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REVIEWED BY

Amit Anil Shahane,
Central Agricultural University, India
Aashu Rajput,
Himgiri Zee University, India

*CORRESPONDENCE

Leonard R. Ndibalema
✉ leonardndibalema18@gmail.com

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Agroecological and socioeconomic determinants of lablab (*Lablab purpureus*) integration in semi-arid and sub-humid farming systems of Tanzania

Leonard R. Ndibalema^{1,2*}, Mkabwa L. K. Manoko², Charles O. Joseph² and Edmond Alavaisha³

¹The Department of Agricultural Science, Mwalimu Nyerere University of Agriculture and Technology, Musoma, Tanzania, ²The Department of Crop Science and Beekeeping Technology, University of Dar es Salaam, Dar es Salaam, Tanzania, ³Institute of Resource Assessment, University of Dar es Salaam, Dar es Salaam, Tanzania

Lablab (*Lablab purpureus* (L.) Sweet) is increasingly recognized for its potential to enhance productivity, resilience, and sustainability in dryland farming systems. Despite these benefits, its acceptability in Tanzania remains low and uneven. Understanding how agroecological and climate variability influence lablab integration is critical for developing site-specific strategies that support climate-resilient agriculture under future climate scenarios. This study employed a mixed-methods approach involving 337 participants from two contrasting agroecological zones: Kondoa District in the Central Zone and Butiama District in the Lake Zone of Tanzania. Data were collected through household interviews, focus group discussions, and climatic trend analyses, enabling the integration of farmers' perceptions with long-term climate data to generate context-specific insights. Socioeconomic factors significantly influenced lablab acceptability across both zones ($P < 0.05$), with over 50% of adopters being younger and middle-aged farmers (<40 years). Climate trend analysis revealed increasing warming in Butiama ($0.048^{\circ}\text{C}/\text{year}$, $R^2 = 0.238$) accompanied by minimal rainfall increase, while Kondoa exhibited slower warming ($0.0073^{\circ}\text{C}/\text{year}$) but a significant rise in February rainfall (Sen's slope = $11.8 \text{ mm}/\text{year}$, $p < 0.05$). Mixed cropping systems were identified as the most suitable integration strategy, with over 70% of farmers highlighting their role in improving land equivalent ratio (LER) between 1.2 to 1.6. Acceptability was facilitated by institutional and market support but constrained by seed shortages, pests, and diseases. The findings highlight lablab's potential to engage youth in climate-resilient agricultural innovation and to strengthen dryland resilience under changing climatic conditions. Targeted, zone-specific scaling strategies that address seed systems, pest management, and market linkages are essential. These insights provide timely evidence to inform policy and programmatic interventions aligned with Tanzania's ASDP II and broader food security and climate-smart agriculture frameworks in Sub-Saharan Africa.

KEYWORDS

agroecology, semi-arid and sub-humid farming systems, *Lablab purpureus*, legume integration, sustainable farming systems

1 Introduction

Agriculture remains a central pillar of food security, rural livelihoods, and economic development globally. In Sub-Saharan Africa, the sector employs nearly 60% of the labor force and contributes between 20% and 30% of Gross Domestic Product (GDP) (Sithole and Olorunfemi, 2024). In Tanzania, agriculture employs over 65% of the population, contributes approximately 26% of national GDP, and accounts for more than 30% of export earnings (Davis and Bezabih, 2022; United Republic of Tanzania (URT), 2022; FAO, 2023). Beyond its economic role, agriculture underpins food and nutrition security, particularly in rural areas dominated by rainfed smallholder systems. However, agricultural productivity in Tanzania's drylands is increasingly constrained by climate change, characterized by rising temperatures, erratic rainfall, and recurrent droughts, which heighten vulnerability among smallholder farmers (Mkonda and He, 2018; IPCC, 2021).

Within this context, Lablab (*Lablab purpureus* (L.) Sweet) has gained renewed attention as an underutilized but strategically important legume for dryland farming systems. Although originating from Africa, lablab accounts for less than 2% of Tanzania's legume production area despite its broad agroecological adaptability. The crop is valued for its multifunctionality, including biological nitrogen fixation, provision of food and livestock feed, and tolerance to low-input and drought-prone conditions, making it suitable for climate-stressed environments (Maass et al., 2010; Guretzki and Papenbrock, 2014; Heuzé et al., 2021). These attributes position lablab as a promising climate-resilient legume within cereal-based smallholder farming systems.

Despite these advantages, lablab acceptability in Tanzania remains low and uneven, particularly in dryland areas where acceptability rates often fall below 25% (ICRISAT, 2020; FAO, 2023). Key constraints include limited farmer awareness, weak seed systems, pest and disease pressures, and inadequate extension services, with extension agent-to-farmer ratios frequently exceeding 1:2500 (Davis et al., 2010; Rubyogo et al., 2010). Moreover, national research and policy priorities have largely focused on major cereals and a narrow range of legumes, resulting in the continued marginalization of underutilized crops such as lablab. Existing studies have primarily emphasized genetic characterization and agronomic performance, with limited attention to farmer-driven acceptability dynamics, climate variability, and agroecological contrasts across regions (Ngailo et al., 2003; Bajjukya et al., 2016; Missanga et al., 2021). Although the vulnerability of dryland agriculture to climate change is well documented, important gaps remain in understanding how climate trends interact with socioeconomic and agroecological factors to shape the acceptability of underutilized legumes. In particular, comparative evidence integrating farmer perceptions with empirical climate trend analysis across contrasting agroecological zones remains limited.

This study addresses these gaps by examining agroecological constraints, climate trends, and opportunities for integrating *Lablab purpureus* into smallholder farming systems in Kondoa District (Central Zone) and Butiama District (Lake Zone). Using a mixed-methods approach that combines farmer-centered socioeconomic analysis with long-term climate trend assessment, the study focuses

on acceptability dynamics and system-level integration rather than experimental yield or intercropping efficiency measurements. The findings aim to inform evidence-based policies and development interventions for scaling climate-resilient legumes in Tanzania's drylands and comparable agroecological contexts.

2 Material and methods

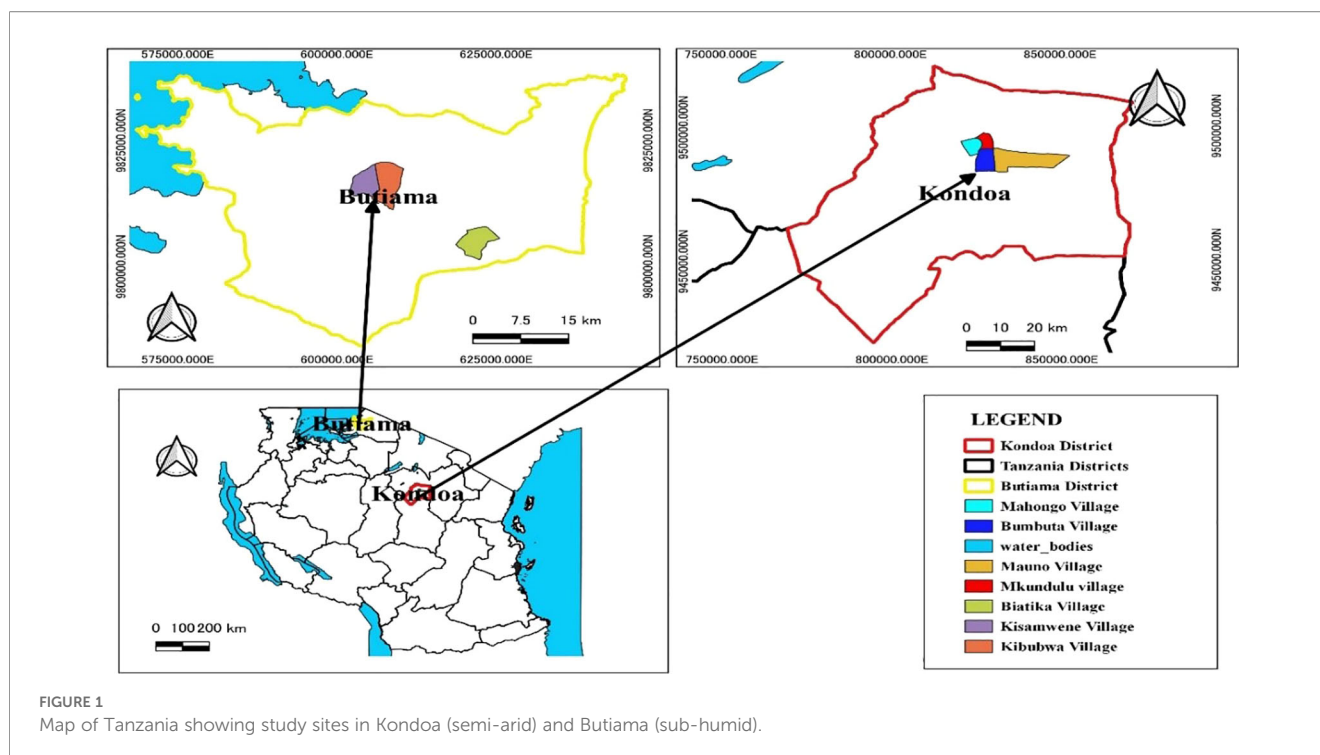
2.1 Description of the study region

The survey was conducted in Kondoa (Dodoma Region) and Butiama (Mara Region), Tanzania, two districts purposefully selected for their contrasting agroecological, climatic, demographic and socioeconomic characteristics (Figure 1). Kondoa district represents a semi-arid climate with unimodal rainfall ranging between 500–1000 mm annually, high temperatures (22–34°C), and predominantly sandy loam to clay loam Ferralic Cambisols, low fertility, and low to moderate water-holding capacity. In contrast, Butiama represents a sub-humid environment with bimodal rainfall (900–1300 mm per year), milder temperatures (18–28°C), and clay loams and vertisols soils moderate fertile (United Republic of Tanzania (URT), 2021; NAPA, 2007). These divergent agroecological settings and livelihood systems offer a comparative approach to explore how environmental variability and socioeconomic diversity influence the acceptability and performance of *Lablab purpureus* an underutilized, resilient, underutilized, yet multifunctional legume in smallholder farming systems. By capturing context-specific interactions often underrepresented in legume adaptation research, this study provides novel and scalable insights into climate-resilient intensification strategies in dryland and sub-humid agroecosystems of Sub-Saharan Africa.

2.2 Research design and data collection

The study adopted a mixed-methods design integrating quantitative and qualitative approaches to collect primary and secondary data in Kondoa and Butiama districts. This design enabled a holistic examination of both technical and sociocultural dimensions of lablab acceptability, consistent with mixed-methods research principles (Kothari and Garg, 2014). A combination of probability and non-probability sampling techniques was applied to ensure broad representation while minimizing selection bias (Kothari, 2004; Kothari and Garg, 2014).

Districts and villages were selected using a transparent, criteria-based purposive sampling approach to capture contrasting agroecological, socioeconomic, and institutional contexts relevant to the study objectives (Krueger and Casey, 2015; Yamane, 1967). Selection criteria included rainfall variability, dominant farming systems, extension service coverage, and prior exposure to lablab cultivation. The household survey covered four villages in Kondoa District and three in Butiama District, reflecting differences in agroecological diversity and familiarity with lablab. Kondoa's greater heterogeneity and lower exposure to lablab required wider



coverage, whereas Butiama's relatively homogeneous conditions allowed for fewer villages without compromising analytical depth.

Within each village, proportionate simple random sampling was used to select one adult respondent (≥ 18 years) per household. Key characteristics such as age, gender, and farming system type were considered to ensure balanced representation. Purposive sampling was applied for focus group discussions (FGDs) and key informant interviews (KIIs) to engage participants with relevant knowledge and experience, including village leaders, agricultural and livestock extension officers, and farmers familiar with lablab production.

Primary data were collected from a total of 337 participants through semi-structured household surveys, FGDs, and KIIs. Field observations and photographs complemented interviews and surveys by documenting farming practices and environmental conditions. Secondary data on population characteristics and long-term climate variables (rainfall and temperature) were obtained from the National Bureau of Statistics (NBS) and the Tanzania Meteorological Authority (TMA). The triangulation of survey data, qualitative narratives, and field observations enhanced the robustness of findings and enabled context-specific insights into lablab acceptability across contrasting dryland agroecologies.

The sample size of the respondents for semi structured interviews determined using equation (i) as proposed by (Yamane, 1967; Kothari, 2004).

$$n = \frac{N}{1 + N \cdot e^2} \cdot (i)$$

Where: n = sample size.

N = total population (1200) from two districts Butiama 520 and Kondoia 680.

e = level of precision (for instance 0.10 for 10%).

Applying this formula yielded a minimum sample size of 93 (53 from Kondoia and 40 from Butiama) respondents. To improve representativeness and enable robust analysis across villages and districts a total of 120 (60 from each district) were considered for semi structured interviews. The 120 household respondents exceed the minimum thresholds for statistical inference in agricultural livelihood studies, ensuring robust subgroup comparisons across socioeconomic and agroecological variables.

In collecting household survey data semi-structured face-to-face interviews were employed. The method supported by other studies such as Bernard (2017) and arguing that it is flexible and inclusive, hence suitable for collecting large samples within a short period of time. Questionnaires were administered to 120 randomly selected active lablab farmers across the seven villages (four in Kondoia and three in Butiama). The participants reflected the diversity in farming systems and socioeconomic settings described above. Each village contributed 17 lablab farmers except the largest village in Butiama, which contributed 18 farmers. Farmers were asked questions related to their socio-demographic characteristics, perceptions of lablab, and agroecological factors influencing its acceptability.

In addition, focus group discussions (FGDs) were conducted to capture gender-differentiated and collective perspectives on lablab acceptability and management. In each village, three FGDs were conducted: one with women only, one with men only, and one mixed-gender group, to allow free expression of views and to account for gender-specific roles in legume production and decision-making. Each FGD consisted of 6–8 participants, in line with established qualitative research guidelines (Roller and Lavrakas, 2015; Woźniak, 2014). Participants were selected based on their experience with lablab cultivation to ensure informed discussion. A total of 21 FGDs were conducted across the seven study villages, involving 168

participants across both districts. The number of FGDs was considered sufficient to achieve thematic saturation, as similar themes emerged repeatedly across villages and gender groups.

A total of 49 KIIs, from each district were conducted across seven villages in the study districts, with seven interviews per village, this means for each interview involved seven participant which is enough as also supported by Guest et al. (2006) based on data saturation. Participants were purposively selected based on their specialized knowledge and relevance to lablab acceptability and integration. Key informants included village leaders, extension officers, livestock officers, input suppliers, village elders, and experienced farmers, each offering unique insights into governance, technical advisory services, livestock integration, seed system dynamics, cultural norms, farming practices, and the diffusion of innovations. This diversity of expertise enriched the analysis and helped identify practical entry points for scaling lablab acceptability in dryland farming systems. This gender- and age-sensitive participatory design in FGDs and KIIs allowed for the inclusion of traditionally underrepresented voices, contributing to more socially responsive insights into lablab uptake.

2.3 Data analysis

Quantitative data from household surveys were coded, cleaned, and analyzed using Microsoft Excel 2024 and IBM SPSS Version 25. Descriptive statistics including frequencies, percentages, bar charts and cross-tabulations, were used to summarize demographic characteristics, lablab production patterns, and acceptability trends.

Pearson's Chi-square tests were used to assess the relationships between age group, gender, marital status education level and lablab acceptability. Relationships were considered statistically significant at p-values less than 0.05. Qualitative data from KIIs, FGDs, and field observations were transcribed and analyzed thematically to identify recurring patterns and themes. These qualitative insights complemented quantitative findings, providing a nuanced understanding of lablab acceptability dynamics. Temperature and rainfall were analyzed using the non-parametric Mann–Kendall trend test to assess statistical significance, and Sen's slope estimator to quantify the magnitude of change over time. All analyses were conducted in Python following standard methodologies for climate variability assessment. The integration of climate trend analysis with household-level acceptability data represents a novel contribution, revealing how rainfall and temperature variability intersect with farmers' legume choices in different agroecological zones.

3 Results and discussion

3.1 Socioeconomic and demographic factors influencing lablab acceptability

Overall, acceptability was significantly influenced by age, education, access to extension services, and livestock ownership, although the strength of these relationships varied between agroecological zones (Table 1). Education was positively associated with acceptability in both districts, though differences

TABLE 1 Socio-demographic characteristics and acceptability rates (%) of lablab in Butiama and Kondoa districts.

Socio-demographic variable	Category	Acceptability rate (%) Butiama (n=60)	Acceptability rate (%) Kondoa (n=60)	P-value
Gender	Male	69.0% (20/29)	58.6% (17/29)	0.327
	Female	53.6% (17/31)	41.4% (12/31)	
Education Level	No formal education	34.0% (5/16)	50.0% (5/10)	0.205
	Primary (Std 4 + 7)	46.2% (17/37)	61.1% (24/39)	
	Secondary & above	71.4% (5/7)	72.7% (8/11)	
Age Group	< 40 years	30.0% (18/60)	35.0% (21/60)	0.036*
	> 40 years	16.0% (10/60)	20.0% (12/60)	
Farming Experience	< 15 years	60.0% (18/30)	70.0% (21/30)	0.21
	≥ 15 years	43.3% (13/30)	52.0% (15/30)	
Marital Status	Married	51.7% (15/29)	66.7% (20/30)	0.148
	Single	50.0% (16/31)	55.2% (17/30)	
Group Membership	Yes	68.4% (13/19)	75.0% (15/20)	0.083
	No	44.7% (16/41)	50.0% (22/40)	
Access to Extension	Yes	80.0% (18/24)	75.0% (20/25)	0.041*
	No	40.0% (12/36)	50.0% (15/35)	
Livestock Ownership	Yes	60.0% (21/35)	71.4% (25/35)	0.068
	No	44.0% (11/25)	48.0% (12/25)	

Significant differences are indicated by p-values < 0.05 and marked with an asterisk (*). Values in parentheses indicate the number of adopters over the total number of respondents in each category (x/y).

between zones were not statistically significant ($p > 0.05$). Farmers with secondary education and above showed consistently higher uptake, reflecting improved capacity to access agronomic information and extension advice (Doss and Morris, 2001; Miller et al., 2018). Gender patterns revealed higher acceptability among male-headed households in both districts, but female-headed households in Butiama often supported by NGOs demonstrated notable acceptability potential, underscoring the role of institutional mediation in addressing gendered constraints (Mudege et al., 2021; Njeru et al., 2021). Age emerged as a statistically significant factor ($p < 0.05$), with younger and middle-aged farmers (<40 years) showing higher acceptability, particularly in Kondoa. While the percentage difference appears modest, qualitative evidence suggests deeper behavioral and risk-related dynamics influencing youth engagement, consistent with Mutabazi et al. (2022). Access to extension services was one of the strongest predictors of acceptability, with over 75% of farmers receiving extension support adopting lablab in both districts, reinforcing findings from Temba et al. (2023) and Mponela et al. (2021). Group membership, livestock ownership, and marital status played complementary roles by enhancing labor availability, information exchange, and perceived benefits of lablab as both food and fodder. However, qualitative data revealed that land tenure insecurity, market access, and seed availability, though not quantified in the survey, critically shaped acceptability decisions particularly among women and youth in Butiama and resource-constrained households in Kondoa (Table 2).

In Butiama District, particularly in villages bordering Kenya, lablab was reported to function both as a food and cash crop, supported by cross-border market access and established consumption preferences.

Focus group discussions and key informant interviews further identified household headship, dependency ratio, and length of residence as influential socioeconomic variables shaping acceptability decisions. Long-term residents with secure land tenure and higher levels of trust in local institutions were more likely to adopt lablab due to their familiarity with local agroecological conditions, market arrangements, and extension support structures.

This combined thematic analysis illustrates how both measurable variables and contextual insights from FGDs and KIIs shaped the understanding of acceptability behavior (Mligo and Mdoe, 2022; Mmbaga et al., 2020). It affirms that lablab acceptability is driven by a combination of education, resource access, social structures, and institutional engagement, with notable differences between the semi-arid in Kondoa district and sub-humid Butiama district zones of Tanzania. However, the acceptability of key lablab agronomic practices varied between Butiama (sub-humid) and Kondoa (semi-arid), reflecting differences in farmers' demographic profiles, agroecological realities, and institutional support (Meinzen-Dick et al., 2017; Quisumbing and Pandolfelli, 2010). Data were gathered through household surveys ($n=120$), supported by insights from focus group discussions (FGDs) and key informant interviews (KIIs). Practices such as improved seed use, recommended spacing, crop rotation, and early weeding were significantly $p < 0.05$ or marginally influenced by socio-demographic variables such as education, age, and farming experience (see Table 3). These results align with previous findings by Mponela et al. (2021), who emphasized the critical role of farmers characteristics and knowledge access in determining the uptake of legume-based innovations in dryland systems of Tanzania. This comparative approach underscores the need to disaggregate extension strategies:

TABLE 2 Socioeconomic factors and their influence on lablab acceptability (Kondoa vs. Butiama).

Factor	Kondoa (Semi-arid)	Butiama (Sub-humid)
Age	Younger farmers adopted more	Older farmer dominance led to lower acceptability
Gender	Male-headed households adopted more	Women adopted through NGO support
Education Level	Higher education higher acceptability	Lower education limited acceptability
Household Size	Larger households supported acceptability	Smaller households had fewer adopters
Farm Size	Large land enabled integration	Small size limited acceptability
Land Tenure	Ownership encouraged acceptability	Inherited land common; gender access constraints
Access to Extension	75% of recipients adopted	80% of recipients adopted
Access to Inputs	Limited access was a key barrier	Availability of seed/manure enhanced acceptability
Group Membership	75% of members adopted	68.4% of members adopted
Farming Experience	Both young and experienced adopted with support	Older farmers more conservative despite experience
Market Access	Remoteness limited market-driven acceptability	Better access boosted acceptability
Livestock Ownership	71.4% of owners adopted due to fodder use during dry season	60% of owners adopted
Time of Residence	Long-term residence increased trust and acceptability	Shorter stay reduced innovation trust
Household Headship	Male-headed households adopted more easily	Female-headed households adopted via NGO support
Dependency Ratio	High dependency strained acceptability capacity	Higher ratio in some homes limited uptake

TABLE 3 Acceptability rates (%) of key lablab agronomic practices in Butiama and Kondoa districts and associated major socio-demographic influencing factors.

Lablab practice	Butiama (n= 60) in (%)	Kondoa (n=60) in (%)	Major influencing demographic	P-value
Use of improved seed	48.3%	63.3%	Education level	0.042*
Intercropping practice	71.7%	78.3%	Farming experience	0.211
Use of organic manure	56.7%	68.3%	Gender	0.078
Recordkeeping	40.0%	55.0%	Education level	0.034*
Recommended spacing	33.3%	50.0%	Age	0.048*
Early weeding	45.0%	58.3%	Farming experience	0.065
Rhizobium inoculation	15.0%	22.0%	extension services	0.120
Timely planting	50.0%	62.0%	Age	0.053
Postharvest handling	30.0%	40.0%	Gender	0.087
Residue retention	35.0%	48.3%	Farming experience	0.070
Crop rotation	42.0%	55.0%	Education level	0.045*
Use of local knowledge	70.0%	50.0%	Age	0.040*
Fodder harvesting at right stage	52.0%	65.0%	Livestock ownership	0.033*

Significant differences are indicated by p-values < 0.05 and marked with an asterisk (*).

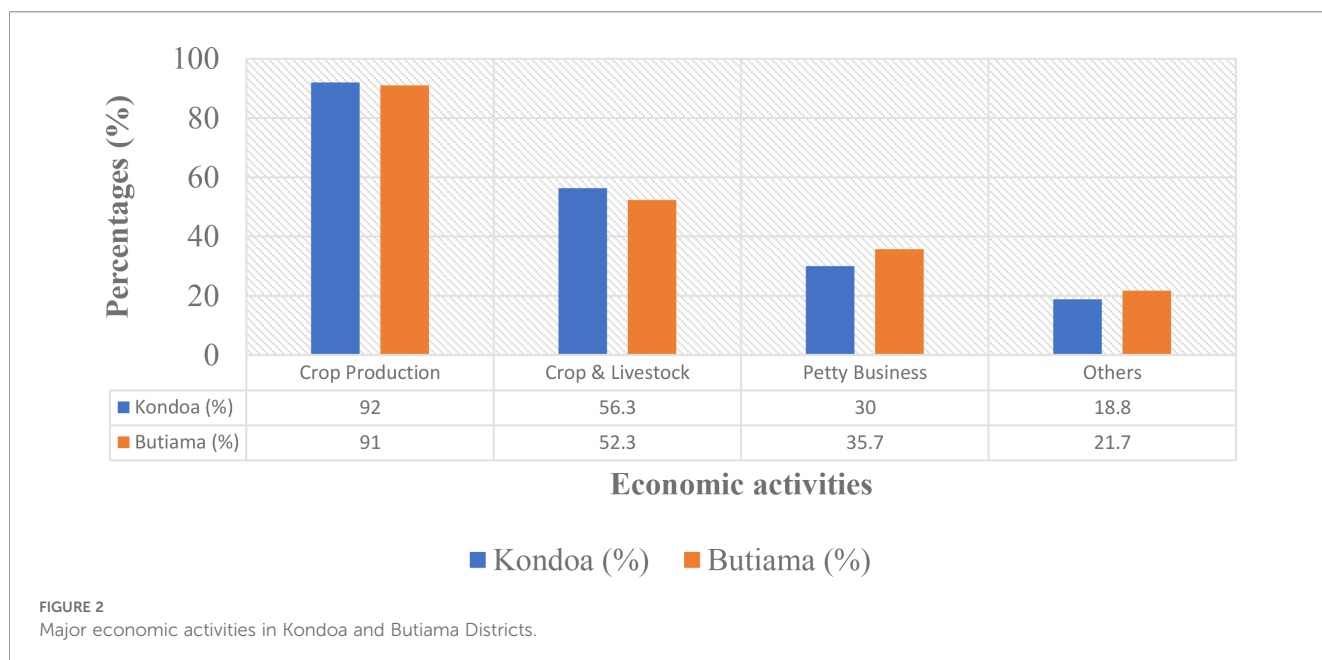
for instance, while education drives acceptability more strongly in Kondoa, participatory outreach compensates for low literacy in Butiama highlighting the importance of agroecological targeting in intervention design.

3.2 Livelihood strategies and alignment with lablab acceptability

Rather than treating acceptability as a standalone decision, this study situates lablab within household livelihood portfolios, revealing

how its multifunctionality aligns with dominant economic strategies across zones (Figure 2). Crop production dominated livelihoods in both districts (>90%), reinforcing lablab’s compatibility with existing farming systems. Integrated crop–livestock systems were more prominent in Kondoa, where lablab’s fodder value during dry spells strengthened acceptability incentives. In contrast, Butiama households exhibited greater livelihood diversification, including petty trade and cross-border market engagement with Kenya, positioning lablab as both a food and income crop.

These patterns demonstrate that the perceived value of lablab shifts with livelihood orientation as forage in livestock-oriented



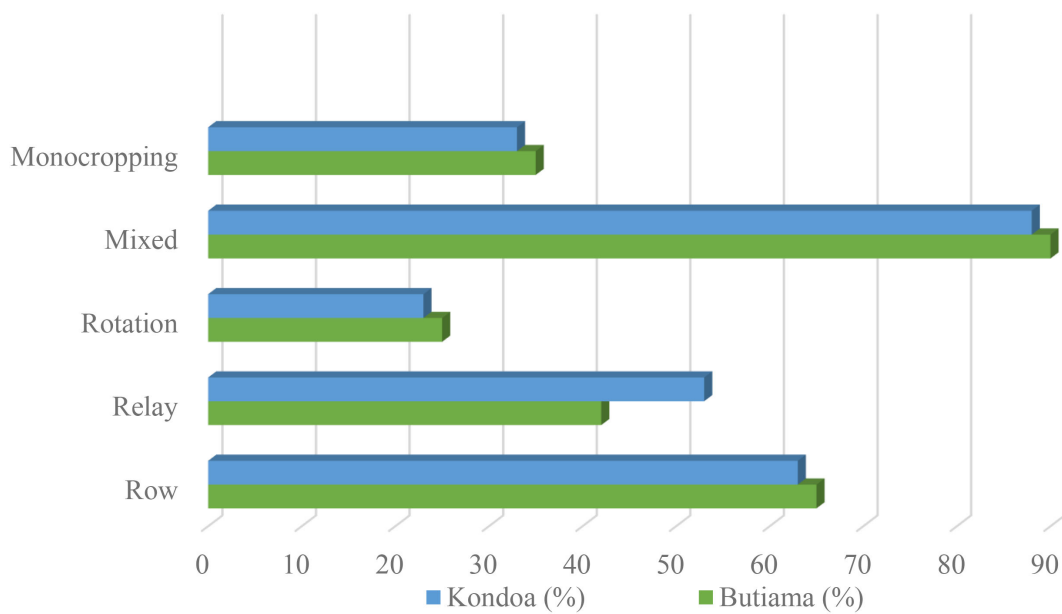


FIGURE 3 Cropping system acceptability in Kondoia and Butiama districts. Mixed cropping dominates, while rotation and monocropping are least practiced, reflecting farmers' preference for diversified systems.

semi-arid systems (Kondoia) and as a nutrition- and market-linked crop in diversified sub-humid systems (Butiama). This livelihood alignment explains observed differences in acceptability motivation more effectively than socioeconomic variables alone and remains underexplored in legume acceptability literature (Mabaya et al., 2020; Makoye et al., 2023).

3.3 Cropping system strategies and lablab integration

Across both districts, mixed cropping systems dominated (>87%), reflecting farmers' preference for risk reduction, efficient land use, and soil fertility enhancement (Orr et al., 2020; Whitbread et

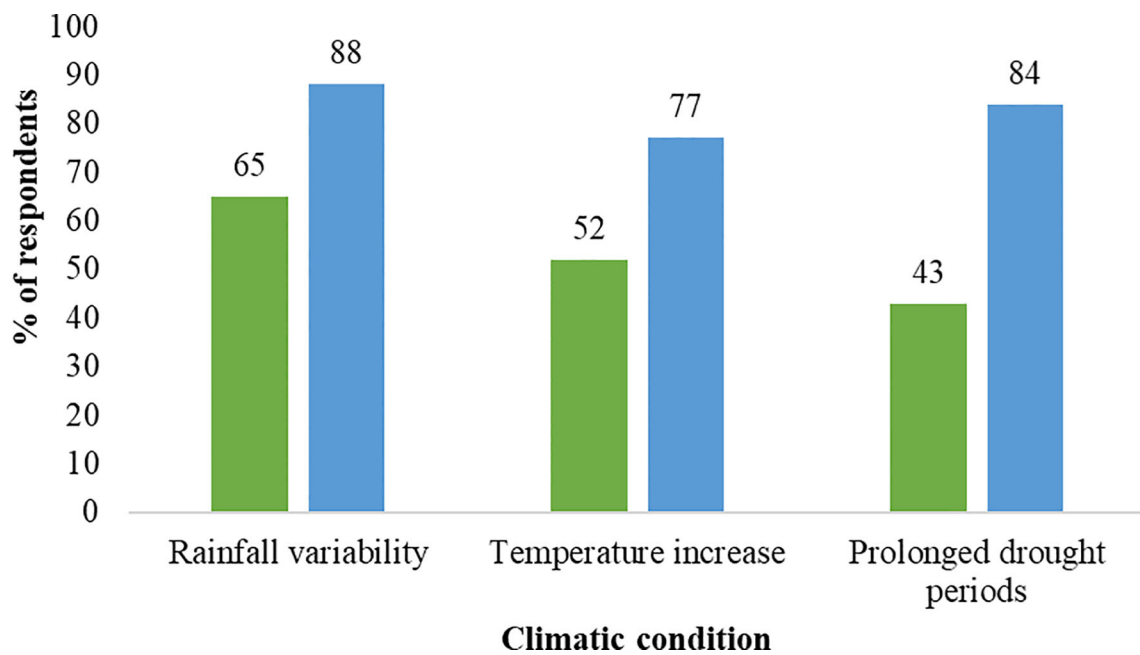


FIGURE 4 Perceived climate variables in Butiama and Kondoia districts.

TABLE 4 Mann-Kendall Trend Analysis and Sen's Slope Estimates of Monthly and Annual Rainfall and Temperature (2012–2024) in Butiama (Lake Zone) and Kondoa (Central Zone), Tanzania: Implications for Climate-Smart Agricultural Planning.

	Mean monthly and annual precipitation						Mean monthly and annual temperature					
<i>Monthly and Annual Rainfall and Temperature in the Lake zone, Mara-Butiama District</i>												
Months	S	Var (S)	Kendall's tau	p-value	Sen's slope	Trend	S	Var (S)	Kendall's tau	p-value	Sen's slope	Trends
January	31	267.667	0.400	0.067	6.147	Increase	-14	268.667	-0.179	0.428	-0.057	Decrease
February	18	266.667	0.234	0.298	5.157	Increase	5	267.667	0.065	0.807	0.022	Increase
March	7	267.667	0.090	0.714	3.563	Increase	-10	268.667	-0.128	0.583	-0.048	Decrease
April	10	268.667	0.128	0.583	4.017	Increase	22	268.667	0.282	0.200	0.102	Increase
May	16	268.667	0.205	0.360	3.196	Increase	26	268.667	0.333	0.127	0.114	Increase
June	9	265.667	0.118	0.624	1.125	Increase	26	268.667	0.333	0.127	0.071	Increase
July	23	256.333	0.314	0.169	1.102	Increase	18	268.667	0.231	0.300	0.049	Increase
August	0	266.667	0.000	1.000	0.000	No change	23	267.667	0.297	0.179	0.082	Increase
September	-5	267.667	-0.065	0.807	-0.704	Decrease	-10	268.667	-0.128	0.583	-0.028	Decrease
October	-9	267.667	-0.116	0.625	-2.075	Decrease	-4	266.667	-0.052	0.854	-0.007	Decrease
November	25	267.667	0.323	0.142	5.023	Increase	18	268.667	0.231	0.300	0.040	Increase
December	5	267.667	0.065	0.807	3.088	Increase	23	267.667	0.297	0.179	0.082	Increase
Annual	16	268.667	0.205	0.360	14.935	Increase	25	267.667	0.323	0.142	0.049	Increase
<i>Monthly and Annual Rainfall and Temperature Trends in Central zone, Dodoma-Kondoa District</i>												
January	5	267.667	0.065	0.807	1.567	Increase	31	267.667	0.219	0.328	0.042	Increase
February	33	267.667	0.426	0.050	11.818	Increase	12	268.667	0.154	0.502	0.047	Increase
March	4	268.667	0.051	0.855	2.060	Increase	2	268.667	0.026	0.951	0.017	Increase
April	-1	267.667	-0.013	1.000	-0.093	Decrease	10	268.667	0.026	0.951	0.014	Increase
May	10	250.000	0.139	0.569	0.000	Increase	2	268.667	0.090	0.714	0.031	Increase
June	11	143.667	0.217	0.404	0.000	Increase	7	267.667	0.256	0.246	0.107	Increase
July	17	143.667	0.335	0.182	0.000	Increase	20	268.667	0.154	0.502	0.184	Increase
August	13	103.667	0.307	0.239	0.000	Increase	12	268.667	0.231	0.300	0.048	Increase
September	15	103.667	0.354	0.169	0.000	Increase	-8	268.667	-0.103	0.669	-0.026	Decrease
October	9	202.333	0.146	0.574	0.000	Increase	-28	268.667	-0.359	0.100	-0.119	Decrease

(Continued)

TABLE 4 Continued

Mean monthly and annual precipitation										Mean monthly and annual temperature									
Monthly and Annual Rainfall and Temperature in the Lake zone, Mara-Butiama District																			
Months	S	Var (S)	Kendall's tau	p-value	Sen's slope	Trend	S	Var (S)	Kendall's tau	p-value	Sen's slope	Trends							
Monthly and Annual Rainfall and Temperature Trends in Central zone, Dodoma-Kondoa District																			
November	14	210.667	0.215	0.370	2.011	Increase	-22	268.667	-0.282	0.200	-0.102	Decrease							
December	14	212.667	0.212	0.373	5.151	Increase	-2	268.667	-0.026	0.951	-0.015	Decrease							
Annual	18	268.667	0.231	0.300	19.452	Increase	6	268.667	0.077	0.760	0.015	Increase							

al., 2013; Nord et al., 2020) (Figure 3). Mixed cropping was more prevalent in Butiama, supported by bimodal rainfall and NGO-led awareness programs, while relay cropping was more common in Kondoa, where residual moisture use is critical under semi-arid conditions (Bishaw et al., 2018; Kimaro et al., 2021; Ramesh and Byregowda, 2016). Monocropping and crop rotation were least practiced due to land constraints and limited awareness, although rotation was selectively used in Butiama to restore soil fertility (Ramesh and Pranesh, 2019; Muthoni et al., 2015; Muthoni et al., 2021). Farmers consistently highlighted lablab's compatibility with maize and sorghum, particularly for improving land equivalent ratio (LER) and stabilizing yields under rainfall uncertainty. Rather than listing each system separately, the comparative evidence shows that agroecology and institutional support rather than farmer preference alone shape cropping strategy choice, reinforcing the need for zone-specific extension recommendations.

3.4 Climate, environmental, and economic drivers of lablab acceptability

Climate variability and environmental stress, including erratic rainfall, rising temperatures, and frequent droughts, strongly influence lablab acceptability in Kondoa and Butiama. Observed meteorological trends align with farmers' perceptions, highlighting lablab's resilience to heat and moisture fluctuations. Early- and late-season rainfall patterns favour flexible intercropping systems, enhancing crop stability. Lablab's low input requirements and adaptability to poor soils reduce cultivation costs. Its multifunctional use for food, fodder, and income generation makes it an economically viable option for smallholders in dryland farming systems.

3.4.1 Climate and environmental influences on lablab acceptability

Both perceived and observed climate data confirm that climate variability is a central driver of lablab acceptability. Farmers in Kondoa reported more severe impacts of erratic rainfall and drought, while Butiama farmers emphasized rainfall variability and rising temperatures (Figure 4). These perceptions closely aligned with Mann-Kendall and Sen's slope analyses of observed climate trends (Table 4), validating farmer knowledge. Observed data show warming trends in both districts, with stronger warming in Butiama (0.048°C yr⁻¹) and more pronounced early-season rainfall increases in Kondoa (February Sen's slope = 11.8 mm yr⁻¹, p < 0.05). These dynamics favor flexible, drought-tolerant legumes such as lablab, particularly when integrated into mixed or relay cropping systems that buffer moisture stress.

3.4.2 Perceived climate and environmental conditions

In this study, the validity of farmers' perceptions is strengthened by the participation of many village elders and long-term residents with over 30 years of farming experience in both districts (see Figure 4; Table 5). Questions focused on climate trends from 1994 to 2024, specifically addressing key variables such as temperature, rainfall

TABLE 5 Thematic summary for perceived and observed climate trends and their influence on lablab farming activities in the study districts.

Lablab farming activity	Perceived climate change	Observed climate trend (2012–2024)	Reported effects on farming	Participants' statement
1. Pre-planting/Planning	Butiama: 65% noted increasing rainfall variability; 52% temperature rise Kondoa: 88% erratic rainfall; 77% temperature rise	Slightly Annual rainfall increase in both zones (Butiama +18.7 mm/year; Kondoa +21.3 mm/year) Butiama warming weak ($R^2 = 23.8\%$)	Disruption in land preparation schedules due to unpredictability of rains and dry spells	"We now wait longer for first rains, and are not sure when to start preparing fields" (Male elder, Butiama, 2024)
2. Planting Time	Butiama: Drought frequency increasing (43%) Kondoa: 84% noted prolonged droughts	Early-season rains improved in Kondoa; late-season reduction in Butiama January warming in Kondoa (Sen's slope = 0.042°C)	Reduced seedling establishment, delayed planting or skipped seasons in beans/cowpea; lablab preferred for its resilience	"Beans no longer survive well, we shifted to lablab which survives harsh sun and starts faster" (Female farmer, Kondoa, 2024)
3. Growth & Flowering	Erratic weather during growth reported by 70% (Kondoa)	October-November cooling in Kondoa; affects temperature-sensitive legumes	Delayed flowering in beans/pigeon pea; lablab performs better due to tolerance to heat and moisture stress	"Cowpea flowers drop in cool months but lablab continues growing" (FGD, Butiama, 2024)
4. Maturity & Harvesting	Late rains affect harvest timing (Butiama) Harvest sometimes skipped due to failed crops	Decreased rains in September-October in Butiama (Sen's slope -2.075) Kondoa rains slightly stable	Lablab allows flexible harvest even under rain variability due to its extended maturity and drought survival	"We now mix lablab with maize to reduce risk; it matures even when rain stops early" (Male farmer, Kondoa, 2024)
5. Soil Fertility Management	Farmers perceive declining soil fertility linked with climate (esp. in Kondoa)	Climate change have impact in soil health (Mkonda and He, 2018; IPCC, 2021)	Lablab increasingly used in rotation and intercropping to restore soil fertility	"After maize, I grow lablab to help soil recover; rainfall is not reliable so I avoid beans" (Farmer, Butiama, 2024)
6. Market Participation & Yield Stability	Yield variability due to climate risk is a concern (especially. in Butiama)	Annual temp increase and inconsistent rainfall noted in both districts	Lablab provides more stable yields under adverse conditions through increasing LER between 1.2 to 1.6, improving market reliability	"Lablab sells well because it grows even in bad years" (Trader, Butiama, 2024)

• *Perceived climate changes* were drawn directly from responses shared by farmers during household surveys, focus group discussions (FGDs), and key informant interviews (KIIs) conducted in Butiama and Kondoa districts which all together involved 337 participants.

Observed climate trends were analyzed using Mann-Kendall trend tests and Sen's slope estimations based on monthly and annual rainfall and temperature data (2012–2024) obtained from the Tanzania Meteorological Authority (TMA) and validated through statistical interpretation.

• *Reported effects on farming including lablab's acceptability* are local field realities, yet consistent to most of published literature on the agronomic and ecological performance of lablab in dryland environments. They reflect interactions between climate trends and adaptive farming practices observed in the study areas.

• *Statement from Participants* included in the table reflect the typical views and lived experiences expressed by participants. They represent themes that emerged consistently during data collection and analysis, and are aligned with qualitative insights observed in similar agroecological research context.

variability, and drought frequency. Results showed contrasting climate concerns between Butiama and Kondoia, significantly influencing lablab acceptability. In Butiama, 65% of respondents reported increasing rainfall variability, 52% noted rising temperatures, and 43% observed more frequent droughts. While Butiama remains relatively sub-humid, these shifts have prompted farmers to consider lablab as a resilient alternative to traditional legumes. In Kondoia, climate worries were even more pronounced, with 88% reporting erratic rainfall, 77% citing temperature increases, and 84% experiencing prolonged droughts. These perceptions reflect Kondoia's semi-arid conditions and strengthen the rationale for lablab acceptability due to its drought tolerance and adaptability. These perceptions are consistent with meteorological data reported by the Tanzania Meteorological Authority, which shows a steady increase in average temperatures and growing rainfall unpredictability over the past three decades. Similar trends have been documented across East Africa, where increased drought frequency and temperature shifts have been observed (IPCC, 2022).

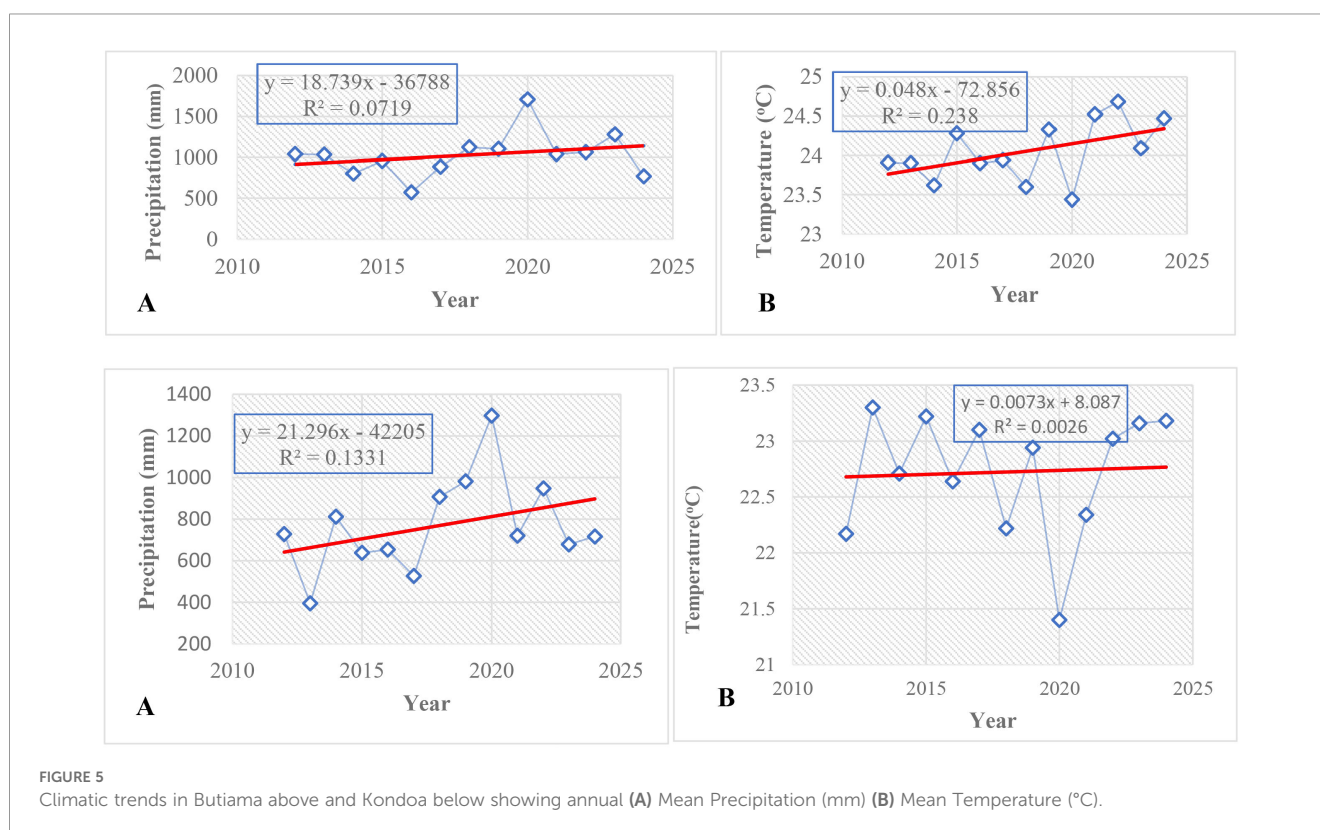
3.4.3 Observed climate trends (2012–2024) and their influence on cropping systems

Observed temperature and rainfall trends in Butiama and Kondoia districts reveal both shared and location-specific shifts affecting cropping systems and lablab integration (Figure 5; Table 4). Annual temperatures increased in both districts, with Butiama warming faster ($0.048^{\circ}\text{C yr}^{-1}$) than Kondoia ($0.0073^{\circ}\text{C yr}^{-1}$), though interannual variability was high in Butiama ($R^2 = 23.8\%$). In Kondoia, January warming (Sen's slope = 0.042) may increase evapotranspiration stress during early crop establishment, while cooler conditions in October–November could affect flowering of temperature-sensitive legumes

such as beans and cowpea. These trends favor heat- and drought-tolerant legumes such as lablab, which performs stably under fluctuating temperatures (Gebrechorkos et al., 2019; FAO, 2021). Rainfall trends varied: Butiama showed a modest increase (18.7 mm yr^{-1}) with declining late-season rainfall, potentially limiting grain filling of long-duration crops, while Kondoia recorded slightly higher early-season rainfall (21.3 mm yr^{-1}) that supports establishment (FAO, 2011; Wang et al., 2017). Such patterns encourage flexible cropping strategies, including mixed and relay intercropping of lablab with cereals to optimize moisture use and reduce climate risk (FAO, 2019; Wangila et al., 2021). Sole cropping of shallow-rooted crops may be increasingly vulnerable under erratic rainfall, emphasizing the importance of site-specific, lablab-based adaptive cropping systems (Thornton et al., 2011; ICRISAT, 2020).

3.4.4 Economics of lablab cultivation

From the study it was revealed that Lablab cultivation offers both subsistence and income-generating opportunities for smallholder farmers. The crop can be harvested for multiple uses, including human consumption, livestock feed, and sale in local or cross-border markets, providing diversified sources of revenue. Input requirements are generally low, as lablab tolerates poor soils and erratic rainfall, reducing the need for costly fertilizers or irrigation. In addition, its integration into existing cropping systems, such as intercropping with maize or sorghum, can enhance land-use efficiency and provide supplementary income without significant additional land or labor costs. These economic advantages, combined with its multifunctionality, make lablab a viable crop for improving household livelihoods, particularly in dryland areas where alternative income sources are limited.



3.5 Agroecological constraints and opportunities for scaling lablab production under climate change

Lablab production in Kondoa and Butiama is constrained by poor-quality, recycled seeds, lack of improved drought-tolerant and early-maturing varieties, unstable markets, and limited access to pest management knowledge. Major pests and diseases during flowering and pod filling, labor shortages, and weak extension services further limit productivity (Rubyogo et al., 2010; Abate et al., 2000; Missanga et al., 2021). Despite these challenges, lablab shows strong agroecological potential. It tolerates drought, produces substantial biomass under moisture stress, suppresses weeds, and improves soil fertility through nitrogen fixation (Singh et al., 2019; Chikowo et al., 2020). Farmers also use it as nutritious fodder during dry seasons, supporting mixed crop-livestock systems (Mulumba et al., 2022). Addressing seed quality, pest management, and extension gaps is critical for scaling lablab sustainably, enabling its multifunctional benefits and climate resilience to enhance productivity and smallholder livelihoods in dryland systems.

3.6 Agroecological drivers of farmers' perceptions and acceptability of lablab

Farmers' acceptability of lablab in Butiama and Kondoa is strongly influenced by agroecological knowledge, prior experience, risk perceptions, and access to extension and institutional support. In Butiama, over 65% of respondents had positive perceptions, driven by bimodal rainfall, NGO-supported training, and lablab's demonstrated ability to enhance maize yields through intercropping (15–25% increase; Mulumba et al., 2022; Khan et al., 2021). In contrast, Kondoa showed moderate acceptability, reflecting limited experience with lablab and lower access to tailored agronomic advice. Across both districts, key drivers include prior successful cultivation, perceived drought resilience, and access to extension services (Kassie et al., 2021; Makumba and Zingore, 2023). Risk perceptions related to rainfall variability, particularly in Kondoa, led farmers to adopt intercropping to buffer soil moisture and productivity losses, aligning with findings by Nyagumbo et al. (2022). Institutional support and farmer groups facilitating knowledge exchange were critical in promoting acceptability, though quality and frequency of extension varied, with Butiama benefiting from more consistent programs. These results highlight the importance of strengthening farmer groups and providing targeted extension to support lablab as a climate-smart legume in dryland systems.

4 Conclusion

Lablab-based intercropping performance differed across the two zones, with Kondoa's sandy-loam soils supporting improved moisture retention and yield stability under increasing early-season rainfall, while Butiama's higher-rainfall environment enhanced soil fertility and pest suppression despite rising temperatures. Mixed cropping systems were most effective, contributing to higher land

equivalent ratios, while acceptability was influenced by local socioeconomic factors and constrained by seed availability and pest pressures. These results indicate that targeted, zone-specific strategies can optimize lablab integration, enhancing productivity and resilience in Tanzania's dryland farming systems.

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/s.

Ethics statement

A research clearance permit was obtained from the University of Dar es Salaam. Additionally, the local government authorities in Butiama and Kondoa districts provided permits to collect data for the study.

Author contributions

LN: Conceptualization, Methodology, Investigation, Formal analysis, Data curation, Software, Visualization, Validation, Project administration, Resources, Writing – original draft, Writing – review & editing, Funding acquisition. MM: Conceptualization, Supervision, Software, Visualization, Validation, Resources, Writing – original draft, Writing – review & editing, Funding acquisition. CJ: Conceptualization, Methodology, Investigation, Software, Visualization, Project administration, Supervision, Resources, Writing – original draft, Writing – review & editing, Funding acquisition. EA: Conceptualization, Methodology, Investigation, Data curation, Software, Visualization, Validation, Project administration, Resources, Writing – original draft, Writing – review & editing, Funding acquisition.

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Conflict of interest

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

Generative AI statement

The author(s) declared that generative AI was used in the creation of this manuscript. For language editing, grammar

checking, proofreading, and improving the clarity and flow of this manuscript. Additionally, AI support was utilized in designing and refining figures. The use of AI was strictly limited to these technical and linguistic improvements and did not influence the interpretation, analysis, or conclusions of the research.

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