium* plants provide other soil health ecosystem services including nitrogen fixation, improved organic matter and phosphorus availability, moisture conservation and increased beneficial microbial activity (Drinkwater et al., 2021; Adan et al., 2024; Jalloh et al., 2024; Mutyambai et al., 2024).

Despite the success of PPT, one of the concerns raised by practicing farmers is that it only catered for cereals limiting options for nutritional and income diversity (Chidawanyika et al., 2023). We recently integrated vegetables and edible legumes in the PPT with maize resulting in a vegetable integrated push-pull (VIPP) system with improvement of various one health outcomes including crop productivity, food security, environmental resilience and livelihoods (Chidawanyika et al., 2023, 2025). While vegetable consumption is associated with better dietary-based health outcomes, such as a lower risk of noncommunicable diseases and obesity, its consumption in Africa is significantly lower than the world average, falling short of the WHO/FAO target minimum intake of 200 g/day/person (or more than 73 kg/year/person) (Kalmpourtzidou et al., 2020). Many factors, such as soil degradation, climate change, pest pressure, and other economic factors limit smallholder vegetable production in Africa and thus impede the food production system (Mason-D'Croz et al., 2019). Given the growing need for sustainable intensification of food production systems (Pretty et al., 2018; Kuyah et al., 2021; Chidawanyika et al., 2023; Librán-Embid et al., 2023), VIPP now becomes highly applicable, especially for African smallholder farmers (Chidawanyika et al., 2023, 2025).

Furthermore, another approach to sustainably intensify the VIPP is by low-cost organic amendments such as farmyard manure. Recently, the black soldier fly (BSF) *Hermetia illucens* L. farming and its outputs such as frass as a source of organic biofertilizer resulting from bioconversion of organic waste, opened a pathway for sustainability and a circular bioeconomy for resource-poor farmers (Beesigamukama et al., 2021). The use of BSF frass as soil organic amendments is associated with various soil health benefits including boosting soil microbiological quality and organic carbon (Anyega et al., 2021; Gebremikael et al., 2022). Thus, integrating the VIPP with organic amendments such as BSF frass can unlock further yield benefits and profitability for farmers through improved soil health, and reduction in inputs of costly agrochemicals.

For any sustainable agriculture practice, it is important to bridge the gap between farmers and researchers in technology development to validation and optimisation of systems, for improved adoption of recent innovations (Goa et al., 2017; Pawera et al., 2024). For instance, VIPP and BSF offer more opportunities to smallholder farmers to improve productivity. However, location-specific factors may influence farmers' vegetable choices and willingness to adopt these innovations. This, therefore, calls for the need to understand the factors driving households' decisions to adopt VIPP and BSF innovations.

Indeed, the co-creation of innovations through participatory rural appraisal (PRA) approaches is an important component of citizen or farmer-centered development (Pawera et al., 2024). Through face-to-face interactions with researchers, PRA approaches empower locals to contribute to technology development ensuring the development of interventions that meet their needs and subsequent rapid adoption. For crop or varietal selection, PRA approaches account for the multiplicity of farmers' requirements and geographic contexts (Begna, 2022). For example, farmer crop or variety selection in various agroecological zones can be prioritized based on both pre-and post-harvest factors including yields, duration to maturity, resistance to climate stressors, and pests and disease incidences (Goa et al., 2017; Mutari et al., 2021; Nchanji et al., 2021). Post-harvest characteristics such as food nutritional value, storage shelf life, seasonality and multiplicity of harvests together with marketability and profitability also differentially contribute to crop choices (Magaisa et al., 2022). In other cases, selection of crop choices can be influenced by gender disparities with men sometimes choosing capital-intensive and high-value vegetables while women can settle for traditional but nutrient-dense vegetables (Ouya et al., 2024). The current study aims to evaluate farmer-preferred vegetables for integration into the PPT with BSF frass organic amendments in Kenya and Uganda following a PRA approach.

2 Materials and methods

2.1 Study location

This study was carried out in selected different agroecological areas covering western (Vihiga, Kisii, Busia and Homa Bay counties) and central regions (Kiambu, Murang'a and Embu counties) of Kenya, and eastern part of Uganda (Namwendwa, Bulopa and Wankole sub-counties) (Figure 1). Kiambu, Murang'a and Embu constitute counties in the central part of Kenya with land areas of approximately 2,538, 2,524 and 2,821 km^2 with population sizes of 2,417,735, 1,056,640 and 608,599, respectively (KNBS, 2019). These regions receive bimodal rainfall with short rain commencing in late February and ceasing in late May, while short rains start around mid-September and end in mid-January (Nathan et al., 2020). The regions consist of four agroecological zones (AEZs), namely, upper highland humid, lower highland semi-humid, upper midland sub-humid and lower midland semi-humid (Sombroek et al., 1982). The main food crops for these counties are maize, common bean (*Phaseolus vulgaris*), pigeon peas (*Cajanus cajan*) and sweet potatoes (*Ipomea batatas*) while the cash crops are tea (*Camellia sinensis*), coffee (*Coffea* spp.), banana (*Musa* spp.), mangoes (*Mangifera indica*) and avocadoes (*Persea americana*) (Recha, 2018).

In western Kenya, Busia, Vihiga, Homa Bay and Kisii counties cover about 1,696, 531, 3,183 and 1,323 km^2, with a population of 893,861, 590,013, 1,131,950 and 1,266,860, respectively (KNBS, 2019). The regions receive bimodal rainfall with a long rain season starting in mid-March to late May, while a short rain season commences in late August to mid-December (Mugalavai et al., 2008). The regions consist of four AEZs, namely, lower midland humid, lower midland sub-humid, upper midland humid and upper midland semi-humid (Sombroek et al., 1982). The main food crops grown in western Kenya are maize, sorghum, beans, cowpeas, cassava and sweet potatoes while sugarcane (*Saccharum* spp.) and bananas constitute cash crops (Recha, 2018).

Kamuli district lies in the eastern region of Uganda covering 1,517 km^2 with an estimated population of 558,500 (UBOS-Statistical Abstract, 2020). Among others, it has several sub-counties including Namwendwa, Bulopa, and Wankole, with land areas of 150, 46 and 51 km^2 and population sizes of 65,900, 33,300 and 23,000, respectively (UBOS-Statistical Abstract, 2020). Kamuli district is characterized by a sub-humid agroecological zone with cropping seasons occurring March–June (560 mm) and July–November (540 mm). The major food crops in this region are finger millet, banana and maize while cotton constitutes a major cash crop (Kayuki et al., 2017).

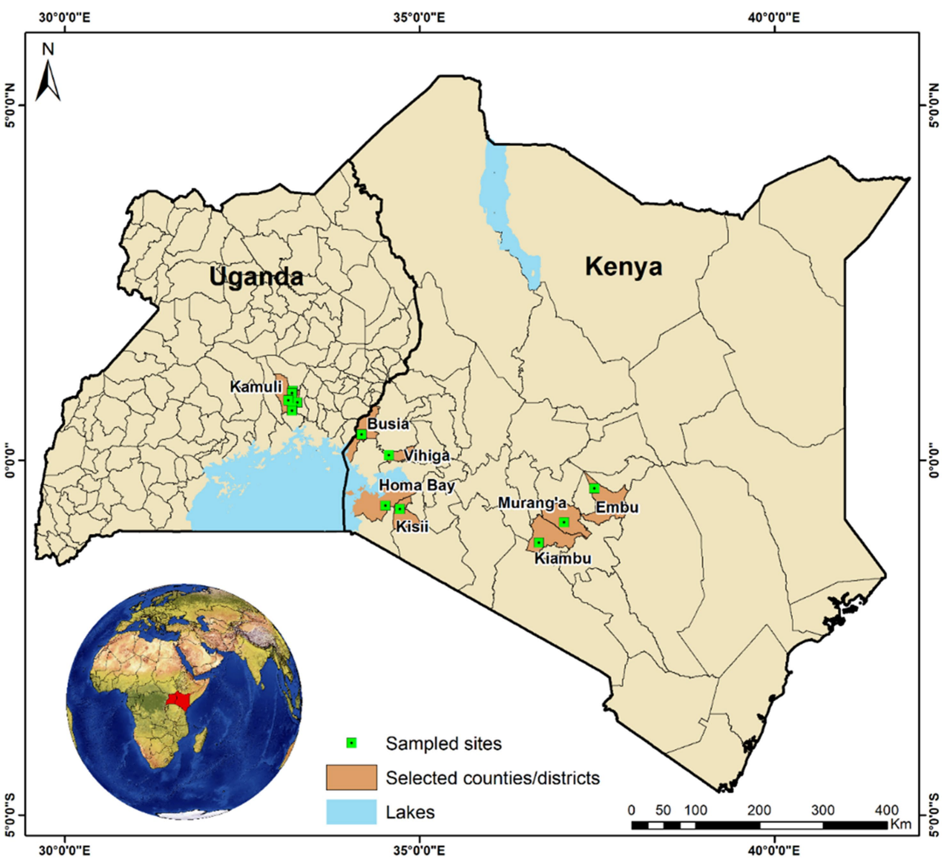

FIGURE 1
Map of the study areas covered in surveys for selecting vegetables for integration in a vegetable integrated push-pull with black soldier fly frass in Uganda and Kenya.

2.2 Sampling methods and data collection

A purposive sampling procedure was adopted to identify villages and participants for focus group discussions (FGDs) as well as in-person interviews. Firstly, the participants in the study were purposively selected at household levels based on the history of vegetable production in rural and peri-urban areas. Secondly, the farmers within localities where previous PPT projects were implemented were targeted as a unit of inquiry and were subsequently admitted into FGDs. Structured, pretested questionnaires were administered to gather quantitative and qualitative data to understand vegetable production practices and location-specific constraints (Supplementary material S1).

The questionnaires were designed to guide discussions and information gathering from the selected focus groups of farmers through FGDs and in-person interviews. In each FGD, farmers listed all vegetables grown in their localities. The top five vegetables were selected based on the frequency of mentions in each FGD. We collected the qualitative opinions on various pre-selected traits for each of the selected vegetables during the discussions. For each vegetable, farmers elected if it carried any of the following traits or usage: household consumption, income generation, nutritional value, extended harvesting, seed production, drought tolerance, resistance to diseases and resistance to insect pests. We recorded the binary choices (yes or no) for each trait or usage of a vegetable as provided by the participants. Overall, 26 FGDs with 6–14 individuals per group were conducted from July to November 2023. Approximately 227 and 106 farmers from Kenya and Uganda, respectively, participated in FGDs.

Further, farmers were interviewed individually to gather information on sociodemographic data including gender, age, education levels, total land owned, farm size under vegetables, type and number of livestock kept and types of alternative sources of livelihood. Farmers were also asked if they faced various vegetable production constraints in their localities. The binary response ("Yes" or "No") of each farmer was scored against each constraint. The production constraints mentioned to farmers included biotic stressors (diseases and pests), environmental stressors (drought and poor rainfall, too much rainfall and floods, and low soil fertility) and socio-economic stressors (high cost of agrochemicals and fertilizers, lack of seeds and poor seed quality). Farmers were shown posters and demonstration plots detailing VIPP, BSF farming and the integration of VIPP with BSF frass fertilizer. After pictorial and field demonstrations, each farmer was asked about his/her willingness to adopt these innovations. Likewise, each farmer was requested to suggest types of vegetables that can be incorporated into VIPP coupled with BSF frass. Vegetables were ranked based on the frequency of mentions and the top five vegetables were selected as most suitable for incorporation in VIPP coupled with BSF frass. All responses were recorded for subsequent analyses.

2.3 Model specifications

The vegetable production constraints and willingness to adopt VIPP and BSF innovations were modeled using binary logistic regression. The response variables were dichotomous, taking the value of 1 (yes) if a farmer agrees that they have experienced vegetable production constraints that were mentioned to them and otherwise 0 (no). The vegetable production constraints suggested to them included diseases, pests, drought/poor rainfall, too much rainfall/floods, high cost of agrochemicals and fertilizers, lack of seeds, low soil fertility and poor seed quality. Additionally, the farmers' choice to adopt either VIPP, BSF or VIPP+BSF innovations also resulted in dichotomous response with a value of 1 for "yes" and 0 for "no." The mathematical expression for the logistic regression model is as follows (Gujarati, 1995):

$$Prob\left(Y\text{i}-1\right)=P\text{i}=F\left(Z\text{i}\right)=F\left(\alpha+\sum\beta\text{i}X\text{i}\right)=\left(\frac{1}{1+e^{-Z\text{i}}}\right) \tag{1}$$

In the model, P_i is the probability that a farmer responds by acknowledging the vegetable production constraints or is willing to adopt regenerative agricultural innovations. X_i represents explanatory variables, and α and β are parameters to be estimated. The probability of not agreeing with certain constraints as major limitations in vegetable production or not being interested in adopting regenerative agricultural innovations was expressed in the equation as follows:

$$Prob\left(Y\text{i}-0\right)=1-Prob\left(Y\text{i}=1\right)=\left(1-P\text{i}\right)=\left(\frac{1}{1+e^{Z\text{i}}}\right) \tag{2}$$

Equations 1, 2 are combined to get,

$$\frac{Prob\left(Y\text{i}-1\right)}{Prob\left(Y\text{i}=0\right)}=\frac{P\text{i}}{1-P\text{i}}=e^{Z\text{i}} \tag{3}$$

Here P_i is the probability that Y_i takes the value 1 and then $(1-P_i)$ is the probability that Y_i is 0 and e is the exponential constant.

Now including the natural logarithm of both sides of Equation 3, we get Equation 4,

$$Z\text{i}=\ln\left(\frac{P\text{i}}{1-P\text{i}}\right)=\beta\text{i}+\beta_1X_{1\text{i}}+\beta_2X_{2\text{i}}+\ldots+\beta\kappa X\kappa+\mu\text{i} \tag{4}$$

Where Z_i represents the logit model; P is the probability of the outcome; X_i represents the independent variable being evaluated; subscript $_i$ stands for the $_i$th observation in the sample; β_0 is the intercept term and $\beta_1+\beta_2+\ldots+\beta_k$ are the coefficients for each independent variable $X_1, X_2, \ldots, X_k$.

2.4 Statistical analysis

The data acquired through the questionnaires was entered in MS Excel. A binary logistic model was used to analyze the vegetable production constraints and willingness to adopt regenerative agricultural innovations in each study site (seven counties in Kenya and three sub-counties in Uganda). All the data analysis was performed in R Statistical Software Version 4.0.3 (R Core Team, 2021). Descriptive statistics (frequencies and percentages) were used to represent farmers' responses. Figures and tables were used to summarize the results.

3 Results

3.1 Sociodemographic characteristics of households

The socio-demographic characteristics of participants are provided in Table 1. Overall, the percentage of male and female participants was 42 and 58%, respectively. In all places, most participants were above 36 years old except for Kiambu (Kenya) and Bulopa (Uganda) which both had most participants who were below 36 years old.

Except for Kiambu and Vihiga counties where most participants had no formal education (44.4 and 38.5%, respectively), other counties had most participants who attained formal education in primary and secondary education. In Uganda, no participants had attained a college/university education. Most participants owned at least 1.09–3.91 acres of land, with the average land allocated for vegetable production ranging from 0.45 to 1.70 acres.

Generally, most farmers practiced a mixed crop-livestock system with chickens, cattle and goats being the main livestock enterprises. Comparatively, pigs were the least reared livestock. More chickens (2.00–2.54 heads/household) were kept in Kenya than in Uganda (1.50–1.96 heads/household). Similarly, the farmers in Kenya had higher cattle herd sizes (0.86–1.25 heads/household) and goats (0.50–1.75 heads/household) than their counterparts in Uganda (0.47–0.58 heads/household). On the contrary, most respondents in Uganda owned more pigs (0.96–2.00 heads/household) than respondents in Kenya (0.43–0.83 heads/household).

In Kenya, the respondents were involved in both agricultural self-employed activities and agricultural labor (wage) work. Busia and Kiambu counties had most of the respondents involved in agricultural self-employed (52.8 and 89.2%, respectively) while Kisii, Murang'a, Homa Bay, Vihiga and Embu counties had most of the respondents participating in agricultural wage labor (70.8, 64.3, 63.9, 61.5 and 51.1%, respectively). In Uganda, all respondents from three survey sub-counties were involved as agricultural self-employed and none of them was involved in agricultural wage labor.

3.2 Desired biological and physical traits

3.2.1 Distribution of traits across vegetable types

FGDs were held to determine why farmers chose the top five most desired vegetables out of all those cultivated on their homesteads. A total of 23 vegetable types were identified in the study areas. Most farmers stated that household consumption, income generation, nutritional value, extended harvesting, drought tolerant and resistance to diseases and insect pests were among the most important features they looked for when selecting vegetables (Figure 2).

Although all vegetables were grown for household consumption, eggplants (*Solanum melongena*), garden eggs (*Solanum* spp.) spinach (*Spinacia oleracea*), Amaranthus (*Amaranthus* spp.), kales (*Brassica oleracea*), African nightshade (*Solanum nigrum*) and cowpeas (*Vigna unguiculata*) constituted the most consumed vegetables by over 75% of households. More than 80% of farmers grow tomatoes (*Solanum lycopersicum* L.), garden eggs, common beans, spinach, carrots (*Daucus carota*), kales and Amaranthus for income generation.

Carrots, vine spinach (*Bassella alba*), jute mallow (*Corchorus olitorius*), Amaranthus, spinach, slender leaf, Amaranthus and African nightshade were preferred by over 50% of farmers based on their nutritional value. Prolonged harvesting of green pepper, spinach, eggplants, African nightshade and vine spinach made them preferred by farmers for household consumption and cash sale. Vine spinach, spinach, Amaranthus, slender leaf, coriander (*Coriandrum* spp.), cowpeas, African nightshade and jute mallow were favored due to their resistance to diseases and pests according to over 50% of the farmers. The ability to produce seeds made farmers prefer garden eggs, green peppers, eggplants, cowpeas, Amaranthus, African nightshade and Jute mallow, thus saving farmers' costs of purchasing seeds for the next season. Over 50% of farmers preferred green pepper, spinach, Amaranthus, eggplants and cowpeas due to their tolerance to drought.

3.2.2 Distribution of traits across vegetable types and regions

The distribution of farmers' preferred traits across vegetable types and regions is illustrated in Figure 3. Kales, slender leaf, Amaranthus, jute mallow, cowpeas, African black nightshade and pumpkin leaves were consumed by over 50% of households in western Kenya. Amaranthus, cowpeas, kales and African black nightshade generated the highest income, with household sales by over 50% of respondents. Amaranthus, pumpkin leaves, slender leaf, vine spinach, African black nightshade, jute mallow, cowpeas and kales were similarly highly rated for their nutritional content and drought tolerance by 50% of respondents.

In central Kenya counties, Amaranthus, cabbage, kales, spinach and African black nightshade vegetables were highly ranked in terms of homestead consumption and income generation, with responses ranging from 50%. Spinach, Amaranthus carrots, and black nightshade were all excellent in nutritional value. Amaranthus, spinach, and kale were suggested as drought-tolerant plants. In the Kamuli area, Uganda, respondents ranked cabbage, eggplants, garden eggs, Amaranthus and kales as highly consumed in households and good income generators. Amaranthus, eggplants and garden eggs were all mentioned as drought-tolerant and rich in nutritional content by over 50% of respondents. Amaranthus and Kale were found to fit all criteria across Kenya and Ugandan sites.

3.3 Constraints faced by farmers during vegetable production

The primary limits to vegetable production in the targeted agroecologies of Kenya and Uganda comprised both biotic and abiotic stressors (Table 2). There was significant variation in vegetable production constraints across countries ($\chi^2 = 530.23$; DF = 1; $p < 0.0001$) and within countries ($\chi^2 = 568.80$; DF = 9; $p < 0.0001$). The high cost of agrochemicals and fertilizers was the biggest constraint to vegetable production in Kenya (45.9–72.0%) and Uganda (87.2–90.2%) for the selected vegetables. Other than the high cost of agrochemicals and fertilizers, poor seed quality was reported as a major constraint by over 50% of respondents in Kenya (Homa Bay, Kiambu, Kisii, Murang'a counties) and Uganda (Bulopa, Namwendwa, Wankole sub-counties). Insect pests were also recorded as a major constraint in Uganda (87.2–94.3%) compared to Kenya (29.7–50.0%). The unavailability of seeds ranked as the least constraint for farmers across the counties in Kenya

TABLE 1 Socio-demographic characteristics of respondents interviewed during assessment of vegetable production constraints, trait preferences and willingness to adopt sustainable intensification options in Kenya and Uganda.

Variables	Kenya							Uganda		
	Busia (*n* = 37)	Embu (*n* = 44)	Homa Bay (*n* = 35)	Kiambu (*n* = 36)	Kisii (*n* = 23)	Murang'a (*n* = 26)	Vihiga (*n* = 26)	Bulopa (*n* = 32)	Namwendwa (*n* = 35)	Wankole (*n* = 39)
Gender (%)										
Male	40.5	40.9	42.9	41.7	43.5	30.8	46.2	28.1	48.6	56.4
Female	59.5	59.1	57.1	58.3	56.5	69.2	53.8	71.9	51.4	43.6
Age (%)										
Below 36 years	13.5	18.2	40.0	52.8	30.4	23.1	30.8	59.4	42.9	28.2
36 and above years	86.5	81.8	60.0	47.2	69.6	76.9	66.2	40.6	57.1	71.8
Education levels (%)										
College/University	8.1	2.3	5.7	16.7	8.7	19.2	7.7	0.0	0.0	0.0
Secondary	75.7	31.8	25.7	30.6	21.7	38.5	30.8	31.3	48.6	28.2
Primary	16.2	38.6	65.7	8.3	52.2	38.5	30.8	37.5	51.4	59.0
No formal education	0.0	27.3	2.9	44.4	0.0	3.8	38.5	31.3	0.0	12.8
Total land owned (acres)	3.19	1.39	2.79	3.91	1.19	1.09	1.12	1.94	2.11	1.78
Land under vegetables (acres)	0.97	0.68	0.36	1.70	0.48	0.45	0.73	0.74	0.93	0.45
Livestock (heads/household)										
Cows	0.86	1.13	1.22	0.89	1.25	1.14	1.19	0.47	0.58	0.56
Goats	0.89	0.89	0.50	1.03	1.75	1.50	0.77	0.76	0.85	0.78
Chicken	2.00	2.20	2.00	2.51	2.38	2.25	2.54	1.50	1.96	1.67
Pigs	0.56	0.62	0.56	0.43	0.83	0.57	0.62	1.18	2.00	0.96
Occupation										
Agricultural self-employed	52.8	48.9	36.1	89.2	29.2	35.7	38.5	100	100	100
Agricultural wage labor	47.2	51.1	63.9	10.8	70.8	64.3	61.5	0.0	0.0	0.0

10.3389/fsufs.2025.1471333

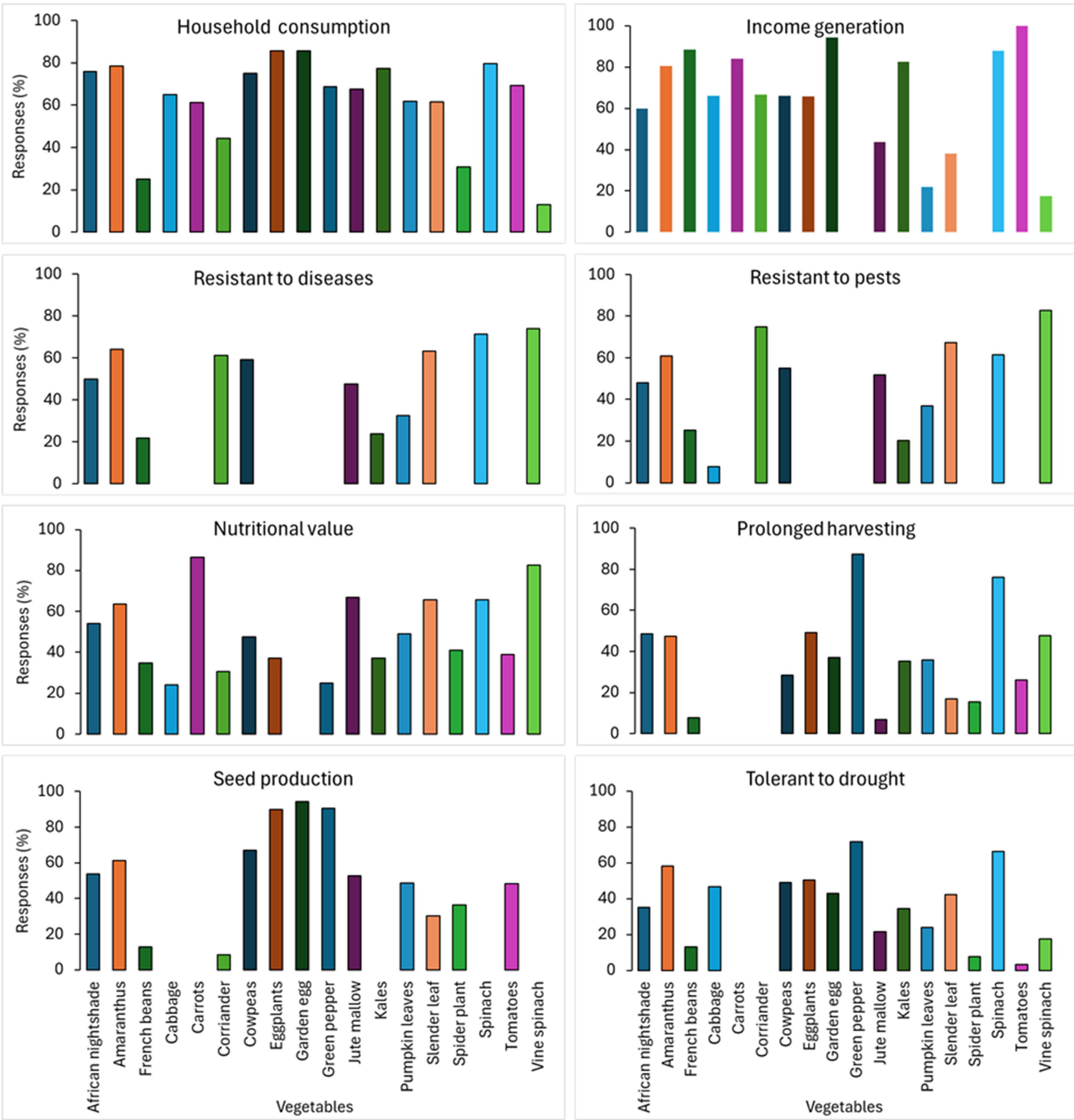

FIGURE 2
Farmers' preferred traits of vegetables they grow in Kenya and Uganda. Empty bars indicate the vegetable lacked a certain trait.

(3.8–13.6%) while it was ranked as major constraint in sub-counties in Uganda (87.2–94.3%). However, low soil fertility and diseases were some of the challenges reported by a large proportion (over 67.5%) of farmers in three surveyed sub-counties of Uganda. Drought and poor rainfall were common constraints in the Namwendwa sub-county while too much rainfall and frequent flooding were common constraints in Bulopa and Namwendwa sub-counties.

3.4 Willingness to accept and adopt regenerative agricultural innovations

Households were assessed for their willingness to accept and adopt VIPP alone, BSF frass alone and VIPP+BSF frass. Across the counties, there were significant variations in the willingness of smallholder farmers to accept and adopt VIPP ($\chi^2 = 121.75$, DF = 9, $p < 0.0001$) and BSF ($\chi^2 = 82.45$, DF = 9, $p < 0.0001$). On the contrary, the willingness of farmers to adopt the combination of these regenerative technologies (i.e., VIPP+BSF frass) did not vary across the counties ($\chi^2 = 6.26$, DF = 9, $p = 0.71$). The results of logistic models based on the probability of farmers accepting and adopting either of the three agricultural innovations are summarized in Table 3. The negative coefficients (β) indicate a <50% likelihood of households adopting the technologies while positive coefficients indicate a more than 50% likelihood of the household adopting the technologies. Overall, there was more willingness to adopt the innovations when integrated (VIPP + BSF frass) compared to individual options (VIPP or BSF frass).

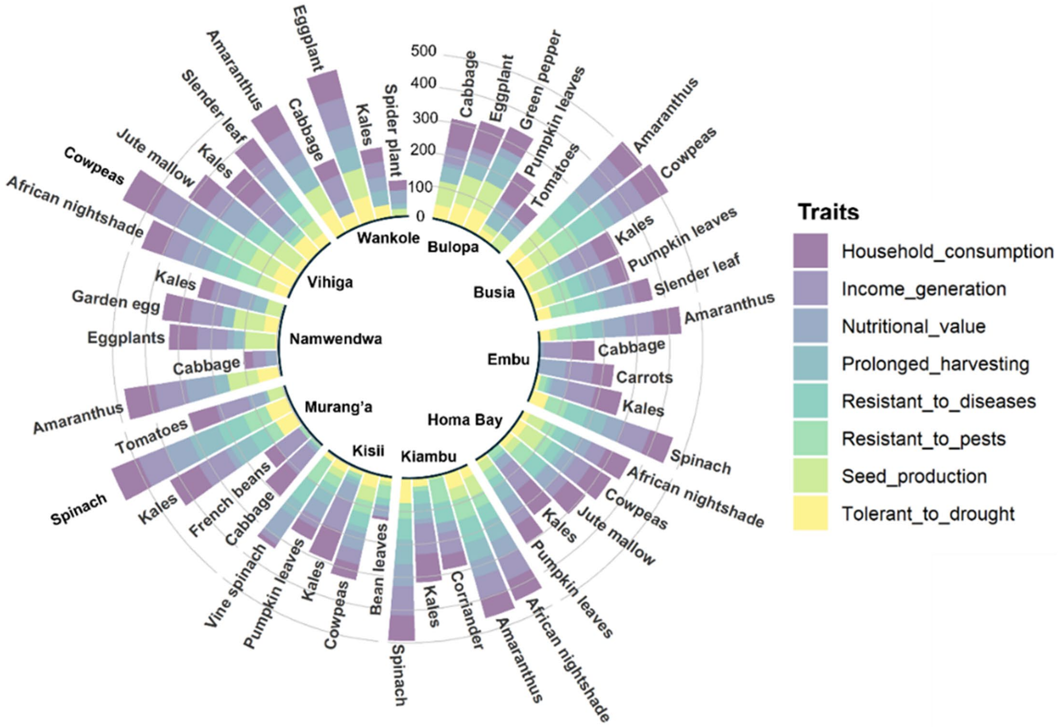

FIGURE 3
Top preferred traits associated with vegetables grown in western Kenya, central Kenya and the Kamuli district of Uganda.

Across Kenyan counties, Kiambu, Embu, Vihiga, and Busia indicated 100% preparedness to embrace VIPP technology, whereas Murang'a and Homa Bay were less prepared with 54 and 57% of farmers expressing willingness. Farmers in Kisii County had comparatively least desire to adopt VIPP (22%). In Uganda, a larger proportion of farmers (94 and 91%) from Bulopa and Namwendwa sub-counties, respectively, expressed willingness to accept and practice the VIPP as compared with Wankole sub-counties where only 62% of farmers showed willingness (Figure 4).

In Kenya, all farmers in Embu County were eager to accept and implement BSF innovation. The growing interest in adopting BSF innovations was expressed by farmers in Busia County (65%), and Murang'a County (65%). Between 24 and 48% of farmers expressed interest in adopting BSF innovations in Homa Bay, Kiambu, Kisii and Vihiga counties.

Integration of VIPP and BSF innovations attracted appreciable interest across all surveyed counties and sub-counties. More than 83% of farmers showed readiness to adopt a combination of regenerative technologies (i.e., VIPP+BSF) across counties in Kenya and Uganda.

3.5 Farmers' vegetable preferences for integration in VIPP with BSF frass

The top five vegetables preferred by farmers across counties to be incorporated in VIPP and BSF frass are presented in Figure 5. The preferred vegetables in central Kenya include kales, spinach, cabbage, Amaranthus, African nightshade, and tomatoes. In western Kenya, kales, African nightshade, cowpeas, Amaranthus, pumpkin leaves, and spider plants constituted the preferred vegetables. Eggplants, Amaranthus, garden eggs, cabbage, kale, and tomatoes are the most popular vegetables in the Kamuli area (Bulopa, Wankole and Namwendwa sub-counties) in Uganda. Ranking across counties and sub-counties, the most preferred vegetables were cowpeas (Busia and Vihiga Counties), kales (Homa Bay, Kisii, Embu, Murang'a Counties), spinach (Kiambu County), Amaranthus (Namwenda and Wankole sub-counties) and tomatoes (Bulopa sub-county).

4 Discussion

The study conducted a participatory selection of farmers' preferred vegetables to be incorporated in a VIPP with BSF frass in Kenya and Uganda. Female respondents were more likely than male respondents to produce vegetables, an indication that gender is a determinant in food production systems in smallholder farming in sub-Saharan Africa. This corroborates previous studies which attribute most food production in the region to women (Loizou et al., 2019; Doss et al., 2018; Kadzamira et al., 2024).

Most respondents were aged 36 years and above, indicating an active group participating in rural agricultural production, as opposed to youth under the age of 36 years. However, less involvement of youth in building future food systems may be attributed to their socioeconomic status including finance, membership association, land ownership and education. Other studies have attributed improved access to credit through relevant agencies with low interest rates and flexible payment options, as well as policies for sustainable implementation programs, as potential solutions to improve youth participation in African rural agriculture (Daudu et al., 2023; Kadzamira et al., 2024). In sub-Saharan Africa (SSA), more than 130

TABLE 2 Proportion and binary logistic model's estimates for the different vegetable production constraints as mentioned by farmers in Kenya and Uganda.

Counties/ Districts	Vegetable production constraints (%)								
	Diseases	Drought/Poor rainfall	High cost of agrochemicals and fertilizers	Lack of seeds	Low soil fertility	Pests	Poor seed quality	Too much rainfall/ floods	Chi-value
Kenya									
Busia	16.2	35.1	45.9	8.1	8.1	29.7	29.7	10.8	30.17***
	(−1.64, 0.45)[b]	(−0.61, 0.34)[a]	(−0.16, 0.33)[a]	(−2.43, 0.60)[b]	(−2.42, 0.60)[b]	(−0.86, 0.36)[ab]	(−0.86, 0.36)[ab]	(−2.11, 0.53)[b]	
Embu	36.4	15.9	59.1	13.6	11.4	43.2	47.7	9.1	57.43***
	(−0.56, 0.31)[ab]	(−1.67, 0.41)[c]	(0.37, 0.31)[a]	(−1.85, 0.44)[c]	(−2.05, 0.47)[c]	(−0.27, 0.30) ab	(−0.09, 0.30)[ab]	(−2.30, 0.52)[c]	
Homa Bay	17.1	25.7	51.4	8.6	37.1	31.4	51.4	20.0	29.54***
	(−1.57, 0.45)[bc]	(−1.06, 0.38)[b]	(0.06, 0.34)[a]	(−2.37, 0.60)[c]	(−0.52, 0.35)[b]	(−0.78, 0.36)[b]	(0.06, 0.338)[a]	(−1.38, 0.42)[b]	
Kiambu	22.2	25.0	58.3	5.6	8.3	33.3	50.0	16.7	46.59***
	(−1.25, 0.40)[b]	(−1.10, 0.38)[b]	(0.34, 0.34)[a]	(−2.83, 0.73)[d]	(−2.39, 0.60)[d]	(−0.69, 0.35)[b]	(0.00, 0.333)[a]	(−1.61, 0.44)[cd]	
Kisii	26.1	26.1	52.2	4.3	34.8	34.8	78.3	0.0	54.47***
	(−1.04, 0.47)[c]	(−1.04, 0.48)[c]	(0.09, 0.41)[b]	(−3.09, 1.02)[d]	(−0.62, 0.43)[bc]	(−0.62, 0.43)[bc]	(1.28, 0.505)[a]	(−18.56, 1.36)[d]	
Murang'a	23.1	42.3	61.5	3.8	11.5	50.0	53.8	23.1	40.44***
	(−1.20, 0.46)[c]	(−0.31, 0.39)[b]	(0.47, 0.40)[a]	(−3.22,1.03)[d]	(−2.03, 0.61)[cd]	(0.00, 0.39)[abc]	(0.15, 0.393)[ab]	(−1.20, 0.46)[c]	
Vihiga	36.0	44.0	72.0	8.0	16.0	44.0	36.0	16.0	34.92***
	(−0.58, 0.42)[b]	(−0.24, 0.40)[b]	(0.94, 0.45)[a]	(−2.44, 0.73)[c]	(−1.65, 0.54)[c]	(−0.24, 0.40)[b]	(−0.57, 0.41)[b]	(−1.66, 0.55)[c]	
Uganda									
Bulopa	78.1	43.8	90.6	90.6	90.6	90.6	90.0	90.6	34.80***
	(1.27, 0.43)[b]	(−0.25, 0.36)[c]	(2.27, 0.61)[a]	(2.27, 0.61)[a]	(2.27, 0.61)[a]	(2.27, 0.61)[a]	(2.27, 0.61)[a]	(2.27, 0.61)[a]	
Namwendwa	65.7	91.4	91.4	94.3	94.3	94.3	68.6	51.4	44.75***
	(0.65, 0.36)[bc]	(2.37, 0.60)[a]	(2.37, 0.60)[a]	(2.80, 0.73)[a]	(2.80, 0.72)[a]	(2.80, 0.72)[a]	(0.78, 0.364)[bc]	(0.06, 0.34)[c]	
Wankole	87.2	35.9	87.2	87.2	74.4	87.2	74.4	0.0	140.60***
	(1.92, 0.48)[a]	(−0.69, 0.34)[b]	(1.92, 0.48)[a]	(1.92, 0.48)[a]	(1.06, 0.36)[a]	(1.92, 0.48)[a]	(1.06, 0.367)[a]	(−18.56, 1.04)[c]	

Focus group discussion results. Values provided outside the brackets are proportion of mention. Values provided in the brackets are the binary logistic models' coefficients (β) and standard errors. Different small letters along the rows indicate significant differences at $p = 0.1$. *** = 1% level of significance. McFadden$n$ = 0.059, Cox and Snell (ML) = 0.078, Nagelkerke (Cragg and Uhler) = 0.104. Likelihood ratio test $\chi^2 = 215.23$, $p = 3.9085e\text{-}42$. Number of observations (Model = 2,656).

10.3389/fsufs.2025.1471333

TABLE 3 Logit model estimates of willingness to accept and adopt regenerative agricultural innovations by farmers across counties in Kenya and sub-counties in Uganda.

Counties	Regenerative agricultural innovations									Chi-value
	BSF frass			VIPP			VIPP + BSF frass			
	β	SE	Siq.	β	SE	Siq.	β	SE	Siq.	
Kenya										
Busia	0.57	0.35	c	1.90	0.45	a	1.29	0.59	b	10.29***
Embu	3.04	0.73	a	−0.43	0.94	a	−1.20	0.84	a	2.49^{ns}
Homabay	−1.22	0.40	c	1.50	0.53	b	2.79	0.60	a	10.29***
Kiambu	3.55	1.01	c	−1.73	1.12	a	−1.15	1.43	a	4.55^{ns}
Kisii	−0.44	0.43	b	−0.59	0.64	b	2.79	0.85	a	24.74***
Murang'a	0.64	0.41	b	0.48	0.57	b	1.85	0.84	a	11.07**
Vihiga	−0.08	0.40	c	3.26	1.09	a	2.07	0.73	b	18.92***
Uganda										
Bulopa	−0.51	0.37	b	2.77	0.71	a	2.77	0.71	a	29.98***
Namwendwa	2.05	0.53	a	0.31	0.80	a	0.31	0.80	a	0.21^{ns}
Wankole	1.77	0.26	a	−1.23	0.32	b	0.59	0.42	a	31.55***

Focus group discussion results. β denotes the binary logistic models' coefficients, SE stands for standard errors and Siq. stands for significant letters. Different small letters along the rows indicate significant differences at $P = 0.1$. ns, no significance, **1% level of significance, *** = 0.1% level of significance. McFadden$n$ = 0.052, Cox and Snell (ML) = 0.053, Nagelkerke (Cragg and Uhler) = 0.081. Likelihood ratio test $\chi^2 = 66.47$, $p = 1.2601e\text{-}13$. Number of observations (Model = 1,230).

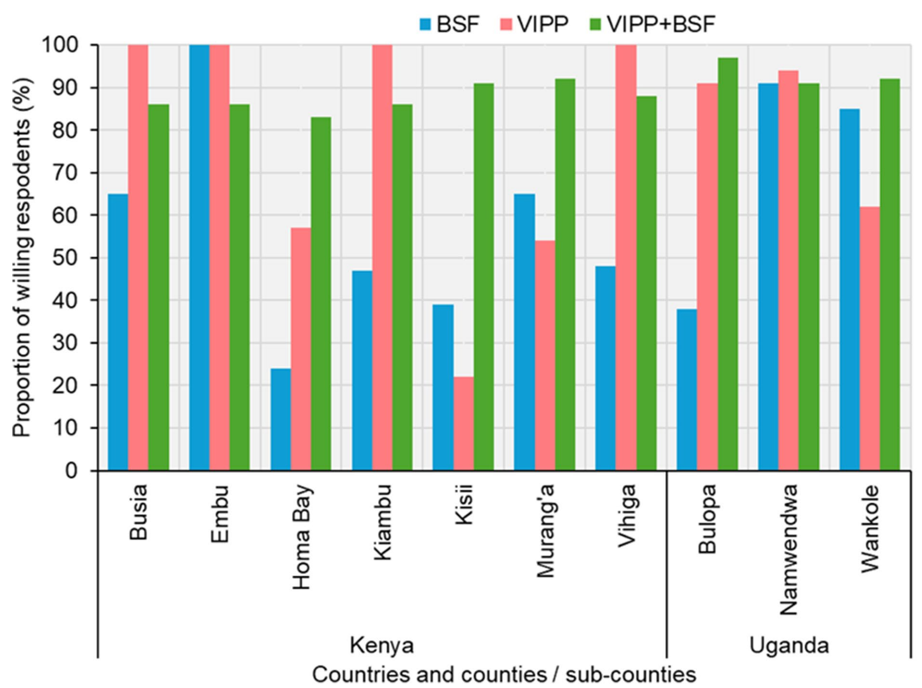

FIGURE 4
Percentage of farmers willing to accept and adopt agricultural innovations across counties. BSF, black soldier fly; VIPP, vegetable integrated push-pull.

million young people have delved into rural agricultural enterprise (Yami et al., 2019; Ouko et al., 2022). This suggests that there is existing potential, but more facilitation may be required to improve profitability that guarantees enterprises as mainstays of income and livelihoods.

Previous studies have stated that land ownership among most smallholder farms in SSA is below a hectare. This impacted negatively on household food self-sufficiency, incomes, and diversification of diets (Giller et al., 2021). In our study, the average land ownership for agriculture production varied across Kenya (3.19 acres) and Uganda (2.11 acres). These small sizes of land coupled with abiotic and biotic stressors limit the production of sufficient food. In a continent with an ever-growing population, there is a need for sustainably intensified regenerative

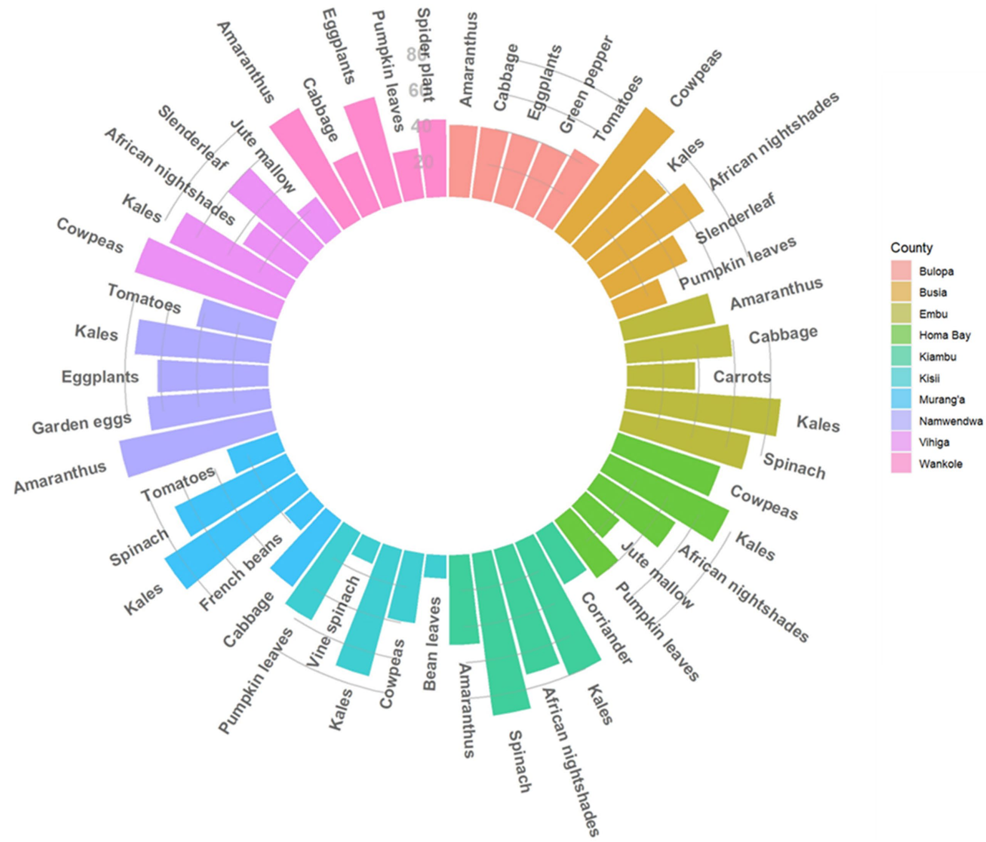

FIGURE 5
Preferred vegetables for incorporation in the vegetable-integrated push-pull with black soldier fly frass soil organic amendments in selected agro-ecologies of Kenya and Uganda.

agricultural production systems to improve yields, income and nutritional diversity.

Vegetable production and consumption are carried out globally, serving as a crucial element of food systems (Aworh, 2018). Across Kenyan counties and Ugandan sub-counties, farmers' most preferred vegetables included spinach, cabbage, African nightshade, tomatoes, kales, African nightshade, cowpeas, Amaranthus, pumpkin leaves, spider plants, eggplants and garden eggs. An ethnobotanical investigation was conducted in the Eastern Cape Province of South Africa to explore the wild and cultivated vegetables where cabbage, pumpkin, spinach and squash were recorded as very important (Maroyi, 2020). These vegetables were all recorded in our study in both Kenya and Uganda underlying their importance across extended geographic ranges.

Farmers consider a variety of qualities including seed and leaf yield, pest and disease resistance, household consumption and seed production of the vegetables they cultivate (Nakyewa et al., 2021). In our study, 50% of respondents ranked Amaranthus, pumpkin leaves, slender leaf, vine spinach, African black nightshade, jute mallow, eggplant, cowpeas and kales as having high nutritional value, which improves health and combat malnutrition. These vegetables are rich in nutrients, vitamins, minerals, and dietary fiber and are widely acknowledged as being essential for food and nutritional security throughout Africa (Bua and Onang, 2017; Traoré et al., 2017; Dinssa et al., 2020; Han et al., 2021; Sangija et al., 2021; Horn et al., 2022; Wild, 2022). However, it is interesting that farmers consider dietary and nutritional outcomes beyond mere sustenance in the choices of vegetables that they cultivate. Perhaps to their known affordability as nutritious diets for smallholder farmers (Ochieng et al., 2019), which in turn can help to curb various non-communicable diseases (Han et al., 2021; Mwadzingeni et al., 2021).

While leafy vegetables may promote dietary diversification and enhance household livelihood, they remain underutilized in some parts of Africa because of lack of research, input requirements, lack of understanding of their benefits, and unorganized markets (Emmanuel and Babalola, 2022). Considering climate change, some vegetables such as Amaranthus, cowpeas, and jute mallow can thrive in water-stressed conditions in Africa (Maseko et al., 2020). In our studies, some of the vegetables that could be considered drought-tolerant according to farmers included Amaranthus, pumpkin, slender leaf, vine spinach, African black nightshade, jute mallow, cowpeas and kales. While some leafy vegetables may be considered tolerant to drought conditions, their growth, physiology and yield responses vary as a function of water stress regimes (Maseko et al., 2020). Therefore, there is a need for research to provide empirical evidence on the growth, productivity, physiology and nutritional profiles of farmers' selected vegetables under limited water availability or flooded conditions as climatic changes have resulted in sporadic heavy downpours causing unprecedented flooding in some areas.

Dube et al. (2019) demonstrated a high incidence of fungal diseases and pests, low soil fertility, restricted breeding, pressures caused by climate change, and scarcity of appropriate inputs due to prohibitively high prices as peculiar tomato production constraints in Africa. We found biotic stressors such as diseases and pests, environmental stressors such as drought and poor rainfall, too much rainfall and floods and low soil fertility and socio-economic factors such as high cost of agrochemicals and fertilizers, lack of seeds and poor seed quality as main vegetable production constraints in Kenya and Uganda. However, these challenges were more rampant in Ugandan compared to Kenyan farmers, implying limited adaptive, coping and mitigation strategies among Ugandan smallholder farmers. Further, the intensity of the constraints varied across the locations. Liliane and Charles (2020) showed biological stressors (diseases, pests, weeds), environmental stressors (soil fertility, climatic condition, topography, water quality) and limited technological approaches (agricultural practices) as factors affecting crop yield. Further, the author showed these factors accounted for yield differences across regions, globally.

In our study, the target regions differed in their willingness to accept BSF frass and VIPP as individual innovations. Interestingly, the propensity to adopt VIPP and BSF frass when integrated was equally high across Kenya and Uganda. The production constraints such as pest incidences, low soil fertility and high input costs influenced willingness to adopt, perhaps upon farmer realization of the promised benefits of an integrated VIPP with frass. Since some of the participants had prior exposure to push-pull farming, this may have played a role in the willingness to adopt due to known benefits. Although insect farming for the circular bioeconomy is a relatively new concept (Tanga et al., 2021), the expressed interest by farmers may largely be associated with its potential benefits. Other factors such as high level of education, agricultural information and agricultural extension services may influence the adoption of innovations as previously reported (Niassy et al., 2020).

Intercropping vegetables and edible legumes with cereals is a key part of farm diversification that not only helps in improving environmental outcomes but also boosts economic prospects by lowering rural poverty and unemployment in developing countries. We found Kenyan farmers in central regions preferred kales, spinach, cabbage, Amaranthus, African nightshade and tomatoes, while farmers in western regions preferred kales, African nightshade, cowpeas, Amaranthus, pumpkin leaves and spider plants as vegetables to be included in VIPP and BSF frass innovations. Ugandan farmers from Bulopa, Wankole and Namwendwa sub-counties considered eggplants, Amaranthus, garden eggs, cabbage, kales and tomatoes as the most popular vegetables that can be incorporated in VIPP and BSF frass innovations.

5 Limitations of the study

Despite this study providing a useful analysis of vegetable types, preferred vegetable traits, production constraints, willingness to adopt VIPP and BSF farming innovations and vegetables that can be included in these rural areas to guide further policy considerations, we are cognizant of its limitations. First, our assessment was based on two survey approaches through FGD and in-person interviews, possibly limiting the accuracy of descriptions that would otherwise be captured using resource-intensive approaches such as direct observations. Second, datasets on vegetable production constraints and willingness to adopt innovations were based on individual opinions which may at a times be biased. Last, our study focused on focal groups of farmers in purposively selected villages and varying sample sizes in study sites, which may impact the completeness of our results on vegetable production constraints, trait preferences and willingness to adopt sustainable intensification. Thus, we recommend that further studies may limit these potentially confounding factors.

6 Conclusions and recommendations for future research

In conclusion, the current study provides a platform for integrating VIPP and BSF farming to advance a rural circular bioeconomy. The higher involvement of women in farming noted in our study needs to also be harnessed as a pathway for increased gender equity. Given the envisaged enhanced environment and yield of VIPP and BSF frass organic fertilizer, there is a need to stimulate the adoption of these innovations following a robust participatory approach that also accounts for the farmers' top preferred vegetables and farmer feedback in the design and validation of these innovations. This will ensure broader diffusion and scaling and ultimately boost the environmental, yield and nutritional outcomes of this diversified food production system. The involvement of policymakers especially in increasing seed availability of vegetables will be crucial to increasing the adoption of VIPP and utilization of BSF frass as soil amendments in diversifying rural food and nutritional security and enhancing rural farmers' livelihood.

Data availability statement

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

Author contributions

RO: Data curation, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Methodology. EO: Formal analysis, Validation, Writing – review & editing. DM: Supervision, Writing – review & editing. DB: Conceptualization, Writing – review & editing. MM: Supervision, Writing – review & editing. SS: Funding acquisition, Resources, Writing – review & editing. FC: Conceptualization, Data curation, Funding acquisition, Methodology, Project administration, Resources, Supervision, Validation, Writing – review & editing.

Funding

The author(s) declare that financial support was received for the research and/or publication of this article. The authors gratefully acknowledge the financial support for this research by the following organizations and agencies: The Ingvar Kamprad Elmtaryd Agunnaryd (IKEA) Foundation through the "Scaling regenerative black soldier fly farming along with vegetable push-pull cropping systems in rural Kenya, Rwanda and Uganda" project (Grant number: 1175); Biovision Foundation through the project Increasing diffusion and impact of the vegetable-integrated push-pull technology (VIPPT) in eastern Africa from a "One Health" perspective (Grant number: BV -DPP-012-2023-2025); the Swedish International Development Cooperation Agency (SIDA); the Swiss Agency for Development and Cooperation (SDC); the Australian Centre for International Agricultural Research (ACIAR); the Norwegian Agency for Development Cooperation (NORAD); the German Federal Ministry for Economic Cooperation and Development (BMZ); and the Government of the Republic of Kenya.

Acknowledgments

We are grateful to Nathan Ochatum, Dickens Nyagol, and Eunice Mumbo for providing field technical support.

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.

The author(s) declared that they were an editorial board member of Frontiers, at the time of submission. This had no impact on the peer review process and the final decision.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2025.1471333/full#supplementary-material

References

Adan, I. H., Asudi, G. O., Niassy, S., Jalloh, A. A., Mutua, J. M., Chidawanyika, F., et al. (2024). Comparative microbiome diversity in root-nodules of three Desmodium species used in push-pull cropping system. *Front. Microbiol.* 15:1395811. doi: 10.3389/fmicb.2024.1395811

Anyega, A. O., Korir, N. K., Beesigamukama, D., Changeh, G. J., Nkoba, K., Subramanian, S., et al. (2021). Black soldier fly-composted organic fertilizer enhances growth, yield, and nutrient quality of three key vegetable crops in sub-Saharan Africa. *Front. Plant Sci.* 12, 1–14. doi: 10.3389/fpls.2021.680312

Aworh, O. C. (2018). From lesser-known to super vegetables: the growing profile of African traditional leafy vegetables in promoting food security and wellness. *J. Sci. Food Agric.* 98, 3609–3613. doi: 10.1002/jsfa.8902

Beesigamukama, D., Mochoge, B., Korir, N., Ghemoh, C. J., Subramanian, S., and Tanga, C. M. (2021). *In situ* nitrogen mineralization and nutrient release by soil amended with black soldier fly frass fertilizer. *Sci. Rep.* 11, 14799–14714. doi: 10.1038/s41598-021-94269-3

Begna, T. (2022). Importance of participatory variety selection and participatory plant breeding in variety development and adoption. *Am. J. Bio. Sci.* 10:35. doi: 10.11648/j.ajbio.20221002.11

Bjornlund, V., Bjornlund, H., and Van Rooyen, A. F. (2020). Why agricultural production in sub-Saharan Africa remains low compared to the rest of the world a historical perspective. *Int. J. Water Resour. Dev.* 36, S20–S53. doi: 10.1080/07900627.2020.1739512

Bua, B., and Onang, C. (2017). Validating the role of African indigenous vegetables for food and nutrition security in Uganda. *J. Food Eng.* 7, 316–322. doi: 10.17265/2159-5828/2017.06.005

Chidawanyika, F., Midega, C. A. O., Bruce, T. J. A., Duncan, F., Pickett, J. A., and Khan, Z. R. (2014). Oviposition acceptance and larval development of *Chilo partellus* stemborers in drought-stressed wild and cultivated grasses of East Africa. *Entomol. Exp. Appl.* 151, 209–217. doi: 10.1111/eea.12186

Chidawanyika, F., Muriithi, B., Niassy, S., Ouya, F. O., Pittchar, J. O., Kassie, M., et al. (2023). Sustainable intensification of vegetable production using the cereal 'push-pull technology': benefits and one health implications. *Environ. Sustain.* 6, 25–34. doi: 10.1007/s42398-023-00260-1

Chidawanyika, F., Omuse, E. R., Agutu, L. O., Pittchar, J. O., and Khan, Z. R. (2025). An intensified cereal push-pull system reduces pest infestation and confers yield advantages in high-value vegetables. *Crop Health* 77:40. doi: 10.1007/s10343-024-01107-3

Cook, S. M., Khan, Z. R., and Pickett, J. A. (2007). The use of push-pull strategies in integrated pest management. *Annu. Rev. Entomol.* 52, 375–400. doi: 10.1146/annurev.ento.52.110405.091407

Daudu, A. K., Abdoulaye, T., Bamba, Z., Shuaib, S. B., and Awotide, B. A. (2023). Does youth participation in the farming program impact farm productivity and household welfare? Evidence from Nigeria. *Heliyon* 9:e15313. doi: 10.1016/j.heliyon.2023.e15313

Dinssa, F., Nyabinda, N., Byrnes, D., Ndinya, C., Merchant, E., and Simon, J. (2020). Performances of vegetable amaranth entries in yield and nutrient contents in Tanzania and Kenya, and variety release. *J. Med. Act. Plants* 9:181.

Doss, C., Meinzen-Dick, R., Quisumbing, A., and Theis, S. (2018). Women in agriculture: four myths. *Glob. Food Secur.* 16, 69–74. doi: 10.1016/j.gfs.2017.10.001

Drinkwater, L. E., Midega, C. A. O., Awuor, R., Nyagol, D., and Khan, Z. R. (2021). Perennial legume intercrops provide multiple belowground ecosystem services in smallholder farming systems. *Agric. Ecosyst. Environ.* 320:107566. doi: 10.1016/j.agee.2021.107566

Dube, J., Ddamulira, G., and Maphosa, M. (2019). Tomato breeding in sub-Saharan Africa - challenges and opportunities. *J. Chem. Inf. Model.* 53, 1689–1699. doi: 10.4314/acsj.v28i1.10

Emmanuel, O. C., and Babalola, O. O. (2022). Amaranth production and consumption in South Africa: the challenges of sustainability for food and nutrition security. *Int. J. Sustain. Agric.* 20, 449–460. doi: 10.1080/14735903.2021.1940729

Gebremikael, M. T., Van Wickeren, N., Hosseini, P. S., and De Neve, S. (2022). The impacts of black soldier fly frass on nitrogen availability, microbial activities, C sequestration, and plant growth. *Front. Sustain. Food Syst.* 6, 1–13. doi: 10.3389/fsufs.2022.795950

Giller, K. E., Delaune, T., Silva, J. V., van Wijk, M., Hammond, J., Descheemaeker, K., et al. (2021). Small farms and development in sub-Saharan Africa: farming for food, for income or for lack of better options? *Food Secur.* 13, 1431–1454. doi: 10.1007/s12571-021-01209-0

Goa, Y., Bassa, D., Gezahagn, G., and Chichaybelew, M. (2017). Farmers participatory evaluation of chickpea varieties in Mirab Badwacho and Damot Fullasa districts of southern Ethiopia. *Hydrol. Current Res.* 8, 8–13. doi: 10.4172/2157-7587.1000264

Gujarati, D. N. (1995). Basic Econometrics. *4th* Edn. New York, NY: United State Military Academy.

Han, M., Opoku, K. N., Bissah, N. A. B., and Su, T. (2021). *Solanum aethiopicum*: the nutrient-rich vegetable crop with great economic, genetic biodiversity and pharmaceutical potential. *Horticulturae* 7:126. doi: 10.3390/horticulturae7060126

Horn, L. N., Nghituwamata, S. N., and Isabella, U. (2022). Cowpea production challenges and contribution to livelihood in sub-Saharan region. *Agric. Sci.* 13, 25–32. doi: 10.4236/as.2022.131003

Jalloh, A. A., Khamis, F. M., Yusuf, A. A., Subramanian, S., and Mutyambai, D. M. (2024). Long-term push–pull cropping system shifts soil and maize-root microbiome diversity paving way to resilient farming system. *BMC Microbio.* 24:92. doi: 10.1186/s12866-024-03238-z

Kadzamira, M., Chege, F., Suntharalingam, C., Bundi, M., Likoko, L., Magero, D., et al. (2024). African women and young people as agriculture service providers—business models, benefits, gaps and opportunities. *CABI Agric. Biosci.* 5, 1–14. doi: 10.1186/s43170-024-00229-y

Kalmpourtzidou, A., Eilander, A., and Talsma, E. F. (2020). Global vegetable intake and supply compared to recommendations: a systematic review. *Nutrients* 12, 22–29. doi: 10.3390/nu12061558

Kayuki, K. C., Angella, N., and Musisi, K. F. (2017). Optimizing fertilizer use within the context of integrated soil fertility in Uganda fertilizer use optimization in sub-Saharan Africa. Wallingford: CABI, 193–209.

Khan, Z., Midega, C., Pittchar, J., Pickett, J., and Bruce, T. (2011). Push-pull technology: a conservation agriculture approach for integrated management of insect pests, weeds and soil health in Africa. *Int. J. Sustain. Agric.* 9, 162–170. doi: 10.3763/ijas.2010.0558

KNBS (2019). 2019 Kenya population and housing census volume 1: Population by county and sub-county. Nairobi: KNBS.

Kotir, J. H. (2011). Climate change and variability in sub-Saharan Africa: a review of current and future trends and impacts on agriculture and food security. *Environ. Dev. Sustain.* 13, 587–605. doi: 10.1007/s10668-010-9278-0

Kumar, L., Chhogyel, N., Gopalakrishnan, T., Hasan, M. K., Jayasinghe, S. L., Kariyawasam, C. S., et al. (2022). Climate change and future of Agri-food production in future foods. New York, NY: Academic Press, 49–79.

Kuyah, S., Sileshi, G. W., Nkurunziza, L., Chirinda, N., Ndayisaba, P. C., Dimobe, K., et al. (2021). Innovative agronomic practices for sustainable intensification in sub-Saharan Africa. A review. *Agron. Sustain. Dev.* 41:16. doi: 10.1007/s13593-021-00673-4

Librán-Embid, F., Olagoke, A., and Martin, E. A. (2023). Combining Milpa and push-pull technology for sustainable food production in smallholder agriculture. A review. *Agron. Sustain. Dev.* 43:45. doi: 10.1007/s13593-023-00896-7

Liliane, T. N., and Charles, M. S. (2020). Factors affecting yield of crops. *Agron. Clim. Change Food Secur.* 9, 9–24. doi: 10.5772/intechopen.90672

Loizou, E., Karelakis, C., Galanopoulos, K., and Mattas, K. (2019). The role of agriculture as a development tool for a regional economy. *Agric. Syst.* 173, 482–490. doi: 10.1016/j.agsy.2019.04.002

Magaisa, A., Manjeru, P., Kamutando, C. N., and Moyo, M. P. (2022). Participatory variety selection and stability of agronomic performance of advanced sorghum lines in Zimbabwe. *J. Crop Improv.* 36, 440–460. doi: 10.1080/15427528.2021.1974635

Maroyi, A. (2020). Ethnobotanical study of wild and cultivated vegetables in the eastern cape province, South Africa. *Biodiversitas* 21, 3982–3988. doi: 10.13057/biodiv/d210908

Maseko, I., Ncube, B., Tesfay, S., Fessehazion, M., Modi, A. T., and Mabhaudhi, T. (2020). Productivity of selected African leafy vegetables under varying water regimes. *Agronomy* 10:916. doi: 10.3390/agronomy10060916

Mason-D'Croz, D., Bogard, J. R., Sulser, T. B., Cenacchi, N., Dunston, S., Herrero, M., et al. (2019). Gaps between fruit and vegetable production, demand, and recommended consumption at global and national levels: an integrated modelling study. *Lancet Planet. Health* 3, e318–e329. doi: 10.1016/S2542-5196(19)30095-6

Mugalavai, E. M., Kipkorir, E. C., Raes, D., and Rao, M. S. (2008). Analysis of rainfall onset, cessation and length of growing season for western Kenya. *Agric. For. Meteorol.* 148, 1123–1135. doi: 10.1016/j.agrformet.2008.02.013

Mutari, B., Sibiya, J., Bogweh Nchanji, E., Simango, K., and Gasura, E. (2021). Farmers' perceptions of navy bean (*Phaseolus vulgaris* L.) production constraints, preferred traits and farming systems and their implications on bean breeding: a case study from south east Lowveld region of Zimbabwe. *J. Ethnobiol. Ethnomed.* 17, 13–19. doi: 10.1186/s13002-021-00442-3

Mutyambai, D. M., Mutua, J. M., Kessler, A., Jalloh, A. A., Njiru, B. N., Chidawanyika, F., et al. (2024). Push-pull cropping system soil legacy alter maize metabolism and fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae) resistance through tritrophic interactions. *Plant Soil* 498, 685–697. doi: 10.1007/s11104-023-06467-9

Mwadzingeni, L., Afari-Sefa, V., Shimelis, H., N'Danikou, S., Figlan, S., Depenbusch, L., et al. (2021). Unpacking the value of traditional African vegetables for food and nutrition security. *Food Secur.* 13, 1215–1226. doi: 10.1007/s12571-021-01159-7

Nakyewa, B., Sseremba, G., Kabod, N. P., Rwothtimutung, M., Kyebalyenda, T., Waholi, K., et al. (2021). Farmer preferred traits and genotype choices in *Solanum aethiopicum* L., Shum group. *J. Ethnobiol. Ethnomed.* 17, 1–9. doi: 10.1186/s13002-021-00455-y

Nathan, O. O., Felix, N. K., Milka, K. N., Anne, M., Noah, A., and Daniel, M. N. (2020). Suitability of different data sources in rainfall pattern characterization in the tropical central highlands of Kenya. *Heliyon* 6:E05375. doi: 10.1016/j.heliyon.2020.e05375

Nchanji, E. B., Lutomia, C. K., Ageyo, O. C., Karanja, D., and Kamau, E. (2021). Gender-responsive participatory variety selection in Kenya: implications for common bean (*Phaseolus vulgaris* L.) breeding in Kenya. *Sustain. For.* 13:13164. doi: 10.3390/su132313164

Niassy, S., Kidoido, M., Nyangau, I., Mbeche, P., Hailu, G., Owino, R., et al. (2020). Adoption and willingness to pay for the push-pull technology among smallholder maize farmers in Rwanda. *J. Agric. Ext. Rural Dev.* 8, 1–15.

Ochieng, J., Schreinemachers, P., Ogada, M., Dinssa, F. F., Barnos, W., and Mndiga, H. (2019). Adoption of improved amaranth varieties and good agricultural practices in East Africa. *Land Use Policy* 83, 187–194. doi: 10.1016/j.landusepol.2019.02.002

Ouko, K. O., Ogola, J. R. O., Ngonga, C. A., and Wairimu, J. R. (2022). Youth involvement in agripreneurship as Nexus for poverty reduction and rural employment in Kenya. *Cogent Soc. Sci.* 8:2078527. doi: 10.1080/23311886.2022.2078527

Ouya, F. O., Pittchar, J. O., Chidawanyika, F., and Khan, Z. R. (2024). Integrating vegetables in push-pull technology: gendered preferences of smallholder farmers in Western Kenya. *Afr. J. Food Agric. Nutr. Dev.* 24, 25167–25188. doi: 10.18697/ajfand.126.23115

Pawera, L., Manickam, R., Wangungu, C., Bonnarith, U., Schreinemachers, P., and Ramasamy, S. (2024). Guidance on farmer participation in the design, testing and scaling of agricultural innovations. *Agric. Syst.* 218:104006. doi: 10.1016/j.agsy.2024.104006

Pretty, J., Benton, T. G., Bharucha, Z. P., Flora, C. B., Goulson, D., Hartley, S., et al. (2018). Global assessment of agricultural system redesign for sustainable Intensification. *Nat. Sust.* 1, 441–446. doi: 10.4324/9781138638044

Pretty, J., and Bharucha, Z. P. (2014). Sustainable intensification in agricultural systems. *Ann. Bot.* 114, 1571–1596. doi: 10.1093/aob/mcu205

R Core Team (2021). R: A language and environment for statistical computing. Vienna: R Foundation for Statistical Computing.

Recha, C. W. (2018). Local and regional variations in conditions for agriculture and food security in Kenya. Uppsala: AgriFoSe2030 Report.

Sangija, F., Martin, H., and Matemu, A. (2021). African nightshades (*Solanum nigrum* complex): the potential contribution to human nutrition and livelihoods in sub-Saharan Africa. *Compr. Rev. Food Sci. Food Saf.* 20, 3284–3318. doi: 10.1111/1541-4337.12756

Shimeles, A., Verdier-Chouchane, A., and Boly, A. (2018). "Introduction: understanding the challenges of the agricultural sector in sub-Saharan Africa" in Building a resilient and sustainable agriculture in sub-Saharan Africa. eds. A. Shimeles, A. Verdier-Chouchane and A. Boly (Cham: Palgrave Macmillan).

Sombroek, W. G., Braun, H. M. H., and Pouw, B. V. D. (1982). Exploratory soil map and agro-climatic zone map of Kenya, 1980, scale 1: 1,000,000. Nairobi: Kenya Soil Survey.

Struik, P. C. (2017). Sustainable intensification in agriculture: the richer shade of green. A review. *Agron. Sustain. Dev.* 37:39. doi: 10.1007/s13593-017-0445-7

Tanga, C. M., Egonyu, J. P., Beesigamukama, D., Niassy, S., Emily, K., Magara, H. J., et al. (2021). Edible insect farming as an emerging and profitable enterprise in East Africa. *Curr. Opin. Insect Sci.* 48, 64–71. doi: 10.1016/j.cois.2021.09.007

Tefera, M. L., Carletti, A., Altea, L., Rizzu, M., Migheli, Q., and Seddaiu, G. (2024). Land degradation and the upper hand of sustainable agricultural intensification in sub-Saharan Africa-a systematic review. *J. Agric. Rural. Dev. Trop. Subtrop.* 125, 63–83. doi: 10.17170/kobra-202403129757

Traoré, K., Parkouda, C., Savadogo, A., Ba Hama, F., Kamga, R., and Traoré, Y. (2017). Effect of processing methods on the nutritional content of three traditional vegetables leaves: Amaranth, black nightshade and jute mallow. *Food Sci. Nutr.* 5, 1139–1144. doi: 10.1002/fsn3.504

UBOS-Statistical Abstract (2020). Uganda bureau of statistics, 2020 statistical abstract, vol. *1*. Kampala: Uganda Bureau of Statistics, 303.

United Nations (2021). Global population growth and sustainable development. New York, NY: United Nations Department of Economic and Social Affairs, Population Division.

Wild, A. S. (2022). Women and African leafy vegetables (ALVs): Cultivation and the informal seed system in Vihiga County, Kenya (doctoral dissertation). Rome: Bioversity International.

Yami, M., Feleke, S., Abdoulaye, T., Alene, A. D., Bamba, Z., and Manyong, V. (2019). African rural youth engagement in agribusiness: achievements, limitations, and lessons. *Sustainability* 11, 1–15. doi: 10.3390/su11010185