



OPEN ACCESS

EDITED BY

Nugun P. Jellason,
Teesside University, United Kingdom

REVIEWED BY

Alio Moussa Abdourazak,
Abdou Moumouni University of Niamey, Niger
Irene Bayiyana,
National Agricultural Research Organisation
(NARO), Uganda

*CORRESPONDENCE

Edith L. Kadege
✉ kadegee@nm-aist.ac.tz;
✉ edith.kadege@tari.go.tz;
✉ edithkadege@gmail.com

RECEIVED 02 June 2025

REVISED 14 December 2025

ACCEPTED 17 December 2025

PUBLISHED 12 February 2026

CITATION

Kadege EL, Venkataramana PB, Assefa T,
Ndunguru JC, Kalemera SM, Ochieng J,
Nchanji EB, Rubyogo JC and
Mbega ER (2026) Tanzanian farmers'
preferred traits for common bean varieties:
breeding insights from the tricot approach.
Front. Sustain. Food Syst. 9:1639680.
doi: 10.3389/fsufs.2025.1639680

COPYRIGHT

© 2026 Kadege, Venkataramana, Assefa,
Ndunguru, Kalemera, Ochieng, Nchanji,
Rubyogo and Mbega. This is an open-access
article distributed under the terms of the
[Creative Commons Attribution License
\(CC BY\)](https://creativecommons.org/licenses/by/4.0/). The use, distribution or reproduction
in other forums is permitted, provided the
original author(s) and the copyright owner(s)
are credited and that the original publication
in this journal is cited, in accordance with
accepted academic practice. No use,
distribution or reproduction is permitted
which does not comply with these terms.

Tanzanian farmers' preferred traits for common bean varieties: breeding insights from the tricot approach

Edith L. Kadege^{1,2*}, Pavithravani B. Venkataramana¹,
Teshale Assefa³, Joseph C. Ndunguru⁴,
Sylvia Monica Kalemera³, Justus Ochieng³, Eileen
Bogweh Nchanji⁵, Jean Claude Rubyogo⁵ and Ernest R. Mbega¹

¹School of Life Sciences and Bioengineering the Nelson Mandela African Institution of Science and Technology, Arusha, Tanzania, ²Tanzania Agricultural Research Institute, Arusha, Tanzania, ³International Center for Tropical Agriculture (CIAT), Arusha, Tanzania, ⁴International Center for Tropical Agriculture (CIAT), Kampala, Uganda, ⁵International Center for Tropical Agriculture (CIAT), Nairobi, Kenya

Common bean (*Phaseolus vulgaris* L.) is an important legume in Tanzania, providing food, nutrition, and income. Since 2017, Tanzanian bean production has increased significantly, driven by factors such as changing dietary preferences, market and consumer demands, population growth, and urbanization. However, adoption of improved bean varieties remains low (14%) due to limited information about farmers' trait preferences for improved varieties. This study evaluated farmers' preferences for common bean varieties using the tricot (triadic comparison of technology) approach, in trials across three diverse agroecosystems of Tanzania. Eighteen bean genotypes were tested with 372 farmers. Each farmer evaluated three genotypes, ranking them in order of preference, providing reasons for their choice. Men's participation (53.9%) was higher than women's (46.1%) in common bean trial establishment, management, and Participatory Variety Selection (PVS), indicating a greater involvement of men in bean production in Tanzania. Genotypes NUA 48, NUA 64, Sweet Violet, and VTT923-23-10 were identified as the top-performing genotypes in terms of yield and farmer preference. High yield, market preference, and disease resistance were key selection criteria. Cooking suitability with banana and compatibility for intercropping emerged as important farmer preferences, reported for the first time in Tanzania, suggesting the importance of incorporating these traits in future variety development. Gender-specific trait preferences were also observed, with women prioritizing post-harvest traits, while men and youth focused on agronomic attributes and marketability, respectively. These findings underscore the importance of incorporating culturally preferred, high-performing agronomic traits into breeding programs, and ensuring equal participation in variety selection by women, men, and youth. Such inclusive approaches are crucial for enhancing improved bean variety adoption rates and boosting crop productivity. Beyond the tricot approach to varietal selection, this study provides deeper insights into gender-differentiated trait preferences and contextual factors influencing adoption, offering evidence to guide more demand-driven and inclusive bean breeding strategies.

KEYWORDS

common bean, gender category, genotypes, preference traits, tricot approach

1 Introduction

In developing countries, common bean (*Phaseolus vulgaris* L.) plays a significant role in smallholder farmers' livelihoods, as a source of income, and in food and nutrition security. Recently, common bean production has significantly increased in Tanzania, as a widely cultivated and commercially traded legume (Food and Agricultural Organization, 2021). Between 2017 and 2022, bean productivity (yield per hectare) increased by 8.4%, reflecting shifts in socio-economic dynamics (Food and Agricultural Organization, 2021). Factors such as population growth, urbanization, and changing dietary preferences have increased the demand for beans, positively impacting rural livelihoods. Cultivation of common beans involves men, women, and youth across the agricultural value chain. Men are often engaged in preparing the land, plowing, planting, and applying fertilizers and insecticides. Men are also engaged in the marketing and sale of beans, especially when the produce is sold beyond the local community or when they are involved in commercial farming. Women play a significant role in bean cultivation, particularly in tasks such as weeding, harvesting, and post-harvest processing. They are often responsible for threshing and sorting beans, as well as preparing them for consumption. Youth involvement in common bean cultivation remains limited, but there is growing recognition of the importance of engaging youth in agriculture to ensure the sector's long-term sustainability (Geza et al., 2021). Despite the importance of the common bean in Tanzania, farmers' adoption of genetically improved bean varieties remains limited (14%) (Katungi et al., 2009; Letaa et al., 2015; Sperling et al., 2021). The reasons for low adoption, among other factors, include breeders' limited information on farmer (or consumer) trait preferences concerning improved varieties (Ochieng et al., 2022).

Farmers' varietal preferences have been documented through Participatory Variety Selection (PVS), where farmers convene at experimental plots, at bean maturity, to assess varieties based on agronomic, consumption, and marketability traits (Bucheyeki and Mmbaga, 2013; Mbiu et al., 2020). The PVS session allows interaction between farmers and researchers, and is where physiologically mature beans are ranked. Participants can exchange ideas, but they may not recall all the observations on each variety's vegetative characteristics, which can influence subsequent varietal selection, positively or negatively. Additionally, participation levels during the growing season can vary, potentially skewing observations on agronomic traits and influencing variety selection (Weltzien et al., 2003; Ceccarelli and Grando, 2007). Limited involvement in PVS during centralized trials contrasts with the widespread bean farming practices across diverse Tanzanian agroecosystems, each potentially favoring different bean varieties (Rowhani et al., 2011; Rubyogo et al., 2019; Philipo et al., 2021).

This study overcomes the limitations of PVS by implementing the tricot (triadic comparison of technologies) decentralized trials approach, which engages numerous farmers throughout the cropping season. This approach ensures that comprehensive feedback on agronomic performance, adaptability, and postharvest/socioeconomic preferences is captured; it also reflects real farming conditions and better-aligns variety selection with farmers' needs across diverse agroecosystems. This study, therefore, aimed to assess and confirm farmers' and consumers' trait preferences to support farmers' adoption of improved common bean varieties in Tanzania's Northern, Lake, and Southern Highland Zones, through the tricot approach. The study also

provides deeper insights into gender-differentiated trait preferences and the contextual factors influencing adoption, to inform and guide more demand-driven and inclusive bean breeding strategies in Tanzania.

2 Materials and methods

2.1 Breeding materials

Eighteen common bean genotypes (Table 1) were evaluated, comprising seven advanced breeding lines, 10 released varieties, and one local cultivar. The advanced breeding lines and released varieties were provided by the Tanzania Agricultural Research Institute (TARI—Maruku, Selian, and Uyole), while the local cultivar was a farmer-preferred variety commonly grown in and sourced from the Siha district, Kilimanjaro region. This local variety is widely cultivated and commands a premium market price. The genotypes were selected according to their anthracnose susceptibility and based on market preferences, including consumer demand for specific market classes.

2.2 Participating farmers and the study location

Farmers were selected through simple random sampling based on specific criteria. These included: (i) at least three seasons of experience in common bean production; (ii) a willingness to participate in the study, reflecting both their knowledge and commitment; and (iii) connection to either a non-governmental organization (NGO) or district extension officers for access to technical guidance, observing genotype performance, and assisting with data collection and sharing. Simple random sampling ensured that the selected bean-producing farmers were representative of the broader population. This contributed to more reliable and generalizable conclusions about the adaptability and stability of common bean breeding materials.

A purposive sampling technique was employed to select productive agroecosystems, regions, districts, and villages based on bean prevalence, accessibility, and representativeness of the target bean-producing farmers. This approach ensured that the selected sites were highly relevant to the study objectives, providing meaningful and contextually appropriate insights into genotype performance across different agroecological Zones in Tanzania. To focus the study on farmers' preferences for common bean varieties, the study locations were further narrowed down to two districts per Zone with the highest incidence of anthracnose (the main bean disease in Tanzania). This selection was supported by anthracnose incidence data from 1,682 on-farm trials conducted by individual farmers across Tanzania's Lake Zone (500 trials), Northern Zone (562 trials), and Southern Highlands Zone (620 trials). Based on this analysis, the two districts with the highest disease incidence in each Zone were chosen for inclusion in the study. Accordingly, the selected districts were Karatu and Siha in the Northern Zone, Kyerwa and Misenyi in the Lake Zone, and Mbarali and Njombe in the Southern Highlands Zone. In each of these selected districts, 62 farmers were randomly selected to participate in the bean trial establishment, management, and data sharing (Table 1). These farmers were involved in tricot trial to evaluate the genotypes' performance, using farmers' crop management practices under on-farm conditions.

TABLE 1 Common bean genotypes tested in the study.

Common bean genotypes	Seed source	Seed size	Market class	Category—remarks
Gloria	TARI Uyole	Medium	Purple	Advanced breeding line
Kablanketi	TARI Uyole	Medium	Purple	Advanced breeding line
Kipapi	TARI Uyole	Medium	Purple	Advanced breeding line
NUA 48	TARI Selian	Large	Red mottled	Advanced breeding line
NUA 64	TARI Selian	Large	Red mottled	Advanced breeding line
Sweet violet	TARI Uyole	Large	Sugar	Advanced breeding line
VTT923-23-10	TARI Uyole	Large	Sugar	Advanced breeding line
COD MLB 0033	TARI Maruku	Medium	Red mottled	Released 2020
KAB 36	TARI Maruku	Medium	Red mottled	Released 2020
RCB 593	TARI Maruku	Medium	Red mottled	Released 2020
RWR 2154	TARI Selian	Large	Sugar	Released 2020
SCR 61	TARI Maruku	Medium	Red	Released 2020
SMC 18	TARI Maruku	Small	White	Released 2020
Selian 12	TARI Selian	Medium	Red	Released 2018
Uyole 18	TARI Uyole	Medium	Purple	Released 2018
Calima Uyole (check)	TARI Uyole	Large	Red mottled	Released 2012
Uyole03 (check)	TARI Uyole	Large	Sugar	Released 2003
Boroto (check)	Farmers	Medium	Sugar	Local cultivar

2.3 Experimental design, planting, and management

Eighteen common bean genotypes were systematically randomized in an incomplete block design (IBD). The IBD is a useful experimental design when there are many treatments and testing locations. Each farmer plot was considered as an IBD plot. In this design, not all treatments are included in each block, but it ensures that each treatment appears in a sufficient number of blocks to allow for valid comparisons. This approach reduces the number of experimental units required compared to a complete block design, making it more efficient and feasible (Yates, 1936; Atlin et al., 2001). The term “incomplete block” corresponds to the number of farmers participating in the trials for on-farm evaluations (Yates, 1936; Atlin et al., 2001), using the ClimMob platform—an online platform/software for agricultural citizen science and participatory trials (Van Etten et al., 2017; Van Etten et al., 2019). The number of blocks needed depends on the farmers’ accuracy in distinguishing between varieties. For a trial with approximately 12 entries (such as different varieties or lines), conducting the trial on 100–200 farms would generally provide reliable data to generate recommendations (Van Etten et al., 2019). Each farmer was provided with three genotypes, which were labeled anonymously as “A,” “B,” and “C” to avoid bias during data collection. The genotype names were not disclosed to the farmers to prevent any preconceived notions or biases, ensuring that the evaluation was based solely on the observed performance of the genotypes during the trial (Van Etten et al., 2017; Van Etten et al., 2019). This approach helps in obtaining more objective and reliable results. The seeds were sown at a spacing of 50 cm between rows and 20 cm between plants, which is the recommended spacing for bean cultivation. Each plot consisted of four rows with 30 holes per row, and two seeds were planted in each hole. The trials were managed by individual farmers using their

experience in common bean cultivation, while field agents or extension officers conducted routine visits to provide technical advice on aspects such as timely planting, weeding, trial observations, and harvesting.

2.4 Data collection

The Open Data Kit (ODK) tool was used to collect data. A semi-structured questionnaire composed of both open and closed-ended questions was developed and used to collect information. The Swahili language was used for easy communication between the field officers and bean farmers. Farmers used field agents’ support to recode qualitative data on anthracnose resistance and grain yield. Individual farmers were asked to rank their most preferred genotype from a set of three genotypes they received, planted, and observed. Anthracnose disease severity was evaluated for each genotype. Field agents scored the severity of the disease on a scale from 1 to 9, where 1–3 indicated resistance, 4–6 indicated moderate resistance, and 7–9 indicated susceptibility (Schoonhoven and Pastor Corrales, 1987). The scores recorded for each genotype were compared to determine their relative resistance to anthracnose. The genotype with the lowest severity score (1–3) was ranked as the best option, indicating strong resistance to anthracnose. The genotype with the highest severity score (7–9) was ranked as the worst option, reflecting its high anthracnose susceptibility. Grain yield was ranked by assessing and comparing the overall grain yield of each genotype in an experimental trial. Harvested grains from each plot were placed in four-liter plastic containers, and the volumes were compared to determine the ranking. The genotype with the highest volume was ranked as having the best grain yield, while the one with the lowest volume had the worst grain yield. All qualitative data were collected using the ODK tool and shared on the

ClimMob platform (Van Etten et al., 2017; Van Etten et al., 2019). Farmers were also asked to share the reason for their preferences by ranking the first, second, and third reasons.

2.5 Data analysis

The preference ranking data were analyzed using R statistical software (version 4.5.1; R Core Team, 2017). The Plackett–Luce package (Plackett, 1975; Luce, 1959) was used for ranking analysis, while the visualizing categorical data (VCD) package was employed to generate preference plots. Chi-square tests were conducted to compare preferences across genders and Zones. The analysis employed descriptive statistics, partial correlation, and non-parametric tests. Non-parametric methods were used because the trikot data are based on farmers' categorical rankings (A, B, C), which are ordinal and do not meet the normality assumptions required for parametric tests (Van Etten et al., 2019). Ranking data represent unequal intervals between categories, making parametric approaches inappropriate without transformation (Conover, 1999). Rank-based models such as the Plackett–Luce model are therefore more suitable for analyzing preference structures without assuming normality or homoscedasticity (Luce, 1959; Turner and Firth, 2012).

Positive votes were coded as 1 and negative votes as 0, which allowed for quantifying the votes received by each genotype. A positive vote represents a favorable assessment or preference for a genotype. These votes were coded as 1 to signify approval or endorsement of a particular genotype. A negative vote indicates an unfavorable assessment or lack of preference for a genotype. These votes were coded as 0 to denote disapproval or rejection of a genotype. The total number of positive votes (coded as 1) and negative votes (coded as 0) for each genotype was quantified by summing the respective votes across all evaluations. This provided a numerical measure of how each genotype was perceived in terms of its performance or preference by the evaluators. This coding and quantification system allowed for a straightforward statistical analysis of the voting data, enabling the identification of the most favored genotypes (high positive votes) or least favored (high negative votes). It also facilitated comparisons among genotypes and provided a basis for ranking them based on overall preference. The positive and negative votes were statistically validated to ensure data reliability. Among the 372 trials, only 0.1% of the data on reasons for preference were missing. The missing value was imputed with the category “unknown” to preserve the total number of observations for analysis. Furthermore, preferences were compared between agroecosystems using non-parametric tests. Demographic frequencies were analyzed to understand the preferred criteria for genotype selection, where farmers were grouped based on shared demographic characteristics (e.g., youth vs. older farmers, male vs. female farmers). These groups allowed for comparison of preferences across different demographic profiles. Frequencies of demographic characteristics were calculated to identify dominant trends within the sample (e.g., percentage of female participants). The genotype rankings and preferences were cross-tabulated with demographic variables. For example, men and women farmers' preferred genotypes were compared. Preference patterns were analyzed to determine whether certain demographic groups showed consistent preferences for specific traits (e.g., high yield, disease resistance).

Insights from demographic analysis were used to tailor recommendations and breeding strategies to specific groups. This ensured that genotypes aligned with the diverse needs and priorities of farmers. By analyzing demographic frequencies and linking them to preferences, the underlying factors driving genotype selection were identified. This approach enabled a more nuanced understanding of farmer needs and informed the development of genotypes that better cater to varied demographic groups.

3 Results

3.1 Common bean genotype performance and farmer preferences

The genotype performance data reveals statistically significant differences among the tested varieties for anthracnose disease resistance and grain yield ($p < 0.05$) (see Table 2). All bean genotypes performed differently for the measured traits. This suggests that some varieties exhibited superior resistance to anthracnose disease and better grain yields than others. The results also confirm that the differences observed in farmers' evaluations reflect real and meaningful variations among the varieties, providing valuable insights for selecting and promoting the best-performing ones for wider adoption. Genotype selection results are presented in Figure 1. The NUA 64 and NUA 48 were the most preferred genotypes by farmers, followed by Sweet Violet and VTT923-23-10. In the Lake and Northern Zones, farmers voted NUA 64 and NUA 48 (red mottled) as their top choices, while in the Southern Zone, Sweet Violet and VTT923-23-10 (sugar bean) were the most favored. Boroto (local variety) received equal ranking by farmers across all three agroecosystems and was the eighth most preferred out of the 18 genotypes. Some genotypes like Kipapi, RWR 2154, and Gloria were ranked equally by farmers in both the Northern and Southern Zones, while Sweet Violet, VTT923-23-10, and SCR 61 were similarly ranked in the Lake Zone and Northern Zone. Generally, genotype selection indicates that different genotypes performed differently in different environments, although their rankings may converge at certain points. Additionally, popular genotypes receive higher preference than unknown genotypes. Notably, unknown genotypes bearing similarities in grain color, size, and shape to known genotypes stood a greater chance of being selected compared to those that are dissimilar.

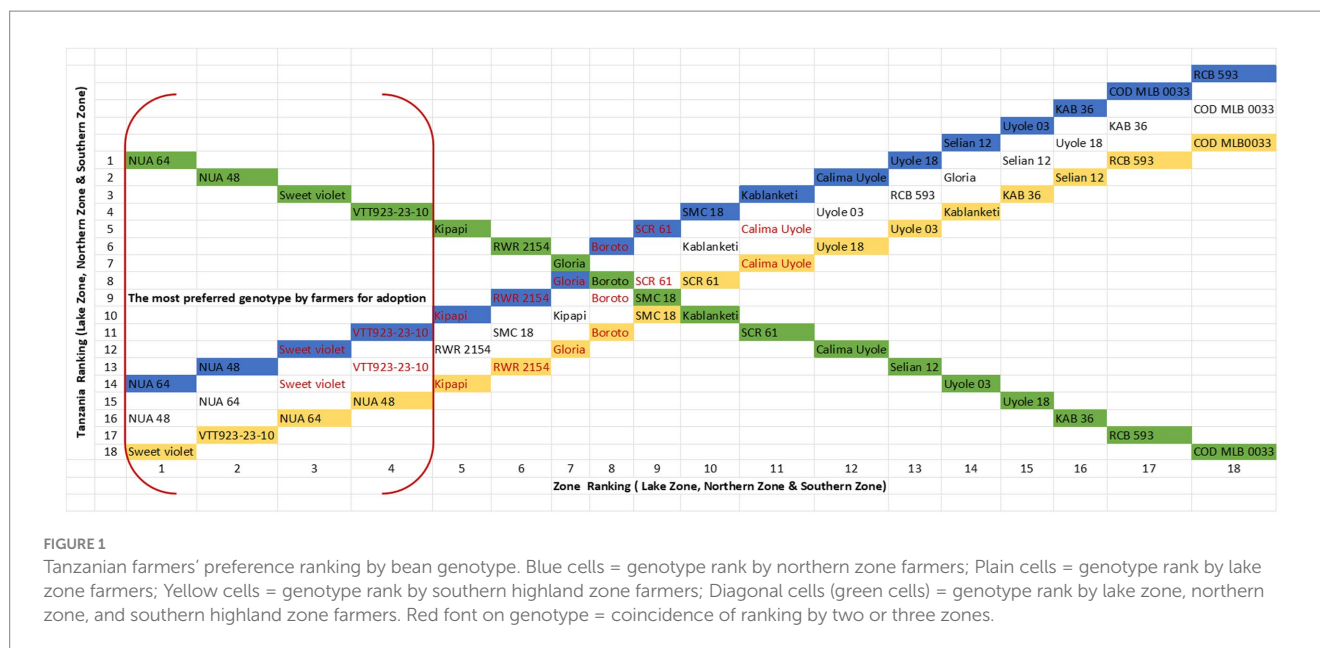
3.2 Trait preferences across agroecosystems

The study shows that farmers in three agroecosystems/agroecologies of Tanzania seek comparable traits, leading to

TABLE 2 Analysis of variance (ANOVA) for genotype performance.

Variable	logLik	DF	F	Pr(>Chisq)
Disease Resistance	−404.5408	1,086	509.654	0.0000 ***
Grain yield	−381.6256	1,089	559.068	0.0000 ***

Significant (0, ***) at ($p \leq 0.05$). “logLik”, Log-likelihood; DF, Degree of freedom; F, Statistic; Pr > Chisq, Probability of chi-square test.



predominantly uniform outcomes; nevertheless, some disparities do exist (Tables 3, 4). Farmers in the Lake Zone and Southern Zone primarily valued market preference as the key factor for determining genotype superiority, while Northern Zone farmers predominantly relied on high grain yield as the primary criterion to determine genotype superiority (Table 4). Farmers prioritized traits such as grain color, shape, and size because these characteristics significantly influence marketability and pricing. For instance, farmers in the Lake Zone and Northern Zone predominantly preferred NUA 64 and NUA 48 (Figure 1) due to their high yields and resemblance to well-known genotypes like Lyamungo 90 and Lyamungo 85, which are popular in the market. In the Southern Highland Zone, Sweet Violet and VTT923-23-10 were preferred because they share similar traits with Uyole 03, a variety with a strong market position in the Southern Zone (Figure 1).

Disease resistance was the third criterion for genotype selection among farmers (Table 3). However, in the Northern Zone, disease resistance was considered the second most important criterion. For example, although Calima Uyole and Uyole 18 were preferred in the market, commanding premium prices, they were less preferred by farmers due to their high susceptibility to anthracnose. The Northern Zone, which has the highest incidence of anthracnose, shows greater concern for disease resistance compared to the Lake Zone and Southern Highland Zone. Farmers in the Lake Zone preferred SMC 18 variety for cooking with bananas, because of its white color. However, this particular genotype did not receive similar attention in the Northern and Southern Highland Zones. In these latter zones, RWR 2154 and VTT923-23-10 were recognized as suitable for intercropping, whereas in the Lake Zone, their ranking differed (Table 4).

3.3 Gender- and age-based differences

Preferences differed by gender (Tables 5–8). All groups (women, men, and youth) highlighted 14 criteria for selecting bean

varieties, though their rankings varied. Women ranked post-harvest traits as the highest criteria for variety choice, while, for the men, these traits were considered less important. Women's top criteria included short cooking time, no flatulence, good taste, and suitability for cooking with bananas. Men, on the other hand, valued agronomic traits such as high yield, disease resistance, suitability for intercropping, and early maturity. Youth prioritized market-related traits, such as premium price, market preference, and good color, alongside agronomic traits like high yield, disease resistance, and intercrop-friendly. During the interviews, many women emphasized that, in addition to considering post-harvest processing, market preference is a top priority. Growing market-preferred varieties ensures that aggregators will collect and pay for the beans directly at the farm gate. If the variety is not preferred, women may face difficulties transporting the beans to the market, requiring men's assistance, which could delay the sale and impact profitability.

Furthermore, women's variety selection also considers disease resistance, as women are less able to carry sprayers for insecticide to manage diseases in the field and would need men to help them. However, men have their own planned activities, and this extra support is time-consuming. Consequently, diseased bean plants are more likely to die due to a delay in applying crop-protectants. Moreover, the analysis reveals a certain disparity in preference selection criteria across gender categories and geographical Zones (Table 5). Among the top seven selection criteria, women in both the Lake and Southern Zones show a higher prioritization of postharvest traits. Conversely, women farmers in the Northern Zone exhibit a greater preference for agronomic traits. In contrast, men and youth farmers in the Northern and Lake Zones prioritize agronomic and marketability traits, whereas in the Southern Zone, agronomic traits are the main focus for men and youth. Furthermore, analysis shows that there were associations between gender, zone, and reasons for variety preference (Figure 2), signifying that the reasons for preference varied considerably across both gender and zone.

TABLE 3 Preference criteria for bean selection by farmers in Tanzania (ranked in preference order).

Reason for preference	Lake zone	Northern zone	Southern highland zone	Total	Rank
High yield	55	115	66	236	1
Preferred in the market	72	68	86	226	2
Disease resistance	61	94	56	211	3
Premium price in the market	22	20	34	76	4
Good for intercropping	3	49	23	75	5
Good taste	12	45	2	59	6
No flatulence	6	17	21	44	7
Short cooking time	6	13	23	42	8
Preferred cooking with banana	42	0	0	42	9
Early maturity	7	2	18	27	10
Good color—could be having good market	15	10	1	26	11
Good taste with thick stew	3	1	11	15	12
Easy availability of seed	2	0	10	12	13
Long shelf life after cooking	3	0	7	10	14

4 Discussion

4.1 Emerging context-specific traits

The study highlights several emerging context-specific traits influencing common bean variety preferences across Tanzania's agroecosystems. The identification of such context-specific trait preferences has important implications for breeding, seed delivery and scaling efforts. Across the three agroecosystems/agroecologies, farmers consistently valued high yield, marketability and disease resistance. Despite these trait priorities, the variation in specific trait combinations suggests that a one-size-fits-all breeding approach may not fully address farmers' needs. Instead, breeding programs should intensify efforts toward developing targeted, environment-specific product profiles that account for localized production constraints and market opportunities. The strong farmer emphasis on high yields aligns with the findings of [Mukankusi et al. \(2015\)](#), who indicated that bean breeders often use grain yield as a key indicator of varietal superiority, recognizing that traits such as disease resistance and yield components ultimately contribute to the grain yield outcome. The convergence between breeder, farmer and consumer priorities underscores the potential for improved adoption when breeding objectives reflect real production challenges. However, it also highlights the need for multi-trait selection strategies that balance yield with resilience traits, especially increasing climate variability and the prevalence of pests and diseases in different regions. Furthermore, farmers' consistent interest in marketability implies that breeding programs cannot focus solely on agronomic traits but must also integrate consumer preferred grain attributes such as seed size, color and cooking quality to enhance value-chain competitiveness. Seed systems and extension services also need to tailor dissemination strategies to ensure that farmers in each agroecological Zone access varieties that match their specific trait demands. Without such alignment, even superior varieties may face limited uptake.

Market preference emerged as the primary trait considered by farmers when selecting bean varieties in the Lake and Southern Zones. This finding aligns with [Sperling et al. \(2021\)](#) and [Ochieng et al. \(2023\)](#), who reported that consumer and market-preferred varieties are the main criteria used by bean grain traders when purchasing beans from farmers. In contrast, farmers in the Northern Zone prioritized disease resistance as the most important selection criterion. This suggests that farmers in this region, particularly in Karatu district, where PVS was conducted, are highly attentive to disease resistance, especially against anthracnose, which had the highest incidence in the area. These findings are consistent with [Nchanji et al. \(2021\)](#), who highlighted the link between disease resistance and farmers' preferences for bean varieties. The Zone-specific preferences demonstrate that effective varietal development and scaling require a nuanced understanding of both market dynamics and biotic stress conditions. Incorporating such insights into breeding and seed system designs will lead to better targeting, higher adoption rates, and improved livelihoods for bean-growing households across Tanzania. Additionally, the study revealed that farmers prioritize bean varieties that are well-suited for cooking with bananas and for intercropping, with both traits reported for the first time in Tanzania. This finding underscores the growing importance of traits that align with farmers' specific farming systems, cultural practices, and evolving challenges. Several factors may explain why these traits are being reported now. Climate change and its associated risks have led to an increased emphasis on intercropping as a strategy to mitigate potential crop losses. Intercropping with maize, for example, reduces risks associated with erratic weather patterns by maximizing land-use efficiency and stabilizing yields. Additionally, rising population pressures have resulted in land scarcity, compelling farmers to adopt intercropping practices to optimize productivity on limited plots. Farmers in the Northern and Southern Highland Zones, where intercropping is common, emphasized a preference for bush bean varieties. These varieties

TABLE 4 Preference criteria for bean selection by zone in Tanzania.

Location	Reason for preference	Preference 1	Preference 2	Preference 3	Total	Rank
Lake zone	Preferred in the market	31	12	29	72	1
	High yield	25	11	19	55	2
	Disease resistant	17	21	23	61	3
	Preferred cooking with banana	21	11	10	42	4
	Premium price in the market	9	4	9	22	5
	Good color—more marketable	0	13	2	15	6
	Good taste	0	9	3	12	7
	Early maturity	0	0	7	7	8
	No flatulence	0	5	1	6	9
	Short cooking time	0	5	1	6	10
	Good taste with thick stew	1	1	1	3	11
	Long shelf life after cooking	0	3	0	3	12
	Good for intercropping	0	1	2	3	13
	Easy availability of seed	0	1	1	2	14
Northern zone	High yield	47	25	43	115	1
	Disease resistant	31	9	54	94	2
	Preferred in the market	34	26	8	68	3
	Good for intercropping	1	36	12	49	4
	Good taste	0	39	6	45	5
	Premium price in the market	7	4	9	20	6
	No flatulence	5	4	8	17	7
	Short cooking time	8	1	4	13	8
	Good color—more marketable	7	1	2	10	9
	Early maturity	0	1	1	2	10
	Good taste with thick stew	0	1	0	1	11
	Preferred cooking with banana	0	0	0	0	12
	Easy availability of seed	0	0	0	0	13
	Long shelf life after cooking	0	0	0	0	14
Southern highland zone	Preferred in the market	42	18	26	86	1
	High yield	26	20	20	66	2
	Disease resistant	20	18	18	56	3
	Premium price in the market	13	3	18	34	4
	Short cooking time	11	6	6	23	5
	Good for intercropping	0	12	11	23	6
	No flatulence	3	12	6	21	7
	Early maturity	3	12	3	18	8
	Good taste with thick stew	2	6	3	11	9
	Easy availability of seed	0	7	3	10	10
	Long shelf life after cooking	0	4	3	7	11
	Good taste	0	1	1	2	12
	Good color—more marketable	0	1	0	1	13
	Preferred cooking with banana	0	0	0	0	14

are easier to manage in intercropped systems, as climbing or semi-climbing varieties complicate field operations such as weeding, insecticide application, and harvesting, which are labor-intensive. This aligns with findings by [Gliessman \(1992\)](#) and [Vandermeer](#)

(2011), who noted that crop variety selection must be tailored to cropping systems, balancing productivity with labor and management demands. These findings call for a more holistic, farming system-based breeding and dissemination approach that

TABLE 5 Preference criteria for bean selection by gender category in Tanzania.

Gender category	Reason for preference	Preference 1	Preference 2	Preference 3	Total	Rank
Women	Preferred in the market	38	32	17	87	1
	Disease resistant	30	28	24	82	2
	High yield	35	31	13	79	3
	Short cooking time	17	11	11	39	4
	No flatulence	17	16	4	37	5
	Good taste	6	12	14	32	6
	Preferred cooking with banana	0	13	17	30	7
	Good for intercropping	4	5	21	30	7
	Premium price in the market	17	4	3	24	9
	Good color—more marketable	0	2	14	16	10
	Good taste with thick stew	3	4	8	15	11
	Early maturity	2	2	9	13	12
	Long shelf life after cooking	0	3	6	9	13
	Easy availability of seed	0	3	5	8	14
Men	High yield	68	55	35	158	1
	Disease resistant	33	64	29	126	2
	Preferred in the market	69	33	15	117	3
	Good for intercropping	1	12	32	45	4
	Premium price in the market	15	20	7	42	5
	Good color—more marketable	3	7	28	38	6
	Ealy maturity	7	2	26	35	7
	Preferred cooking with banana	4	6	8	18	8
	Good taste	1	5	11	17	9
	No flatulence	2	3	7	12	10
	Easy availability of seed	0	1	3	4	11
	Short cooking time	2	0	1	3	12
	Long shelf life after cooking	0	0	1	1	13
	Good taste with thick stew	0	0	0	0	14
Youth	Premium price in the market	36	17	6	59	1
	Preferred in the market	22	17	11	50	2
	High yield	6	23	9	38	3
	Disease resistant	12	14	2	28	4
	Good for intercropping	0	8	11	19	5
	Good color—more marketable	1	1	14	16	6
	Short cooking time	7	3	6	16	6
	Good taste	1	3	6	10	8
	Ealy maturity	0	1	9	10	8
	No flatulence	3	3	4	10	8
	Preferred cooking with banana	5	2	2	9	11
	Good taste with thick stew	0	0	4	4	12
	Easy availability of seed	0	1	3	4	12
	Long shelf life after cooking	0	1	1	2	14

TABLE 6 Women's preference criteria for bean selection by zone in Tanzania.

Gender category	Agroecosystems	Lake zone		Northern zone		Southern highland zone	
	Reason for preference	Total		Rank		Total	
Women	Preferred in the market	33	1	13	5	41	1
	Preferred cooking with banana	24	2	0	11	0	13
	Disease resistant	19	3	34	1	23	4
	High yield	17	4	30	2	31	2
	Premium price in the market	12	5	4	9	21	5
	Good taste	6	6	22	3	12	7
	Short cooking time	5	7	11	8	30	3
	No flatulence	4	8	12	7	16	6
	Good taste with thick stew	3	9	1	10	11	8
	Ealy maturity	3	9	0	11	10	9
	Good color—more marketable	3	9	13	5	0	13
	Easy availability of seed	2	10	0	11	6	11
	Good for intercropping	2	10	16	4	2	12
	Long shelf life after cooking	2	10	0	11	7	10

TABLE 7 Men's preference criteria for bean selection by zone in Tanzania.

Gender category	Agroecosystems	Lake zone		Northern zone		Southern highland zone	
	Reason for preference	Total		Rank		Total	
Men	High yield	42	1	81	1	35	2
	Preferred in the market	42	1	30	4	45	1
	Disease resistant	36	3	64	2	26	3
	Preferred cooking with banana	18	4	0	11	0	11
	Premium price in the market	13	5	16	7	13	4
	Good color—more marketable	12	6	22	6	1	10
	Ealy maturity	7	7	2	9	8	6
	Good taste	6	8	30	4	2	9
	No flatulence	2	9	5	8	5	7
	Good for intercropping	1	10	33	3	11	5
	Short cooking time	1	10	2	9	0	11
	Long shelf life after cooking	1	10	0	11	0	11
	Good taste with thick stew	0	13	0	11	0	11
	Easy availability of seed	0	14	0	11	4	8

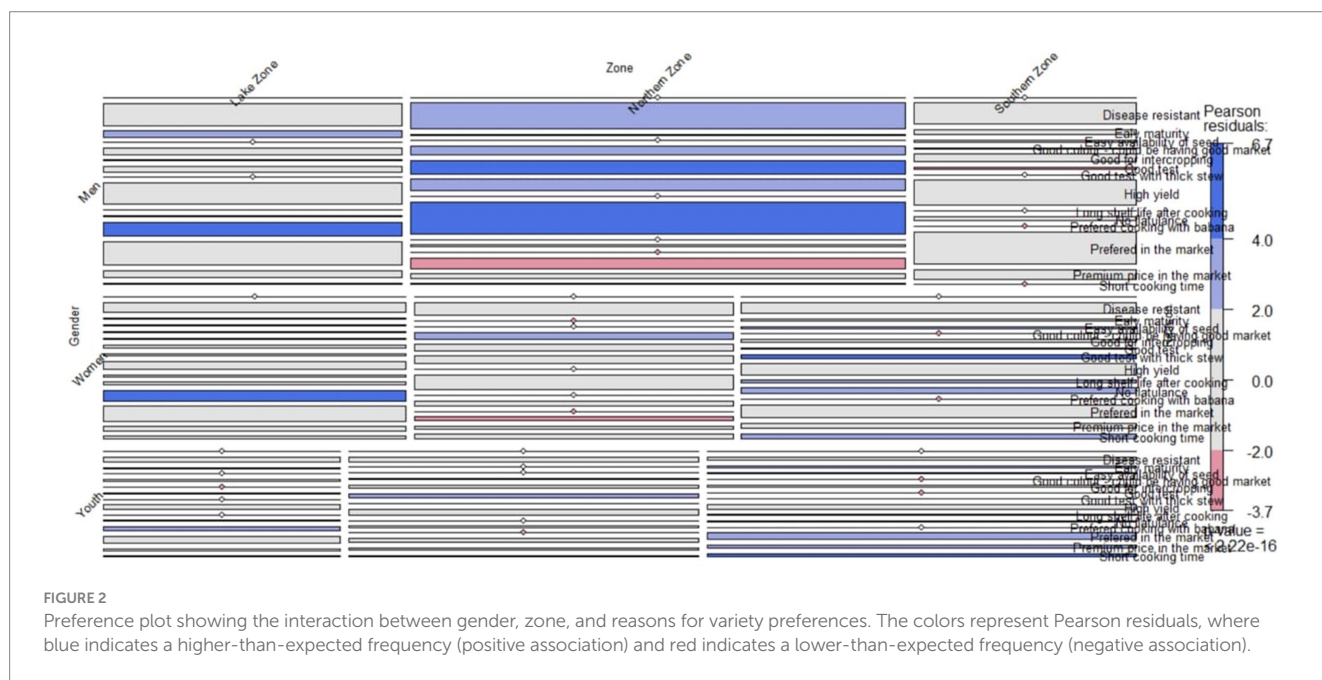
blends agronomic resilience, cultural relevance, and labor efficiency to meet the changing needs of Tanzanian bean farmers.

Similarly, in the Lake Zone, farmers highlighted the importance of selecting bean varieties that are suitable for cooking with bananas, a traditional food in the region. Such traits are increasingly significant as farmers adapt to changes in consumption patterns influenced by education, health awareness, and economic considerations. As the awareness of the nutritional benefits of beans as a plant-based alternative protein grows, farmers may prioritize varieties that meet both dietary needs and cultural preferences. These findings suggest that breeding programs should incorporate socio-cultural and

agroecological considerations into selection processes. Traits such as intercropping compatibility, culinary suitability, and nutritional value should complement yield and disease resistance in future breeding objectives. This implies that breeding pipelines should integrate sensory and culinary evaluations, such as cooking time, texture, and flavor into a variety testing frameworks. Overall, the findings demonstrate that breeding and seed system strategies must evolve beyond conventional focuses on yield and disease resistance. To enhance adoption and impact, future breeding objectives should incorporate sociocultural preferences, intercropping compatibility, nutritional value, and local food preparation practices. This will

TABLE 8 Youth preference criteria for bean selection by zone in Tanzania.

Gender category	Agroecosystems	Lake zone		Northern zone		Southern highland zone	
	Reason for preference	Total		Rank		Total	
Youth	Preferred in the market	19	1	14	3	26	1
	High yield	12	2	20	1	18	2
	Disease resistant	9	3	16	2	13	4
	Preferred cooking with banana	9	4	0	11	0	12
	Premium price in the market	7	5	7	6	14	3
	Good color—more marketable	5	6	5	7	12	5
	Ealy maturity	2	7	0	11	8	7
	Good taste	2	7	14	3	0	12
	No flatulence	1	9	4	8	5	8
	short cooking time	1	9	3	9	9	6
	Good taste with thick stew	0	11	1	10	3	10
	easy availability of seed	0	11	0	11	4	9
	Good for intercropping	0	11	10	5	2	11
	Long shelf life after cooking	0	11	0	11	0	12



ensure that new varieties are not only agronomically superior but also culturally appropriate, system-compatible, and aligned with the everyday realities of smallholder farmers across Tanzania’s diverse agroecosystems.

Among the common bean varieties, NUA 64 and NUA 48 (Red mottled) were the most preferred varieties in Tanzania, especially in the Lake and Northern Zones. These findings align with Ochieng et al. (2023), who indicated that red mottled beans were the second most sold type (21.4%) in Tanzania from March 2022 to March 2023 after yellow beans (53.7%). The strong preference for NUA 64 and NUA 48 (Red mottled) in the Lake and Northern Zones highlights the influence of cross-border market dynamics on

varietal choice. Their popularity aligns with regional trade patterns, as red mottled beans are highly demanded in neighboring Kenya and Uganda. This demonstrates that farmers near border regions respond not only to local market incentives but also to broader regional value-chain signals. The implication is that breeding programs and seed systems must consider regional trade flows when prioritizing varieties for multiplication and dissemination, especially in border-producing areas where cross-border markets significantly shape demand.

Additionally, Sweet Violet and VTT923-23-10 (sugar bean) were the second most preferred varieties for adoption in Tanzania, particularly in the Southern Highland Zone. The high preference

for Sweet Violet and VTT923-23-10 reflects the influence of export-oriented markets in Malawi and Zambia, where sugar beans hold strong consumer and trader appeal. These patterns support findings by [Birachi et al. \(2020\)](#) and [Ochieng et al. \(2023\)](#), reinforcing the idea that market integration, both domestic and regional, plays a central role in determining adoption potential. These insights have several important implications. First, breeding programs should strategically align product profiles with varieties that have demonstrated market traction across the East and Southern African region, ensuring that new releases match the grain types most likely to generate income for farmers. Second, seed companies and public seed enterprises should prioritize the production of these preferred market-linked varieties. This will increase uptake and reduce the risk of unsold seed. Third, extension and dissemination efforts should incorporate market information, helping farmers understand price trends and the comparative advantages of different grain types.

4.2 Gender differences in trait preferences

The percentage of men engaged in common bean trial establishment, management, and PVS was higher (53.9%) than that of women (46.1%), indicating that men's engagement in common bean production in Tanzania is higher than women's. This disparity may be due to the increased commercial value of common beans, with 48% of common bean grains sold to neighboring countries and beyond ([Birachi et al., 2020](#)). This shift has transformed common beans from a subsistence crop to a commercial one. According to [Nakazi et al. \(2017\)](#), men often assert their role as income providers to exert control over the income generated from food crops. Additionally, women face disparities in land access and ownership rights, coupled with limited access to financial capital compared to men. This implies that future breeding, extension and seed system interventions must adopt deliberate gender-responsive strategies to ensure equitable participation and benefit sharing. Without targeted efforts such as improving women's access to land and credit, and training, women may be further marginalized from emerging economic opportunities in the bean value chain. Gender-sensitive programming is therefore essential to promote inclusive adoption, enhance household welfare, and avoid reinforcing existing inequalities within farming communities.

As mentioned in section 3.3, women, exhibited stronger preferences for post-harvest traits such as short cooking time, no flatulence, good taste, and suitability for cooking with bananas. Men emphasized agronomic and market traits while youth prioritized market-related traits, such as premium price, market preference and good color. These findings align with [Assefa et al. \(2014\)](#) and [Tigist et al. \(2020\)](#), who indicated differences among women and men bean farmers in variety selection criteria. Farmers from different groups (women, men, and youth) in participatory studies may have varying preferences and selection criteria when it comes to choosing crop varieties ([De Boef and Thijssen, 2007](#)). The observed differences in varietal preferences among women, men, and youth highlight the importance of adopting inclusive and segmented breeding and dissemination strategies. Women's stronger emphasis on post-harvest traits reflects their central role in household food preparation and nutrition. Men's focus on

agronomic and market traits, alongside youth prioritization of market-related attributes, indicates that each group evaluates varieties based on their distinct responsibilities and livelihood goals. This implies that breeding programs must intentionally integrate gender- and age-responsive trait priorities into product profiles to ensure broader acceptance and adoption.

Failing to incorporate these diverse preferences risks developing varieties that meet the needs of only one segment of the farming population, which could limit adoption and reduce overall impact. Additionally, extension and seed delivery systems should tailor messaging and outreach to different farmer groups to ensure equitable access to varieties that align with their priorities. By addressing the differentiated needs of women, men and youth, breeding and seed system interventions can enhance inclusivity, strengthen adoption rates, and improve both household nutrition and market opportunities.

Differences were also observed across agroecosystems. Women in the Lake and Southern Highland Zones exhibited a strong preference for post-harvest traits, whereas preferences varied among women in the Northern region. On the other hand, men and youth farmers in the Lake and Northern Zones emphasized on agronomic and marketability traits, while those in the Southern Zone prioritized agronomic traits. This variance may be attributed to cultural distinctions, such as the Lake Zone's practice of mixing beans with bananas, which is a staple in their diet. The variation in trait preferences across agroecosystems and gender groups demonstrates that varietal selection is shaped not only by production environments but also by cultural practices and household roles. Women's stronger preference for post-harvest traits in the Lake Zone reflects food preparation norms and culinary traditions such as mixing beans with bananas, while men and youth in the Lake and Northern Zones prioritize agronomic and market traits associated with income generation. This implies that breeding programs must avoid uniform trait targeting and instead adopt zone-specific, gender-responsive breeding and dissemination strategies. By integrating cultural considerations, dietary habits and region-specific production conditions into product profiles, breeding efforts can ensure that new varieties meet the practical and cultural needs of different user groups. Additionally, extension and seed-system interventions should be tailored to each zone to reflect these distinct preferences. Recognizing and addressing such localized and gendered differences will enhance adoption, improve satisfaction with new varieties and ultimately strengthen the effectiveness and equity of bean improvement programs across Tanzania.

4.3 Implications for breeding programs

The findings have important implications for bean breeding programs in Tanzania and similar contexts. First, breeders should move beyond conventional selection criteria such as yield and disease resistance to include context-specific and user-driven traits. Breeders should also consider main consumer traits including cooking time, taste and flatulence. Demand-led breeding should be considered as a platform for Bean breeding program. Integrating traits like intercropping compatibility, cultural suitability (e.g., cooking with banana), and post-harvest quality would enhance adoption and sustainability. Second,

gender-responsive breeding is essential. Programs should involve both men and women equitably in participatory variety selection to ensure that developed varieties meet diverse household and market needs. Furthermore, the increasing commercialization of beans necessitates a focus on market-preferred types, particularly red mottled and sugar beans, to enhance farmers' income potential by involving traders who have been the drivers for the bean market.

4.4 Advantages of triadic comparison of technologies over participatory variety selection

Triadic comparisons of technologies (tricot) and PVS are both valuable methodologies used in agricultural research and development to evaluate and select crop varieties or technologies. However, tricot offers several advantages over PVS in certain contexts. For instance, tricot trials involve many farmers from diverse environments in technology or variety evaluations. The PVS approach engages a limited number of farmers, who might not accurately reflect the entire farming population. Tricot involves comparing only three options at a time (Van Etten et al., 2019), making it simpler and less time-consuming for farmers. The PVS often requires farmers to evaluate a larger number of varieties simultaneously (Witcombe et al., 2003), which can be more demanding and complex. The simplicity of evaluating only three options reduces the cognitive burden on farmers, leading to potentially more accurate and reliable assessments. Tricot's simplicity allows for participation from a larger number of farmers, enhancing the scalability of the study (Van Etten et al., 2019). This can lead to a more extensive and diverse dataset (Occelli et al., 2024), improving the statistical robustness of the results. With many farmers participating, tricot can aggregate data across a wide range of environments and conditions, providing a more comprehensive understanding of technology performance (De-Sousa et al., 2024). Tricot's method of pairwise comparisons among three options can generate a large amount of comparative data from relatively few trials. This is more efficient than PVS, where farmers may need to compare multiple varieties across many traits. The structured nature of tricot data (simple rankings) simplifies the analysis process, making it easier to derive meaningful insights from the collected data (Van-Etten et al., 2020). Tricot's less intensive approach requires less time and effort from farmers, potentially leading to higher participation rates and lower dropout rates compared to the more demanding PVS process. Tricot typically requires fewer resources in terms of time, personnel, and materials (Van Etten et al., 2019; De-Sousa et al., 2024) compared to the more extensive PVS trials. This makes it a cost-effective option for evaluating agricultural technologies.

4.5 Drawbacks/limitations of triadic comparison of technologies

While the tricot approach has many advantages, it also has drawbacks, which need to be managed:

Tricot focuses on simple rankings rather than in-depth evaluations, which can limit the granularity of the data collected

compared to PVS. For example, while PVS might gather 10–15 detailed trait evaluations per variety, tricot typically collects 2–3 comparative rankings per farmer.

Mitigation: Supplement tricot trials with targeted follow-up surveys or focus groups involving a subset of farmers to gather more detailed trait-specific data. This hybrid approach can balance scalability with depth.

Analyzing data from Tricot requires sophisticated statistical techniques, such as Bayesian models or rank-based aggregation techniques to interpret the rankings and pairwise comparisons (De-Sousa et al., 2023). This can be a barrier for organizations lacking expertise in these methods.

Mitigation: Provide training or access to statistical tools like ClimMob, which simplifies tricot data analysis. Partnering with research institutions or data analysis experts can also address this barrier. Combining data from 100 to 1,000 of farmers can introduce variability and complexity (De-Sousa et al., 2023).

Aggregating data from many farmers across many villages might result in inconsistencies due to differing local conditions.

Mitigation: Use stratified analysis to group data by environmental or socio-economic factors, ensuring comparisons are made within similar contexts.

Data cleaning protocols can also minimize errors or inconsistencies in farmer-reported rankings. Farmer's assessments may be influenced by factors such as recent experiences, local conditions at the time of evaluation, or social desirability, potentially skewing the results. For instance, farmers may rank a variety higher if they recently performed well under specific weather conditions.

Mitigation: Rotate the order of options presented to farmers to minimize bias. Incorporate environmental data (e.g., rainfall or soil conditions) to contextualize evaluations and identify potential biases.

The tricot method assumes that all participating farmers have a comparable level of expertise in evaluating technologies (Van Etten et al., 2019), which may not be the case, leading to variability in the quality of data collected.

Mitigation: Include basic training for participating farmers on evaluation criteria and techniques. Cross-validate farmer rankings with agronomic performance data collected by researchers to ensure consistency.

While tricot offers a streamlined, scalable approach to technology evaluation, these drawbacks highlight the need for careful design and implementation to mitigate potential issues.

4.6 Study limitations and future work

While the study provides valuable insights into farmers' preferences across regions and gender groups, certain limitations exist. The sample size and geographical coverage, although representative, may not capture all local variations in preferences. Moreover, the study focused primarily on farmer perceptions rather than quantitative measurements of trait performance under different agroecological conditions. Future studies should integrate participatory approaches with on-farm performance evaluations to

validate farmer-identified traits. Future research should also explore consumer preference dynamics, linking on-farm traits to downstream market and nutritional needs. Incorporating climate-resilience traits such as drought tolerance and heat stress adaptation into breeding pipelines will further enhance the relevance of new varieties in the face of changing climatic conditions. Although the study covered three zones, it was conducted over a single season; therefore, multi-season trials are recommended to confirm these findings and capture temporal variability.

5 Conclusion

The study reveals that although farmers across Tanzania consistently prioritize high yield, marketability and disease resistance, their trait preferences vary widely by region, gender and farming system. This variation highlights the need for breeding programs to develop targeted, context-specific product profiles rather than uniform varieties. A major contribution of this research is the identification of previously undocumented traits, notably, suitability for cooking with bananas and compatibility with intercropping systems as important drivers of variety choice. These traits, reported for the first time in Tanzania, reflect evolving farming realities shaped by climate change, land scarcity, dietary traditions, and labor demands. Their emergence highlights the need for breeding programs to integrate cultural and system-specific attributes alongside conventional agronomic traits.

The study also shows that varietal preferences are shaped by regional market dynamics, especially cross-border trade with Kenya, Malawi, Uganda, and Zambia, which drives demand for types such as NUA 64, NUA 48, Sweet Violet, and VTT923-23-10.

Additionally, gender-disaggregated findings reveal distinct priorities: women emphasize postharvest qualities, men focus on agronomic and market attributes, and youth prefer market-linked traits, underscoring the need for gender-responsive breeding and dissemination. Methodologically, the study demonstrates the strengths and limitations of the tricot approach relative to PVS, highlighting its scalability and simplicity but also the need for complementary methods to capture more detailed trait evaluations. Overall, the research provides actionable evidence for breeders, seed system actors, and policymakers. It demonstrates that future bean improvement efforts must go beyond yield-focused objectives to encompass socio-cultural preferences, intercropping needs, nutritional considerations, market integration, and gender inclusiveness. By embedding these multifaceted insights into breeding pipelines, Tanzania can accelerate the development and uptake of bean varieties that are agronomically robust, culturally relevant and economically rewarding, ultimately strengthening the resilience and livelihoods of smallholder farming communities.

Data availability statement

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

Ethics statement

The requirement of ethical approval was waived by the Institutional Review Board (IRB) of the Alliance of Bioversity International and CIAT for the studies involving humans because research is exempt from full review. The studies were conducted in accordance with the local legislation and institutional requirements.

Author contributions

EK: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Writing – original draft, Writing – review & editing. PV: Investigation, Methodology, Supervision, Validation, Visualization, Writing – review & editing. TA: Funding acquisition, Investigation, Resources, Supervision, Validation, Visualization, Writing – review & editing. JN: Supervision, Validation, Visualization, Writing – review & editing. SK: Data curation, Formal analysis, Methodology, Writing – review & editing. JO: Investigation, Validation, Visualization, Writing – review & editing. EN: Investigation, Methodology, Validation, Visualization, Writing – review & editing. JR: Funding acquisition, Resources, Validation, Visualization, Writing – review & editing. EM: Conceptualization, Investigation, Methodology, Supervision, Validation, Visualization, Writing – review & editing.

Funding

The author(s) declared that financial support was received for this work and/or its publication. This research was supported by a tricot PhD scholarship administered by Accelerated varietal improvement and seed delivery of legumes and cereals in Africa (AVISA), PABRA academy and 1000FARMS initiatives.

Acknowledgments

The authors would like to thank staff from the Nelson Mandela African Institution of Science, the Tanzania Agricultural Research Institute (TARI), and the Alliance of Bioversity International and the International Center for Tropical Agriculture (CIAT) for administration and technical support. Special thanks are extended to De Sousa Kaue from University of Inland Norway and “Digital Inclusion, Bioversity International, Montpellier France for trial design, Immaculate Chaula from the International Center for Tropical Agriculture (CIAT) for her technical support with data analysis. The authors thank Vincent Johnson (consultant) and Olga Spellman of the Alliance of Bioversity International and CIAT Science Editing Unit for copyediting of this manuscript.

Conflict of interest

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

Generative AI statement

The author(s) declared that Generative AI was not used in the creation of this manuscript.

Any alternative text (alt text) provided alongside figures in this article has been generated by Frontiers with the support of artificial

intelligence and reasonable efforts have been made to ensure accuracy, including review by the authors wherever possible. If you identify any issues, please contact us.

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.

References

- Assefa, T., Sperling, L., Dagne, B., Argaw, W., Tessema, D., and Beebe, S. (2014). Participatory plant breeding with traders and farmers for white pea bean in Ethiopia. *J. Agric. Educ. Ext.* 20, 497–512. doi: 10.1080/1389224X.2013.824385
- Atlin, G. N., Cooper, M., and Bjørnstad, Å. (2001). A comparison of formal and participatory breeding approaches using selection theory. *Euphytica* 122, 463–475. doi: 10.1023/A:1017557307800
- Birachi, E. A., Sperling, L., Kadege, E., Mdachi, M., Upendo, T., Radegunda, K., et al. (2020). Analysis of the yellow bean corridor in Tanzania. A feed the future global supporting seed systems for development activity (S34D) report. Baltimore, MD, USA: Catholic Relief Services (CRS).
- Bucheyeki, T. L., and Mmbaga, T. E. (2013). On-farm evaluation of beans varieties for adaptation and adoption in Kigoma region in Tanzania. *Int. Sch. Res. Notices* 2013:436064. doi: 10.1155/2013/436064
- Ceccarelli, S., and Grando, S. (2007). Decentralized-participatory plant breeding: an example of demand driven research. *Euphytica* 155, 349–360. doi: 10.1007/s10681-006-9336-8
- Conover, W. J. (1999). Practical nonparametric statistics. 3rd Edn. New York, USA: Wiley.
- De Boef, W. S., and Thijssen, M. H. (2007). Participatory tools working with crops, varieties and seeds: a guide for professionals applying participatory approaches in agrobiodiversity management, crop improvement and seed sector development. Wageningen, The Netherlands: Centre for Development Innovation.
- De-Sousa, K., Brown, D., Steinke, J., and Van-Etten, J. (2023). Gosset: an R package for analysis and synthesis of ranking data in agricultural experimentation. *SoftwareX* 22:101402. doi: 10.1016/j.softx.2023.101402
- De-Sousa, K., Van-Etten, J., Manners, R., Abidin, E., Abdulmalik, R. O., Abolore, B., et al. (2024). The tricot approach: an agile framework for decentralized on-farm testing supported by citizen science. A retrospective. *Agron. Sustain. Dev.* 44:8. doi: 10.1007/s13593-023-00937-1
- Food and Agricultural Organization. (2021). Crop production data. Available online at: <http://www.fao.org/faostat/en> (Accessed May 10, 2024).
- Geza, W., Ngidi, M., Ojo, T., Adetoro, A. A., Slotow, R., and Mabhaudhi, T. (2021). Youth participation in agriculture: a scoping review. *Sustainability* 13:9120. doi: 10.3390/su13169120
- Gliessman, S. R. (1992). Agroecology in the tropics: achieving a balance between land use and preservation. *Environ. Manag.* 16, 681–689. doi: 10.1007/BF02645658
- Katungi, E., Farrow, A., Chianu, J., and Beebe, S. (2009). Common bean in Eastern and Southern Africa: a situation and outlook analysis. Palmira, Colombia: International Centre for Tropical Agriculture. 61, 1–44.
- Letaa, E., Kabungo, C., Katungi, E., Ojara, M., and Ndunguru, A. (2015). Farm level adoption and spatial diffusion of improved common bean varieties in southern highlands of Tanzania. *Afr. Crop. Sci. J.* 23, 261–277.
- Luce, R. D. (1959). Individual choice behavior: a theoretical analysis. New York, NY: Courier Corporation.
- Mbiu, J. P., Susan Nchimbiá, M. N. W., and Rubyogo, J. C. (2020). Performance and adaptability of common bean genotypes at different agro-ecological environments in Kagera region. *J. Plant Breed. Crop Sci.* 12, 237–245.
- Mukankusi, C. M., Nkalubo, S., Katungi, E., Awio, B., Luyima, G., Radeny, M., et al. (2015). Participatory evaluation of common bean for drought and disease resilience traits in Uganda. No. 143. CCAFS working Paper. Copenhagen, Denmark: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).
- Nakazi, F., Njuki, J., Ugen, M. A., Aseete, P., Katungi, E., Birachi, E., et al. (2017). Is bean really a women's crop? Men and women's participation in bean production in Uganda. *Agric. Food Secur.* 6, 1–11. doi: 10.1186/s40066-017-0102-z
- 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. *Sustainability* 13:13164. doi: 10.3390/su132313164
- Ocellini, M., Sellare, J., Sousa, K. D., Dell'Acqua, M., Mercado, L., Paredes, S., et al. (2024). Group-based and citizen science on-farm variety selection approaches for bean growers in Central America. *Agric. Econ.* 55, 270–296. doi: 10.1111/agec.12819
- Ochieng, J., Abucheli Birachi, E., Kessy, R., Rubyogo, J. C., Odhiambo, W., Masimane, J., et al. (2023). Accelerated varietal turnover for open-pollinated crops (beans, sorghum, groundnuts) in Tanzania—seed sector stakeholders' landscaping. Baseline Report. Arusha, Tanzania: International Center for Tropical Agriculture (CIAT).
- Ochieng, J., Afari-Sefa, V., Muthoni, F., Kansime, M., Hoerschle-Zeledon, L., Bekunda, M., et al. (2022). Adoption of sustainable agricultural technologies for vegetable production in rural Tanzania: trade-offs, complementarities and diffusion. *Int. J. Agric. Sustain.* 20, 478–496. doi: 10.1080/14735903.2021.1943235
- Philipo, M., Ndakidemi, P. A., and Mbega, E. R. (2021). Environmentally stable common bean genotypes for production in different agro-ecological zones of Tanzania. *Heliyon* 7:e05973. doi: 10.1016/j.heliyon.2021.e05973
- Plackett, R. L. (1975). The analysis of permutations. *Appl. Stat.* 24, 193–202. doi: 10.2307/2346567
- R Core Team (2017). R: a language and environment for statistical computing. Vienna: R Foundation for Statistical Computing.
- Rowhani, P., Lobell, D. B., Linderman, M., and Ramankutty, N. (2011). Climate variability and crop production in Tanzania. *Agricultural and forest meteorology* 151, 449–460. doi: 10.1016/j.agrformet.2010.12.002
- Rubyogo, J.-C., Lungaho, M. G., Ochieng, J., Binagwa, P., Mdachi, M., Zakayo, E., et al. (2019). Consumer acceptance of and willingness to pay for high-iron beans in northern Tanzania. Nairobi, Kenya: International Center for Tropical Agriculture (CIAT) in collaboration with Tanzania Agricultural Research Institute (TARI).
- Schoonhoven, A. V., and Pastor Corrales, M. A. (1987). Standard system for the evaluation of bean germplasm. Cali: Centro Internacional de Agricultura Tropical.
- Sperling, L., Birachi, E., Kalemera, S., Mutua, M., Templer, N., Mukankusi, C., et al. (2021). The informal seed business: focus on yellow bean in Tanzania. *Sustainability* 13:8897. doi: 10.3390/su13168897
- Tigist, S. G., Melis, R., Sibiya, J., Amelework, B., and Keneni, G. (2020). Participatory variety selection of common bean (*Phaseolus vulgaris* L.) genotypes in the major bean producing areas of Ethiopia. *Aust. J. Crop. Sci.* 14, 1055–1063. doi: 10.21475/ajcs.20.14.07.p1924
- Turner, H., and Firth, D. (2012). Bradley Terry models in R: the Bradley Terry 2 package. *J. Stat. Softw.* 48, 1–21. doi: 10.18637/jss.v048.i09
- Van Etten, J., Beza, E., Calderer, L., Van Duijvendijk, K., Fadda, C., Fantahun, B., et al. (2019). First experiences with a novel farmer citizen science approach: crowdsourcing participatory variety selection through on-farm triadic comparisons of technologies (tricot). *Exp. Agric.* 55, 275–296. doi: 10.1017/S0014479716000739
- Van Etten, J., de Sousa, K., Aguilar, A., Barrios, M., Coto, A., Dell'Acqua, M., et al. (2017). Replication data for: crop variety management for climate adaptation supported by citizen science. Harvard Dataverse, 3. Cambridge, MA, USA. 10.7910/DVN/4ICF6W

- Vandermeer, J. H. (2011). *The ecology of agroecosystems*. Sudbury, MA: Jones & Bartlett Learning.
- Van-Etten, J., Manners, R., Steinke, J., Matthus, E., and De-Sousa, K. (2020). *The tricot approach. Guide for large-scale participatory experiments*. Rome: Alliance of Bioversity International and CIAT.
- Weltzien, E., Smith, M. E., Meitzner, L. S., and Sperling, L. (2003). *Technical and institutional issues in participatory plant breeding—from the perspective of formal plant breeding: a global analysis of issues, results, and current experience*. Cali, Colombia: CGIAR Systemwide Program on Participatory Research and Gender Analysis for Technology Development and Institutional Innovation and Centro Internacional de Agricultura Tropical (CIAT), 152.
- Witcombe, J. R., Joshi, A., and Goyal, S. N. (2003). Participatory plant breeding in maize: a case study from Gujarat, India. *Euphytica* 130, 413–422. doi: 10.1023/A:1023036730919
- Yates, F. (1936). A new method of arranging variety trials involving a large number of varieties. *J. Agric. Sci.* 26, 424–455. doi: 10.1017/S0021859600022760