

Full Length Research Paper

Reviving Lablab (*Lablab purpureus* (L.)) with agronomically superior, market-attractive accessions in northern Tanzania

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Lablab (*Lablab purpureus* (L.)) has substantial nutritional, agronomic, and cultural importance in Africa, yet remains largely underutilized. The study investigated the adaptation potential of 27 lablab accessions to northern Tanzania cropping systems through agronomic and consumer-preference screening. Early and late-season growth, relative maturity, pest susceptibility, grain yield, and consumer preference were evaluated in nine research station environments and eleven on-farm environments. Accession grain yield was highly variable; some accessions yielded almost 2000 kg ha⁻¹ in some environments while experiencing crop failure in others. Under drought, Q 6880B and HA-4 yielded 1185 and 585% higher than the average, owing to early flowering and avoidance of mid-season high temperatures and drought. Stability analysis identified DL1002 and Q 6880B as high yielders and most responsive to high-yield environments. PI195851 and Kola Black yielded poorly and were not responsive to better environments. Karamoja Red and Eldoret Black 2 yielded well on-farm and were preferred in sensory evaluations by most farm communities. Some communities preferred lower-yielding cream-colored accessions (ECHO Cream). Q 6880B was high-yielding but was not preferred due to its bitter taste. The study demonstrated lablab's potential as a drought-resilient crop and the necessity of integrating agronomic performance with consumer preference to drive wider adoption.

Key words: Cultivars, consumer preference, yield stability.

INTRODUCTION

Lablab grain and leaves have fed African families for millennia. Wild lablab originated on the African continent but may have been domesticated independently by African and Indian farmers (Maass, 2016). Subsequently, it has spread as a minor crop throughout the tropics. The Kikuyu ethnic group, in central Kenya, further assigns religious significance to the crop, which plays a key role in their

cultural rites (Robertson, 1997). Despite its historical and cultural significance, lablab cultivation diminished drastically through the colonial era (Maass et al., 2010; Robertson, 1997) and today is grown mostly in isolated pockets scattered throughout the continent. The main exception to this trend is central Kenya and northern Tanzania, where demand from Kikuyu consumers has

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sustained widespread production. Many lablab-producing areas are dry environments which do not have reliable rainfall for consistent *Phaseolus* bean production.

The crop is sometimes planted in association with maize, but in the driest regions, it is planted as a sole crop. In northern Tanzania, lablab grain is principally grown for sale and secondarily for consumption, and the green foliage, which continues to grow after grain harvest, is highly valued as human food and dry-season forage for livestock (Maass et al., 2010). The ability of lablab to survive extended periods of drought positions it as a key tool for adaptation to climate change. Increasingly erratic and unpredictable rainfall is the single greatest impact of climate change on small farmers in the tropics. In this context, a crop which can survive months of drought stress, then respond to unpredictable rainfall events with new growth and production, is a valuable tool in maintaining food security. Only a few studies have investigated lablab as both a food and forage crop in the context of African farming systems (Ewansiha et al., 2007; Nord et al., 2020; Whitbread et al., 2011). Maass et al. (2010) characterized lablab germplasm, while others have screened lablab cultivars as human food (Kankwatsa, 2018; Kimani, 2010; Nord et al., 2020; Wangila et al., 2021).

However, these studies did not evaluate diverse lablab germplasm in northern Tanzanian growing conditions or test the consumer preference of accessions in local communities. Significant challenges exist in developing lablab as a significant component in food security in localized contexts. First, the genetic identity of lablab cultivars being grown by African farmers is largely unknown. Prior to this study, Kenya was the only African country where varieties have been formally selected and registered, and despite its importance in the Kikuyu diet, the only widely planted certified seed is that of KAT/DL-1 (also known as DL-1002), a cultivar released in 1978 (KEPHIS, 2017). Only informal seed systems exist in Tanzania, despite lablab also representing a significant component of local diets. Therefore, screening global and local lablab germplasm for adaptability to Tanzania's environment and local agronomic practices is imperative for future breeding programs ushering in accession development.

A second challenge for lablab producers throughout the tropics is lablab's susceptibility to insect pests, especially at flowering and podding stages. Chief among these pests in northern Tanzania are lepidopteran larvae (e.g., *Maruca vitrata* Fabricius, *Helicoverpa armigera* Hubner, *Etiella zinckenella* Treitscke, etc.), commonly referred to as pod borers (Sharma, 1998). Pod borer predation can cause near-complete losses in grain yield and leads commercial producers in Tanzania to spray insecticides repeatedly beginning at flowering. Small-scale producers, who have less access to insecticides, often suffer substantial losses (Missanga et al., 2023). While some genotypic resistance to these pests has been found in cowpea and pigeon pea

(Kaoneka et al., 2016; Sharma, 1998), results with lablab have not been particularly encouraging (Chakravarthy and Lingappa, 1988), and very little research has been done among the genetically diverse collections of African accessions (Boit et al., 2018). Successful market development of lablab cultivars in local diets must consider consumer preference. While the Kenyan Kikuyu palate insists on black-seeded lablab, other consumers prefer milder-flavored cream and brown cultivars (Ewansiha et al., 2007). During the colonial era, consumer preference in many African communities swung largely to common bean (*Phaseolus vulgaris* L.) as traditional lablab recipes were largely lost, and because lablab takes longer to cook than common bean.

In response to these challenges, there is a large reserve of lablab genetic diversity to be utilized. World collections of lablab include over 3000 accessions with a broad range of geographic, morphological, and genetic characteristics (Maass et al., 2010); however, the genetic diversity of lablab cultivars grown on Kenyan farms was limited (Kimani, 2010). If this pattern holds true throughout Africa, selection and breeding could bring significant benefits to lablab producers across the continent and help uncover new tools for reducing food insecurity and environmental degradation in an era of climate uncertainty. This work builds and expands on the work presented by Nord et al. (2020), examining the performance and feasibility of diverse lablab accessions in partnership with local farmers and incorporating consumer preference. The objectives of this study were to test a diversity of lablab accessions under locally relevant agronomic management practices and investigate local adaptation of accessions through on-station and on-farm agronomic and consumer preference screening.

MATERIALS AND METHODS

Experiment locations

The on-station experiments were conducted at three sites during the 2016-2018 growing seasons in northern Tanzania, totaling nine environments (Tables 1 and 2). Baseline soil nitrogen was not measured due to seasonal fluctuations. Experiments were only conducted at the lowland TPRI environment in 2016 and 2017 and were replaced with the lowland NM-AIST site in 2018, since TPRI's hot and dry conditions resulted in very poor crop performance. On-farm trials were conducted in six (2018) and five (2019) agroecologically diverse communities in northern Tanzania (Table 3 and Figure 1). These communities were selected because they have a history of lablab production. Within each community, local extension agents were asked to select six farmers with experience growing lablab and an interest in participating in cultivar selection.

Genetic material

Twenty-seven unique lablab accessions were studied on-station. This included accessions from a core collection identified by Pengelly and Maass (2001), obtained from the International Livestock Research Institute in Addis Ababa (Table 4). Because some

Table 1. Experimental site locations, environment characteristics, and soil status conducted from 2016-2018 in North Tanzania.

Site name	Tanzania Research Institute	Coffee Research Institute	Tanzania Agricultural Research Institute Selian Centre	Tropical Pesticides Research Institute	Nelson Mandela Institute for Science and Technology
Site acronym	TACRI		TARI	TPRI	NM-AIST
Geo-coordinates	-3.242075, 37.251301		-3.365324, 36.633767	-3.431916, 37.451750	-3.528538, 36.838864
Years of study	2016-2018		2016-2018	2016-2017	2018
Agroecological zone	Highland		Mid-land	Lowland	Lowland
Mean temperature (°C) ^b	19.6		19.7	23.8	22.8
Altitude (MASL)	1287		1387	719	950
Rainfall (mm/year) ^b	1629 (bimodal)		890 (weakly bimodal)	541 (unimodal)	639 (unimodal)
Soil texture	clay loam		silt loam	clay loam	sandy loam

^aSituated on the lower slopes of Mt. Kilimanjaro, the weather at this site is typical of the Tanzanian highlands, despite its moderate altitude; ^bBased on 30-year Worldclim average.

Source: Fick and Hijmans (2017).

Table 2. Soil nutrient status of the experimental sites conducted between 2016 and 2018 in the Northern Zone of Tanzania.

Site	Depth (cm)					
	0-20	20-40	0-20	20-40	0-20	20-40
	Phosphorus (P) ^a (kg mg ⁻¹)		Potassium (K) ^b (kg mg ⁻¹)		pH ^c	
TACRI	14.6	5.1	343	265	4.8	5.1
TARI	8.7	12	-	-	6.7	6.9
TPRI	45.9	59.1	35.1	319	7.1	7.2
NM-AIST	11.9	6.0	-	-	7.4	7.5

^aBray P1 extraction (TACRI and TARI 0-20 cm) and Olsen-P extraction (TARI 20-40 cm, TPRI and NM-AIST); ^bAmmonium acetate extraction;

^cIn water 1:2.5.

Table 3. Sites and characteristics of on-farm trials of lablab accessions in 2018-2019 in northern Tanzania.

Site name	Mungushi	Hedaru	Mang'ola	Ilkiushin	Kondoa	Karatu
District location	Arumeru	Hedaru	Karatu	Arusha	Kondoa	Karatu
Years participating	2018	2018, 2019	2018, 2019	2018, 2019	2018, 2019	2018, 2019
GPS coordinates ^a	-3.528538, 36.838864	-4.483290, 37.890815	-3.499895, 35.435166	-3.287243, 36.575635	-4.695681, 35.871015	-3.288165, 35.798651
Number of farmer-investigators	5	6	6	5	6	7
Agroecological zone	Lowland	Lowland	Low-midland	Mid-land	Mid-land	Highland
Mean temperature (°C) ^b	22.6	23.0	21.7	18.7	21.6	19.7
Altitude (MASL)	900-1000	600-800	1100-1200	1300-1500	1400-1500	1500-1800
Rainfall (mm/year) ^b	638	658	550	815	738	799
Lablab production history (years)	25	15+	60+	15+	Many generations	30

^aLocation of each district. Actual trial locations were spread throughout each district; ^bBased on 30-year Worldclim average.

Source: Fick and Hijmans (2017).

accessions were added after the first year, and others were dropped due to poor performance, the number of accessions tested in each on-station experiment varied from 27 to 18 (NM-AIST 2018). Two registered cowpea varieties, recommended by the Tanzania Ministry of Agriculture, were included as a standard of comparison in all on-

station experiments because of the superior body of knowledge available for this species. Seven lablab accessions were chosen for on-farm trials based on their performance in the 2016-2017 on-station trials and were screened alongside one local accession provided by each farmer-investigator (denoted as 'Farmer Lablab').

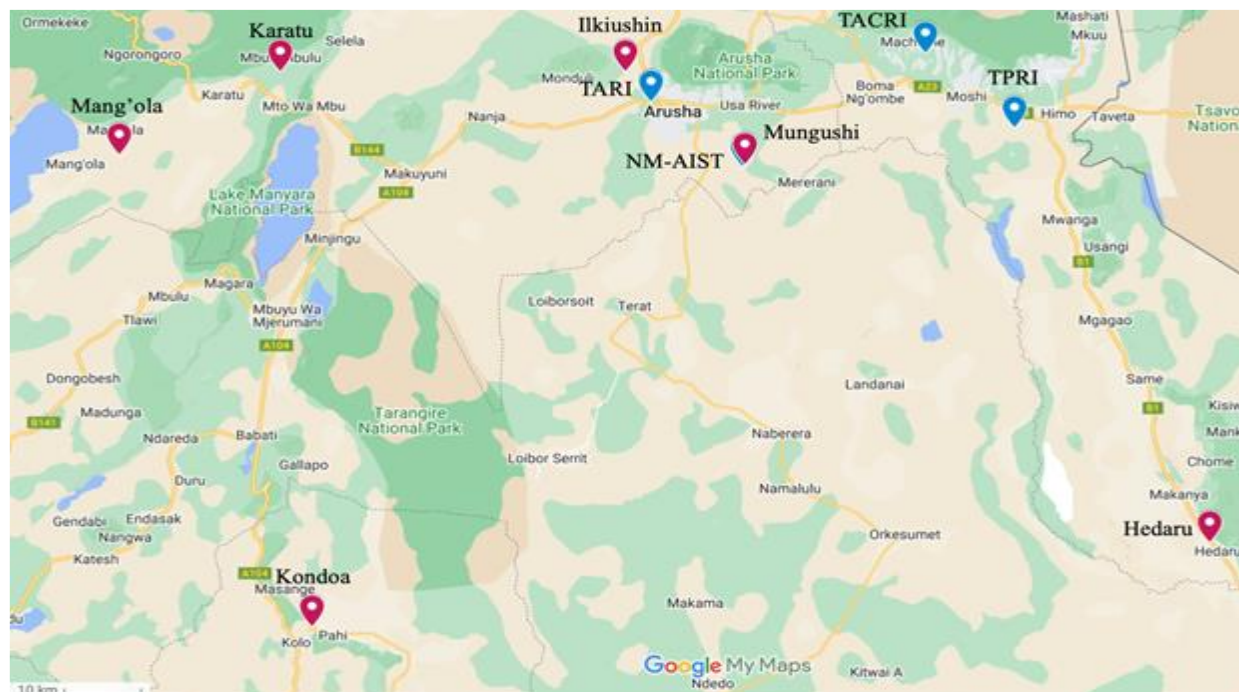


Figure 1. The geographic location of the on-station experimental locations (denoted in blue) and on-farm experimental locations (denoted in red) between 2016 and 2019.

Table 4. Lablab accessions and cowpea reference varieties evaluated in this study.

Name	Synonyms	Seed color	Origin	Tested in Africa (additional to Pengelly & Maass, 2001) or other notes
Part of core collection, RB2/Zw2 "Highworth" type				
Highworth ^a	ILRI 147, PI401553	Black	Kenya	Sennhenn et al. (2017), South Africa; Ewansiha et al. (2007), Nigeria; Nord et al. (2020), Tanzania
ILRI 6930	N-79062	Brown, red	-	Ewansiha et al. (2007), Nigeria ; Tefera (2006), Tanzania
ILRI 14411	K-68129	Brown, red	Taveta, Ethiopia	Tefera (2006), Tanzania
ILRI 14437	K-54224H	Black	Zimbabwe	Tefera (2006), Tanzania; Nord et al. (2020), Tanzania
ILRI 6536 ^b	A-51268	Dark brown	Ethiopia	-
Part of core collection, RB2/Zw3 "Rongai" type				
Rongai ^a	ILRI 21037	Tan	Kenya	Sennhenn et al. (2017), South Africa; Gitari et al. (2011), Kenya; Nord et al. (2020), Tanzania
ILRI 10979	CPI-29398, IRFL-770, PI-316574	White	-	-
ILRI 11630	N-69002	Brown, red	Mali	-
ILRI 13700	PGRC-211423	black	Gondar, Ethiopia	Tefera (2006), Tanzania; Nord et al. (2020), Tanzania

Table 4. Contd.

Registered varieties in Kenya				
DL1001		Brown	Kenya	Nord et al. (2020), Tanzania
DL1002 ^b		Black	Machakos, Kenya	Nord et al. (2020), Tanzania
Eldoret Maridadi	B1, ELDO-KT Maridadi	Brown-speckled	Kenya	-
Eldoret Black 2 ^b	G1, ELDO-KT Black 2	Black	Kenya	-
Eldoret Cream	M5, ELDO-KT Cream	Red-brown	Kenya	-
Registered Variety in India				
HA-4		Tan	India	Non-vining
Accessions from the forage agronomy program of CIAT				
CIAT 22759		Black	Eldoret, Kenya	Nord et al. (2020), Tanzania
Q 6880B ^b		Black	Brazil	Sennhenn et al. (2017), South Africa; Kankwatsa and Muzira (2018), Uganda; Grotelüschen (2014), Kenya; Nord et al. (2020), Tanzania
Unregistered accessions maintained and distributed by TARI				
TARI Chungu		Black	Tanzania	
TARI Nyeupe		White	Tanzania	Nord et al. (2020), Tanzania
TARI Rongai		Black	Tanzania	Nord et al. (2020), Tanzania
Landraces collected from Tanzania, Kenya, and Uganda				
Dodoma White ^b		White	Kondoa, Tanzania	
ECHO Cream ^b		White	Tanzania	Nord et al. (2020), Tanzania
Karamoja Red ^b		Red	Kotido, Uganda	Nord et al. (2020), Tanzania
Karatu black		Black	Karatu, Tanzania	
Kola black		Black	Kola, Kenya	
Other lablab varieties of interest				
PI 195851	ILRI18605	Dark brown mottled	Egypt	Ewansiha et al. (2007), Nigeria ; Nord et al. (2020), Tanzania
CPI 81364		Brown	USA	Sennhenn et al. (2017), South Africa; Grotelüschen (2014), Kenya
Cowpea reference varieties				
Fadhari cowpea		Red-brown	Tanzania	
Vuli 2 cowpea		Red-brown	Tanzania	

^aRegistered variety in Australia (ACIAR, 2020); ^bAccessions chosen to be tested on-farm.

Experimental design and trial management

On-station experiments

Experiments at the TARI, TPRI, and NM-AIST environments

were randomized complete block designs with strips of eight (TARI), seven (TPRI), or six (NM-AIST) sole-cropped experimental units. Lablab accessions were randomized within these strips and replicated three times at all sites. Plots were 4.5 m by 5.4 m with 1.5 m unplanted borders

between plots within each strip. TACRI experiments were 4.5 m by 5 m with 1.4 m unplanted borders between plots and 2 m alleys between plot ends.

Lablab accessions were seeded in rows 0.9 m apart, with hills of lablab 0.5 m apart within rows and two seeds

per hill. Cowpea spacing was 0.45 and 0.5 m (cv. Fadhari) or 0.25 m (cv. Vuli 2) within rows. No fertilizer was applied in planting holes. At the TACRI site, lablab was planted with rows 0.7 m apart and 0.6 m within rows, with two seeds per hill. Lablab planting dates at TPRI in 2016 and 2017 were April 14 and March 14, respectively. The NM-AIST environment planting date was March 23, 2018. At TARI, the planting dates in 2016, 2017, and 2018 were March 23, March 20, and March 26, respectively. The planting dates at TACRI in 2016, 2017, and 2018 were May 10, June 16, and May 12, respectively.

Fields were tilled with a disc plow in 2016 but planted without tillage in 2017 and 2018. Weed control was achieved using a pre-plant glyphosate application (2.5 L ha^{-1}) at planting and by hand-hoe control throughout the growing season as needed. Insect pests, including aphids (*Aphis craccivora*), pod flower/pod borers (*M. vitrata*, *H. armigera*, *E. zinckenella*), and pod-sucking insects (*Riptortus pedestris*, *Clavigralla tomentosicollis*), were monitored closely beginning at the flowering stage. Insecticides were applied when populations reached damaging levels, and sites were sprayed two to four times per season, rotating modes of action (cypermethrin and chlorpyrifos) to reduce the potential for resistance development. The TACRI site was sprayed for insects two, three, and four times in 2016, 2017, and 2018, respectively. TARI was sprayed four, four, and two times in 2016, 2017, and 2018, respectively, and TPRI and NM-AIST were sprayed three, four, and four times in 2016, 2017, and 2018, respectively.

On-farm experiments

On-farm experiments were randomized, non-replicated sole-cropped experimental units that were 3 m by 3 m with a 1 m unplanted border. Farmer-investigators were provided with seed as well as technical support throughout the growing season. No fertilizer was applied, in keeping with typical practice in the area. Farmer-investigators were supplied with Duduall 450EC (Cypermethrin 150 g L^{-1} + Chlorpyrifos 300 g L^{-1}) for insect pest control, which was applied at their discretion.

Data collection

Meteorological data

Rainfall data for the TARI site was provided by the Arusha Airport weather station 1.4 km away, while TACRI, TPRI, and NM-AIST rainfall measurements were obtained from rain gauges located on site. Mean monthly temperatures were collected from Climatic Research Unit gridded Time Series (CRU) data (Harris et al., 2020) in R using package “terra” (Hijmans, 2025) and reported for the main growing season (January to September). Thirty-year average temperature and precipitation data were retrieved from the WorldClim 2 dataset at a 1 km resolution (Fick and Hijmans, 2017).

Biophysical and insect data

On-station: Days to flowering were evaluated by estimating when 50% of plants in each experimental unit were flowering by counting 20 plants on a 10 to 14-day schedule. Due to the vining nature of lablab, among later-maturing accessions, individual plants were difficult to separate and distinguish and therefore problematic to evaluate flowering percentage. Therefore, in 2018, counting frames with 0.9 m x 0.5 m cells were placed over each experimental unit, and flowering was counted per cell rather than per plant. This method resulted in more consistent counts. Days to 50% flowering were recorded at all environments in every year. Live lablab plant soil cover was measured in experimental units at TARI in 2016 and

2017 and TPRI in 2016 and 2017. Early-season live plant soil cover was taken between 40-60 days after planting by using two 4 m transects in each experimental unit and counting plants every 10 cm along each transect. Late-season soil cover was recorded 184 to 228 days after planting at all sites using digital photographs taken from a 3 m height above each experimental unit.

A standardized rating scale was developed using photographs of experimental units with a range of 0 to 90% live plant cover (as measured along two 4 m transects). The standardized rating scale was then compared visually with photographs of each experimental unit to rate live plant soil cover of other plots. Late-season plant survival was recorded at TARI in 2016 and 2017, TPRI in 2016, and TACRI in 2018 by counting the number of live lablab plants at the end of the growing seasons. Aphid, pod borer, and pod-sucking bug populations were rated separately. Aphid rating occurred during lablab reproductive stages seven times at TARI and TACRI in 2017. For pod-borers and pod-sucking insects, ten inflorescences were selected at random from each experimental unit and tapped eight times on the inside of a 10 L plastic bucket (Forsythe, 2019). Care was taken to prevent flying insects from escaping before recording the type and number of insects collected. To minimize differences due to flowering dates, the maximum count during the season was used. Aphid rating was conducted by counting 10 random inflorescences in each experimental unit and calculating the percentage of inflorescences with aphid colonies. Lablab and cow, pea harvest began as soon as dried pods were present on the earliest-maturing plots from two 3 m rows and was repeated on a roughly monthly schedule with 3-5 harvest dates depending on the location and year. Dry pod weight was recorded at each harvest date, and pods from all harvest dates were combined for threshing and were used for determining overall yield.

On-Farm: Lablab pods were hand-harvested and stored by farmer-cooperators when matured. Harvested samples were then weighed by researchers. A 500 g subsample was taken from each experimental unit, and transported to TARI for threshing, sorting, and weighing each year.

Consumer preference

The seven lablab accessions plus the local farmer-supplied accessions that were tested in the on-farm experiments were also tested for consumer preference. Consumer rating of lablab accessions took place in the same locations as the on-farm experiments: Hedaru (7 participants), Ilkiushin (11 participants), Karatu (11 participants), Kondoa (11 participants), Mang'ola (12 participants), and Mungushi (14 participants), for a total of 67 participants. The participants were farmers and ranged from 13 to 75 years old, with female and male participants from 11 different regional tribes. Grain for testing was sorted to remove shriveled and weevil-damaged seed, and 200 g of each lablab accession was soaked overnight in 1 liter of fresh water. After soaking, accessions were washed and cooked in 1 liter of fresh water with one teaspoon of salt until the grains were soft (Grotelüschen, 2014). Cooking time for each variety was recorded, as well as perceived uniformity of cooking. Cooking water was discarded, and each accession was placed in a serving container with moderate heat and just enough water to keep them from scorching. Accessions were completely randomized and assigned a letter for identification.

Participants received instructions and a rating sheet and were instructed not to discuss or indicate their preferences with each other until after the rating session. During rating of each parameter, each participant began with a different accession. Participants were asked to rate the accessions for appearance, taste, smell, texture, market acceptability (dry grain), and overall rating. To rate appearance, panelists first viewed each accession, then returned to their starting

place and rated successive accessions on a five-point hedonic scale indicating their intensity of preference or non-preference (Shivachi et al., 2012). Panelists next rated smell using a similar procedure (smelling all accessions first, then returning to their starting place for rating). Panelists took a sample of about one teaspoon of cooked grain for evaluation of taste and texture of each accession. After every tasting, they rated the accession, then rinsed their mouth with water and cleaned the teaspoon. Panelists were allowed to return to re-taste any accession for confirmation of their initial rating. Dry grain samples were presented, and panelists rated the dry grain for marketplace acceptability using the same procedure for cooked appearance. Panelists reviewed their ratings of individual parameters, including appearance, smell, taste, texture, marketability, and overall general perception. A sample evaluation form is in the supplementary material.

Data analysis

Analysis of variance

Each environment (location-year) combination for the on-station trials was considered unique, totaling nine "environments." Cowpea yields were not included in the statistical analysis among cultivars. Data were compiled and subjected to Analysis of Variance (ANOVA) in R software with the R package "lme4" (Bates et al., 2015). Lablab accession was considered a fixed effect, and environment and block were considered random effects. Data were shown to be normally distributed by examining QQ plots, and homogeneity of variance was verified using Levene's test. Aphid susceptibility was not subjected to ANOVA because the data could not be transformed to fit the homogeneity of variance assumptions for ANOVA analysis.

Environments were separated for individual analysis if an accession by environment interaction was significant ($P > F 0.05$). Individual accession performance LSmeans were separated using the LSD method. Experimental units of accessions were not replicated on each farm, and therefore farmer was considered the block to analyze on-farm accession data. Each environment (location-year) was considered unique, totaling 11 environments. Accession was considered the fixed effect, and replicate (environment) and environment were considered random effects. A two-way analysis of variance was conducted using PROC MIXED in SAS Software 9.4 (SAS, 2013). Data heterogeneity of residuals was evaluated using PROC Univariate in SAS, with Shapiro-Wilk values greater than 0.9 considered normally distributed. To analyze overall preference of accessions across all environments and evaluate if different locations preferred different accessions, farmers were used as replicates in the two-way ANOVA. Accession was a fixed effect, and replicate (environment) and environment were random effects, and the analysis was conducted using the same statistical procedures as on-farm yield data.

Yield stability analysis

Yield stability of lablab accessions for on-station and on-farm data was evaluated using the Finlay-Wilkinson (F-W) (Finlay and Wilkinson, 1963) and Eberhart-Russell (E-R) (Eberhart and Russell, 1966) models. Least-squares means (lsmeans) that were generated in the ANOVA procedures for each accession and environments were used. The accession lsmeans were plotted against the environmental mean, and a regression line was then fit to each accession's yield performance at each environment. The slope of the regression line (named linear regression coefficients or b_i) was then plotted against the aggregated mean from all environments of each accession. The accession was the fixed effect, and the environment was the random effect. The E-R model using the deviation from regression value (S^2d_i) that indicates the 'spread' of the data points

away from the original regression line created. Using both models, a stable accession would have $b_i = 1.0$ and $S^2d_i = 0$ and fall within one standard error of mean yield and regression coefficient/deviation from regression value.

RESULTS

On-station evaluation

Environmental conditions

Precipitation at the lowland sites (TPRI and NM-AIST) was approximately half the annual average of 600 mm in all three years (Supplementary Figure S1). Below-normal precipitation combined with relatively high mean temperatures led to significant plant stress, especially during the reproductive stages of the later-maturing lablab cultivars. In 2016, the TPRI site received 231 mm of rainfall in the 11 days immediately following planting, but thereafter, rain fell only once over the following eight months. The mid-altitude TARI site received more total rainfall and a generally broader distribution of rain through the growing season in 2017 and 2018 (Supplementary Figure S2). However, in 2016, the site received only 124 mm of precipitation two months after planting, and extremely little for the subsequent eight months. In 2018, precipitation was excessive at TARI following planting, leading to 65% lablab mortality. The experiment was replanted but never fully recovered. The highland site at TACRI received significantly more rainfall than the other locations, and distribution was far more uniform throughout the year (Supplementary Figure S3). Planting was intentionally delayed at TACRI until after April and May to avoid the heaviest rains, which typically hinder lablab performance.

Accession screening

Growth: Early and late-season living plant soil cover was monitored at TARI and TPRI in 2016 and 2017 only. Early soil cover was heavily influenced by moisture availability. Overall, early-season live soil cover differed among accessions and ranged from 38 (CPI 81364) to 64% (TARI Rongai). No significant accession by environment interaction was detected, indicating that accessions' relative early soil cover was not influenced by environment (Table 5 and Supplementary Table 1). Accessions TARI Chungu, TARI Rongai, and Karamoja Red provided the most soil cover (64, 62, and 60%, respectively) early in the season, while CPI 8136, PI 1958, and ILRI 1163 covered the least (38, 43, and 44%, respectively). Lablab accessions averaged from 15 (Eldoret Black) to 37% (ILRI 6536) across all environments (Table 5; Supplementary Table 2). There was no significant accession by environment interaction. ILRI 6536 and Rongai demonstrated the most late live plant soil cover across environments.

Table 5. P-values of performance parameters among 28 lablab accessions tested in Northern Tanzania between 2016 and 2018.

Variable	Early soil cover ^{a,c}	Late soil cover ^{b,c}	Late-season survival ^d	Maturity ^b	Pod-sucking insects ^e	Pod-boring insects ^e	Aphid ^e	Yield
Accession (A)	<0.0001	<0.0001	<0.0001	<0.0001	0.08	0.0017	-	<0.0001
Environment (E)	<0.0001	<0.0001	<0.0001	<0.0001	-	-	-	<0.0001
A × E	0.1256	0.0807	0.9234	<0.0001	-	-	-	0.0369

^aAssessed in sole-cropped lablab, only; ^bTACRI environment removed; ^cTARI 2016 & 2017, and TPRI 2016 & 2017, only; ^dTARI 2016 & 2017, TPRI 2016, and TACRI 2018, only; ^eTARI and TACRI 2017 only.

Accessions differed significantly for late-season survivability (Table 5). Late-season survival was greatest at TARI in 2016 and lowest at TARI in 2017, but accessions' relative survivability did not differ by growing environment (Table 5). The accessions Q6880B, ILRI 6536, and ECHO Cream had the greatest survivability across environments (26, 24 and 20%, respectively; Supplementary Table 3). The accessions Karamoja Red, ILRI 13700, and TARI Rongai (4, 4 and 5%, respectively) demonstrated the poorest survivability across environments. Days to 50% flowering varied by 33 days between the earliest flowering environments (TARI and TPRI in 2016) and the latest flowering environment (TACRI in 2018) (Table 6). Lablab accession days to 50% flowering varied from 64 (HA-4) to 102 days (TARI Nyeupe) (Table 6), with a significant interaction ($P < 0.001$) between accession and environment (Table 5). This interaction is complicated by the fact that some accessions did not reach 50% flowering due to extreme heat and moisture stress. For example, 15 accessions did not reach 50% flowering at TPRI in 2017.

Insect susceptibility: Susceptibility to aphid predation ranged from 0 to 5%. The data could not be analyzed statistically due to a lack of normality in the dataset; however, it was observed that Eldoret Maridadi, Karatu Black, and ILRI 13700 demonstrated the greatest aphid incidence in both environments (Supplementary Table 4). Pod-sucking bug incidence ranged from 3 to 27 insects per 10 inflorescences, but no statistically significant differences among accessions were observed (Table 5). Accessions varied significantly in pod-borer incidence (Table 5), ranging from 0.16 (Rongai) to 3.6 (HA-4) insects per 10 inflorescences (Figure 2). DL1002 also had high pod-borer incidence, and other accessions, such as Karatu Black, PI 196851, Dodoma White, DL 1001, ECHO Cream, and Rongai, had very low pod-borer presence. Pod-boring incidence was very low among cowpea reference checks.

Grain yield: Lablab grain yields among environments and within environments were highly variable (Table 7). The highest yield environments were TARI 2017 (1002 kg ha⁻¹) followed by TARI 2018 (619 kg ha⁻¹). The most challenging environments were TPRI 2016 (32 kg ha⁻¹)

and 2017 (28 kg ha⁻¹). Lablab accession mean grain yields varied from 101 (PI 195851) to 732 kg ha⁻¹ (Q 6880B) and were heavily influenced by environment (Table 5). HA-4 and CIAT 22759 yielded 43% and 381% higher than the average yield of all other accessions at TPRI 2016. At the other drought-stricken environment, TPRI 2017, Q 6880B and HA-4 yielded 1185 and 585% higher than the average accession, respectively. Fourteen and twenty accessions yielded less than 10 kg ha⁻¹ at TPRI 2016 and 2017, respectively. At the highest yielding environment, TARI 2017, DL1002 had the greatest yield (1996 kg ha⁻¹), and the lowest yielding accession was PI 195851 (132 kg ha⁻¹).

Stability analysis: Across nine environments, the Finlay-Wilkinson yield stability model was used to visually assess lablab accessions' performance and response to poor and favourable growing conditions (Figure 3, Table 8). Most accessions fell inside the 'average yield and average stability' section of the visual model (Figure 3). DL1002, TARI Rongai, Q 6880B, TARI Chungu, and Eldoret Black 2 fell above the standard error of mean yield and therefore were the top performers in the on-station experiments. DL1002, TARI Chungu, and SARI Rongai were the most responsive to favourable environments, but also the least 'stable'. Q 6880B and Eldoret Black 2 demonstrated high yield and average stability indicating that these accessions had consistently high performance. PI195851, Kola Black and Karatu Black fell one standard error below the average overall yield and average stability, and interpreted as the lowest yielding accessions and the least responsive to favourable environments. Both cowpea cultivars demonstrated average stability, Fadhari cowpea demonstrated high yield compared to most lablab accessions. Most accessions fell within one standard error above and below the average deviation from regression value (Figure 4), indicating that most accessions followed a similar pattern of performance variability across multiple environments. ILRI 10979, Dodoma White, Karamoja Red, Dodoma White, ECHO Cream, and TARI Nyeupe had the greatest extremes of poor and good performance across environments. The two cowpea cultivars (Vuli 2 and Fadhari) had the largest deviations from regression value, and therefore the cowpea cultivars in this study had greater yield variability across environments than lablab

Table 6. Days to 50% flowering of 27 lablab accessions and two cowpea varieties across nine environments in northern Tanzania from 2016-2018.

Accession (A)	Mean	TARI 2016	TACRI 2016	TPRI 2016	TARI 2017	TACRI 2017	TPRI 2017	TARI 2018	TACRI 2018	NM-AIST 2018
Days to 50% flowering										
CIAT 22759	81	64	89	67	98	87	.	73	101	73
CPI 81364	72	61	83	49	88	92	70	73	99	53
DL1001	95	91	93	98	98	91	-	93	106	88
DL1002	74	62	79	59	86	77	83	75	93	58
Dodoma white	98	82	101	.	106	90	-	87	106	106
ECHO cream	94	69	97	108	105	90	-	84	102	94
Eldoret black 2	77	61	81	59	97	81	82	76	100	58
Eldoret cream	81	63	96	58	80	86	87	78	102	-
EldoretMaridadi	83	66	90	57	106	94	-	74	107	-
HA-4	64	52	80	-	67	72	60	58	86	42
Highworth	75	59	89	53	83	72	73	73	106	60
ILRI 10979	83	61	86	56	105	81	79	80	110	-
ILRI 11630	100	81	100	103	113	96	-	84	117	-
ILRI 13700	87	72	98	70	98	86	91	77	105	-
ILRI 14411	87	65	95	66	110	92	-	83	105	-
ILRI 14437	81	67	89	69	83	83	82	77	106	75
ILRI 6536	92	79	93	86	105	87	-	90	103	85
ILRI 6930	82	66	96	68	96	85	-	73	106	72
Karamoja red	80	63	-	64	108	-	81	75	100	69
Karatu black	88	73	102	66	109	93	-	79	111	76
Kola black	101	119	115	77	98	99	-	82	118	-
PI 195851	102	119	113	85	109	99	-	78	117	96
Q 6880B	71	56	92	.	79	89	51	70	108	41
Rongai	93	82	91	95	102	89	.	87	101	91
TARI Chungu	84	64	92	66	98	75	95	71	101	-
TARI Nyeupe	102	86	106	.	118	100	-	86	114	-
TARI Rongai	81	63	92	67	86	86	-	83	104	73
Mean	84	72	94	72	97	87	78	78	105	72
CV (%)	4	6	4	6	9	5	4	4	5	9
LSD	4	9	9	9	17	10	7	7	13	13
Accession	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.015
Fadhari cowpea ^b	64	61	106	69	64	90	65	73	102	54
Vuli 2 cowpea ^b	62	61	102	66	64	89	60	70	98	53

***Between-accession $P < 0.0001$. ^bCowpea cultivars were not included in the ANOVA.

Source: Author

(Figure 4).

On-farm evaluation

Environmental conditions

Precipitation at all on-farm sites in 2018 and 2019 followed the typical pattern for northern Tanzania with most of the

rain falling early in the growing season followed by little or no rain during lablab reproductive stages (Supplementary Figures S4 and S5). Mungushi and Ilkiushin experienced exceptionally high 2018 precipitation with Ilkiushin receiving over half its annual average in the month of April. Hedaru and Mang'ola in both years and Kondoa in 2019 received less than 125 mm precipitation in each season. Mang'ola received the majority of growing season precipitation in April 2018 and 2019 and in the following

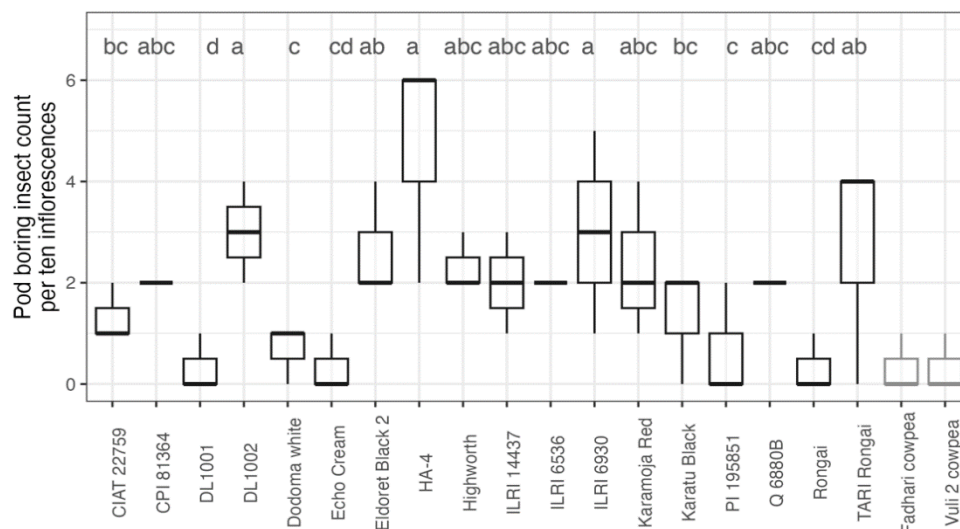


Figure 2. Pod-borer insect presence per ten inflorescences sampled in NM-AIST 2018 (center of box line is median, upper and lower box lines are first and third quartiles, points are outliers). Where letters are the same there was not a significant difference in yield within that environment ($P=0.05$).

four months recorded 0 mm, and 6 mm, respectively.

Accession screening

Grain yield: Seven lablab accessions identified through the on-station experiments were tested on farmers' fields in 2018 and 2019. On-farm lablab grain yields exceeded on-station yields with seven of 11 environments averaging over 1000 kg ha⁻¹ and three environments averaging over 1500 kg ha⁻¹ (Table 9). The lowest yields occurred in environments with low rainfall or late onset rain (Hedaru, 2018; Ilkiushin and Kondoa, 2019). Three cultivars, Eldoret Black 2, Karamoja Red and Q 6880B were consistently high yielding, performing among the top four accessions in 11 environments. Farmer-supplied accessions (Farmer lablab) yielded in the top four of the cultivar rankings in four of the environments. Over all environments, farmer lablab ranked sixth, indicating that the introduced accessions have the potential to significantly increase small-farmer lablab yields (Table 10).

Stability analysis: When the on-farm evaluations of accessions were subjected to the Finlay-Wilkinson model, Karamoja Red, Q 6880B and Eldoret Black 2 produced higher grain yields than the other accessions and demonstrated average responsiveness to favourable growing conditions (Table 10 and Supplementary Figure 6), but according to the Eberhart-Russell model, Eldoret Black 2 and Q 6880B were more stable and adapted to northern Tanzania farm management (Supplementary Figure 7). Karamoja Red had greater variability and therefore less reliable performance (as shown when comparing the accession's grain yield between Mang'ola 2019 and Kondoa 2019). Interpretation of yield stability

using the Finlay-Wilkinson and Eberhart-Russell models must consider that the Farmer Lablab accessions were unique to each farmer's field in each environment, giving them a presumed advantage in fitness. Overall, Farmer Lablab accessions' yield performances were more stable than ILRI16536 and Karamoja Red but were more variable than DL1002 and Eldoret Black 2.

Consumer preference ratings: An accession by community interaction was observed for appearance, smell, taste, texture, and marketability (Supplementary Table S5) suggesting that these traits were valued differently by different communities. For appearance, consumers generally preferred lighter-colored white (Dodoma White and ECHO Cream) and red (Karamoja Red) accessions. One exception was Kondoa, where ECHO Cream was rated highly, but Dodoma White was not. For smell, most communities rated Q 6880B poorly, compared to other accessions. However, Hedaru rated ILRI 6536 very poorly and Eldoret Black 2 highly. Most communities rated Karamoja Red highly for smell. Q 6880B was strongly disliked for taste at most sites, and participants commented on its strong bitter flavor. Ilkiushin rated Q 6880B very highly for taste, however. The exceptions to these trends were the extremely high rating of black-seeded Eldoret Black 2 in Mungushi and Q 6880B in Ilkiushin and Kondoa. For texture, Karamoja Red rated highly in most communities; Eldoret Black 2 was also rated very highly in Mungushi. Q 6880B was rated lowest for texture in most communities. The lowest overall marketability rating was assigned to Dodoma White in all but the Kondoa community.

Overall cultivar preference by participants (Figure 5) was consistent among communities with significant differences between accessions ($P<0.001$).

Table 7. Combined grain yield means and analysis of variance comparing 27 lablab accessions and two reference cowpea varieties across nine environments in Northern Tanzania from 2016-2018.

Accession	Mean Yield	TARI 2016	TACRI 2016	TPRI 2016	TARI 2017	TACRI 2017	TPRI 2017	TARI 2018	TACRI 2018	NMAIST 2018
kg ha⁻¹										
CIAT 22759	523	397	541	154	1652	706	37	535	436	251
CPI 81364	224	115	160	2	640	321	6	548	145	83
DL1001	428	289	238	4	1360	444	0	486	907	123
DL1002	688	728	666	22	1996	541	9	1023	632	580
Dodoma white	584	365	799	2	1198	1421	0	790	638	41
ECHO cream	549	525	1070	5	842	1034	1	852	594	20
Eldoret black 2	620	359	603	109	1270	990	21	857	732	635
Eldoret cream	377	375	219	7	955	414	15	666	367	-
Eldoret Maridadi	288	317	133	3	941	418	0	340	154	-
HA-4	317	266	113	171	800	94	192	584	169	462
Highworth	389	844	101	12	692	423	84	609	535	196
ILRI 10979	427	181	19	0	567	1260	7	674	710	-
ILRI 11630	404	76	477	45	603	617	0	393	1023	-
ILRI 13700	224	135	60	20	789	97	9	481	202	-
ILRI 14411	225	80	35	14	434	391	1	303	544	-
ILRI 14437	494	472	478	5	1662	243	5	489	746	345
ILRI 6536	458	152	749	28	1099	397	0	524	985	187
ILRI 6930	311	318	366	79	860	169	2	395	421	189
Karamoja red	601	1059	-	8	1474	-	13	631	501	520
Karatu black	283	522	153	3	744	65	0	756	63	242
Kola black	153	92	10	2	426	296	0	286	114	-
PI 195851	110	132	117	0	132	209	0	198	115	90
Q 6880B	732	1031	658	26	1378	1040	360	741	631	725
Rongai	428	328	363	19	1289	502	0	842	451	58
TARI Chungu	648	598	903	30	1239	448	2	959	1002	-
TARI Nyeupe	447	433	892	9	383	838	0	743	278	-
TARI Rongai	637	401	932	105	1645	628	4	1024	705	292
Mean value	437	392	429	38	996	548	28	280	620	512
CV (%)	66	50	69	159	35	44	115	40	39	42
LSD	398	609	122	719	485	64	64	229	496	443
Accession P>F ^{a,b}	<0.0001	<0.0001	0.004	0.071	<0.0001	<0.0001	<0.0001	<0.0001	0.069	<0.0001
Fadhari cowpea ^b	658	499	123	144	1812	121	1221	682	830	486
Vuli2 cowpea ^b	523	237	46	250	1957	94	268	866	747	239

^aMeans are considered significantly different at (>0.05). ^bCowpea cultivars were not included in the ANOVA.

Source: Author

Participants rated five accessions at 3.5 or higher, confirming their taste and/or marketability ratings. Q 6880B rated the lowest.

DISCUSSION

On-station

Accession growth as influenced by environments

Early-season soil cover was significantly impacted by

drought conditions. Similar slow early growth due to drought was reported by Mugi-Ngenga et al. (2023), who observed a significant reduction in plant height due to drought in lablab in northern Tanzania. Q 6880B, DL1001, and DL1002 had the greatest early soil cover under drought conditions at TARI 2016, possibly signifying early-season drought tolerance. Greater late-season soil cover did not necessarily correlate with the highest yields. For example, ILRI 6536, Rongai, and TARI Nyeupe were good to average yielders at TARI 2017 but had low late-season soil cover. Therefore, greater late-season soil cover was

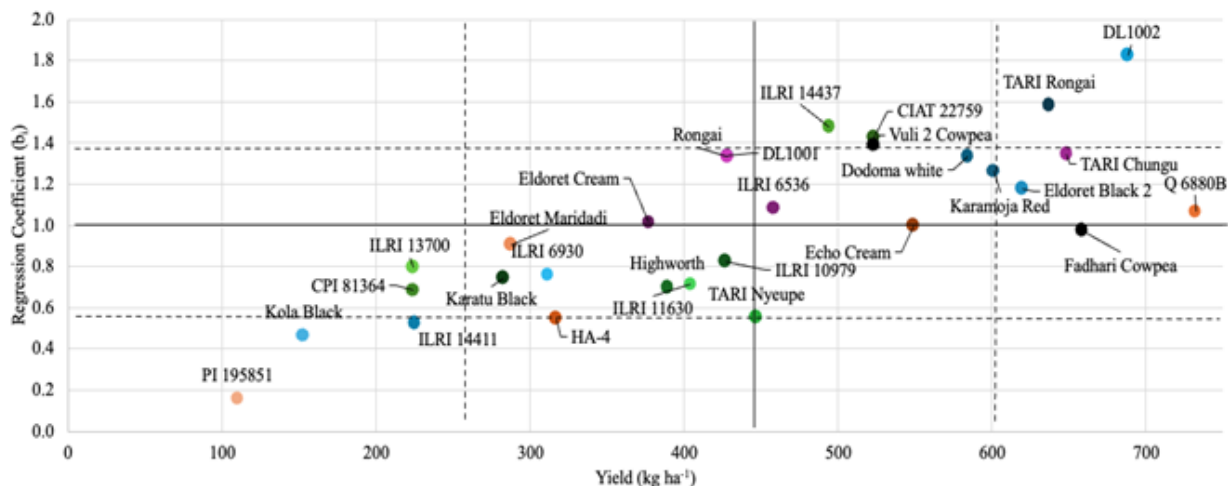


Figure 3. Finlay-Wilkinson yield stability model of 27 lablab accessions tested in nine environments between 2016-2018 in Northern Tanzania. The vertical line represents the mean yield of all accessions across nine environments, and the horizontal line represents the mean regression coefficient. The dotted lines are one standard error above and below the regression coefficient and mean yield.

more indicative of biomass production and plant survival, not seed production. The cowpea reference crops demonstrated very poor late-season live soil cover due to their determinate growth habits. Lablab's deep rooting system allows for effective drought recovery (Mugi-Ngenga et al., 2023), as demonstrated in this study at TARI (2017). Lablab's superior late-season soil cover is valuable for multiple reasons. Many farmers consume lablab leaves as a food source (Letting et al., 2022) and as fodder for livestock (Minde et al., 2021; Forsythe, 2019; Njarui et al., 2004).

Additionally, longer-season soil cover is beneficial for soil shading, moisture conservation, and reducing soil erosion (Kariaga, 2004; Zougmore et al., 2000; Ewansiha et al., 2017). Many accessions remained alive well beyond the rating date, and following a 9 mm rainfall at TARI 2016, plants even produced an additional grain harvest equivalent to 18% of the total season's grain yield. The ability to survive periods of drought, yet take advantage of unseasonable rainfall, positions lablab as an effective resilience tool for adapting to the climate uncertainty of today's tropical farming environments (Grotelüschen, 2014). Others have reported genotypic variability in drought tolerance among lablab accessions (Robotham and Chapman, 2017). Similarly, the findings of this study demonstrate that some lablab accessions cover soils more quickly and persist later into the dry season, thus providing the potential for selection of cultivars that cover and protect soils most effectively.

Insect susceptibility

Similar to this study, the accession HA-4 was also identified as susceptible to pod-borer predation by Rashmi

et al. (2020) in India. Boit et al. (2018) reported that pod damage and fewer days to 50% flowering were positively correlated, and results agree. HA-4 and DL1002, two accessions with high pod-borer incidence, flowered earlier than most accessions, particularly in NM-AIST 2018 (Table 6). Earlier flowering may have made them a target for pod-borers due to a lack of other flowering accessions. Karimi et al. (2024) found evidence of increased attractiveness of some lablab accessions to aphid colonization. Although statistical analysis of aphid data proved problematic, observations support the idea that the potential for lablab genetic resistance or non-preference to aphids is high and should be investigated further. Pod-sucking insect levels in this study were similar to other values in the literature in India (Prasad et al., 2011). Even if pod-sucking insects are a major challenge for Tanzanian farmers (Letting et al., 2022), research on pod-sucking insects is lacking for Eastern Africa.

Cultural methods such as intercropping (Missanga et al., 2023), breeding for resistance (Boit et al., 2018), and maintenance of habitats that encourage predator populations (Ochieng et al., 2022) are integral parts of an integrated pest management system. A combination of these approaches could provide adequate control of reproductive-stage insects to assure economically viable lablab production (Karimi et al., 2024). To this end, there is a need to develop economic thresholds to guide the prudent use of insecticides.

Grain yield stability and adaptability on-station and on-farm

Lablab grain yield performance was extremely variable and heavily influenced by environment. Karamoja Red,

Table 8. Mean yield stability and adaptation values as expressed by Finlay and Wilkinson (1963) regression coefficient (b_i) and Eberhart and Russell (1966) deviation from regression (S^2d_i).

Accession	Mean yield (kg ha ⁻¹)	b_i	S^2d_i
CIAT 22759	523	1.4	30942
CPI 81364	224	0.7	9146
DL1001	428	1.3	33847
DL1002	688	1.8	30262
Dodoma white	584	1.3	118425
Echo cream	549	1.0	114641
Eldoret black 2	620	1.2	35451
Eldoret cream	377	1.0	7255
Eldoret Maridadi	288	0.9	13529
HA-4	317	0.5	35715
Highworth	389	0.7	49940
ILRI 10979	427	0.8	153923
ILRI 11630	404	0.7	89286
ILRI 13700	224	0.8	12027
ILRI 14411	225	0.5	23916
ILRI 14437	494	1.5	45242
ILRI 6536	458	1.1	62892
ILRI 6930	311	0.8	9145
Karamoja red	601	1.3	145734
Karatu black	283	0.7	48726
Kola black	153	0.5	5617
PI 195851	110	0.2	3400
Q 6880B	732	1.1	54345
Rongai	428	1.3	7264
TARI Chungu	648	1.3	66321
TARI Nyeupe	447	0.6	115386
TARI Rongai	637	1.6	28397
Mean value	437	1.0	50028
Standard error	169	0.39	44549
Fadhari cowpea [†]	658	0.974865	263050
Vuli2 cowpea	523	1.39045	207453

[†]Cowpea cultivars added as a reference crop.

DL1002, TARI Chungu, Q 6880B, Eldoret Black 2, and TARI Rongai demonstrated comparably high, stable yield and were most responsive to better management and growing conditions in on-station trials. Karamoja Red, Eldoret Black 2, Q 6880B, and DL1002 was confirmed through on-farm trials to be well adapted and responsive to local farmer production methods and environments. At all on-farm environments, introduced lablab accessions (especially the early-mid season accessions Karamoja Red, Eldoret Black 2, and Q 6880B) were more productive than the local accessions (Farmer Lablab), which demonstrates the opportunity to increase lablab yields with the introduction of new genetics. In the driest environments, the early-maturing accessions clearly performed the best. At TPRI 2017, yield and days to 50%

flowering were significantly negatively related (Corr = -0.6; $P = 0.005$).

The highest-yielding accessions at TPRI 2016, Q 6880B, HA-4, and CIAT22759, were 63, 57, and 78 days to 50% flowering, respectively. These accessions matured approximately 24 to 39 days earlier than the latest-maturing accession (Kola Black), possibly escaping the mid-season drought and high temperatures during flowering. The use of early-maturing accessions to escape mid-season drought and high temperatures has also been recognized by Sennhenn et al. (2017) and Missanga et al. (2023), and this results support such a strategy for extremely dry environments. Q 6880B has unique potential since it is both early flowering and indeterminate and persistent and could be the focus of future breeding efforts

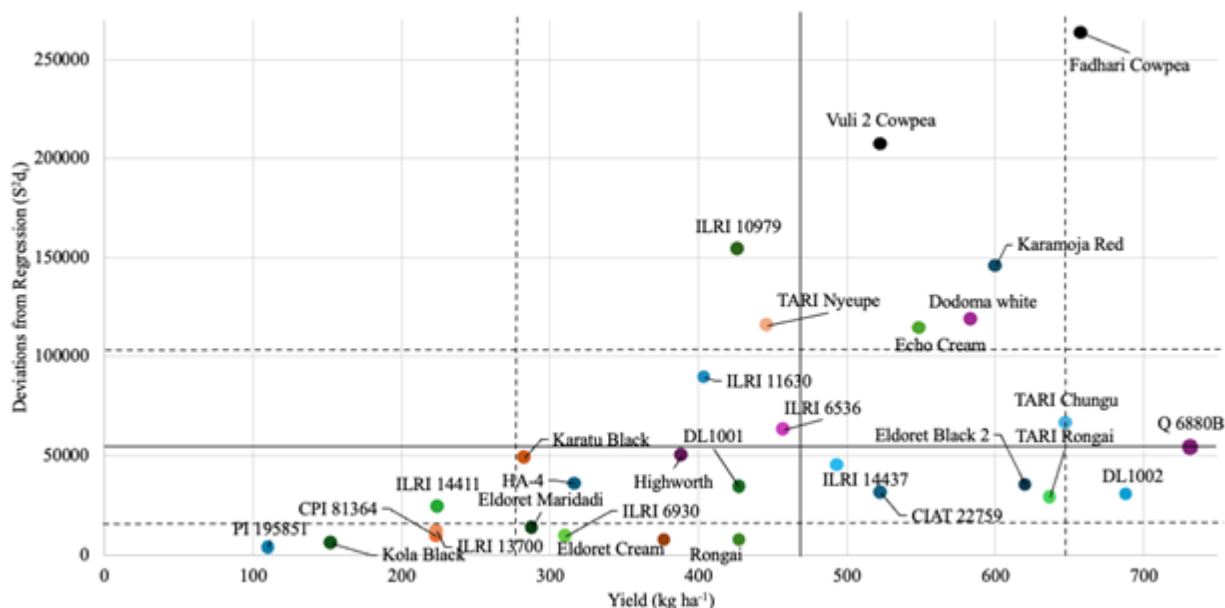


Figure 4. Eberhart-Russel yield stability model of 27 lablab accessions tested in nine environments between 2016-2018 in Northern Tanzania. The vertical line represents the mean yield of all accessions across 10 environments, and the horizontal line represents the deviations from the regression line of each accession. The dotted lines are one standard error above and below the deviations from the regression line and mean yield.

Table 9. On-Farm lablab grain yields from 11 environments in Northern Tanzania.

Accession	Hedaru		Ilkiushin		Karatu		Kondoa		Mang'ola		Mungushi
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018
kg ha⁻¹											
Eldoret Black 2	937	1749	1768	690	1165	1458	1713	619	1822	2356	1181
Karamoja Red	392	2154	928	858	1504	1365	1460	521	1861	2686	1513
Q 6880B	996	1946	2128	563	1208	1735	1229	399	1262	2179	1267
DL1002	143	1452	1912	365	874	1236	1453	409	1737	2175	1209
ILRI6536	355	1573	1953	521	608	1128	2012	415	478	2475	1003
Farmer Lablab	686	977	1300	497	497	1311	1447	172	1254	1428	1754
Dodoma White	112	280	1436	144	371	976	1711	279	433	1502	1683
ECHO Cream	218	759	1483	103	566	1105	1022	202	584	1464	824.4
Env. Mean	480	1361	1614	468	849	1289	1506	377	1179	2033	1304
Acc. $P>F^a$	0.440	0.143	0.972	0.052	0.023	0.766	0.929	0.036	0.113	0.011	0.317
CV(%) ^b	144	70	75	70	64	54	85	63	74	17	50
SE $\pm$	386	386	546	386	345	315	315	315	386	445	345
Accession (A) $P>F$	<0.0001										
Environment (E) $P>F$	0.003										
A x E $P>F$	0.009										

^a Analysis of variance considered significant at the $P>F$ 0.05 level; ^b Coefficient of variation.

if its taste can be improved. The latest-maturing accessions tended to yield poorly overall. For example, at TARI 2017, the top performers were DL1002, ILRI14437,

and CIAT22759, with days to 50% flowering of 71, 78, and 78, respectively. In fact, the latest-flowering accessions, Kola Black and PI195851, were the poorest-yielding

Table 10. Mean yield stability and adaptation values as expressed by Finlay and Wilkinson (1963) regression coefficient (b_i) and Eberhart and Russell (1966) deviation from regression (s^2d_i).

Accession	Mean Yield kg ha ⁻¹	b_i	s^2d_i
Eldoret black 2	1405	0.94	52885
Karamoja red	1386	1.03	278119
Q 6880B	1356	0.94	109873
DL1002	1178	1.14	63794
ILRI6536	1138	1.2	154720
Farmer Lablab	1029	0.87	111254
Dodoma white	812	1.0	237719
Echo cream	757	0.81	37059
Mean	1132	1.0	130678
SE $\pm$	116	0.22	87728
$P>F^a$	<.0001		

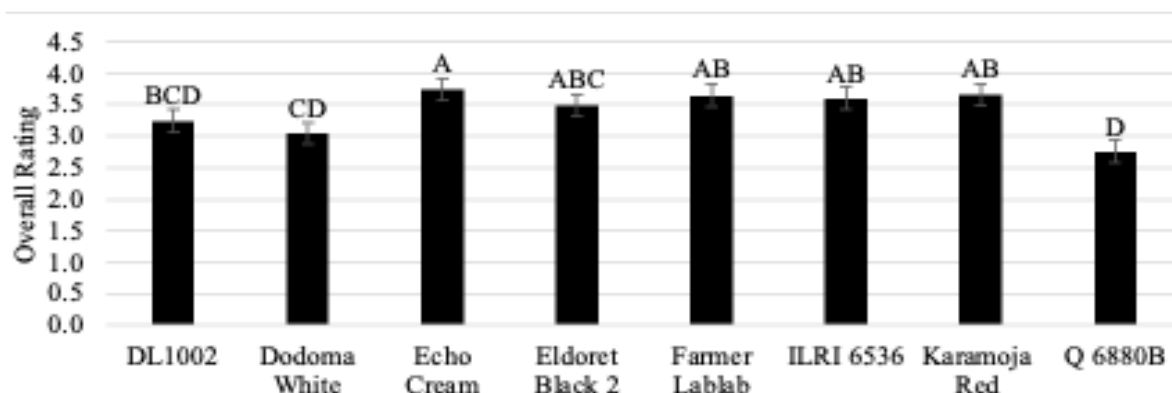


Figure 5. Overall rating of seven lablab accessions when considering appearance, smell, texture, taste, and marketability to local markets among seven communities ($n=67$) in northern Tanzania. Means are significant different at ($P>0.05$) when column letters are different. Rating was based on a 1-5 scale; 1-least favourable, 5-most favourable.

accessions at TARI 2017. One anomaly is Dodoma White, which had similar days to flowering as PI195851 but yielded very well (1,198 kg ha⁻¹). Dodoma White is a Tanzanian landrace accession and may have other traits that enabled higher yields. Later-maturing accessions tested in this study may have been generally too late for northern Tanzania for grain production but may be better suited to forage production (Nord et al., 2020).

Comparison to commonly grown legume, cowpea

The remarkable drought resilience of lablab was illustrated clearly by these experiments, particularly at the TARI location where many lablab plots remained productive after six months with minimal rainfall. Once established, lablab plants were able to survive extreme drought, clearly

superior to cowpea. In situations of extreme early drought, however, such as that experienced at TPRI, lablab plants were not able to establish, and their ability to produce was compromised. In these conditions, the drought-avoidant cowpea cultivars out-produced all the lablab accessions tested.

Consumer preference

Sensory preferences differed among communities depending on the attribute. Consumers generally liked lighter-colored beans, a phenomenon encountered in most African communities due to their lower tannin content. The greatest exceptions to these general trends were the extremely high rating of black-seeded Eldoret Black 2 in Mungushi and Q 6880B in the communities of Ilkiushen

and Kondoa. The latter is particularly surprising since the Kondoa community has grown and consumed white-seeded lablab cultivars for many generations. Two dark-seeded accessions (Eldoret Black 2 and ILRI 6536) and the farmer's seed (mostly black-seeded) were among the highest-rated overall. This observation aligns with the fact that the predominant market for Tanzanian-grown lablab is the Kikuyu community in Kenya, where, in contrast to most communities in Africa, black-seeded cultivars are preferred. Exceptions to this trend included lower ratings for Eldoret Black 2 in Ilkiushen and Kondoa and for the farmer's seed in Karatu. The lowest overall preference rating was assigned to Dodoma White, except for the Kondoa community, where consumers historically prefer white-seeded cultivars. Q 6880B, a stable, responsive, high grain yielder, was not desired by all communities due to its bitter flavor. While it may be beneficial as parental material in a breeding program for its high, stable yield, day-neutral, early flowering characteristic, Q 6880B is not recommended as an accession to be adopted by farmers for grain production in northern Tanzania.

Conclusion

The high yield and stable performance of Q 6880B, DL1002, and HA-4 from the on-station experiments were attributed to short days to flowering and early-season soil cover. On-farm testing revealed that Karamoja Red, Eldoret Black 2, and Q 6880B yielded consistently better compared to local farmer-sourced lablab accessions. While agronomic factors are critical, consumer preference plays an equally vital role in the successful adoption of new cultivars. In northern Tanzania, where consumers are attracted to lighter-seeded cultivars, local consumption preferences differ from those demanded by the Kikuyu export market. While Q 6880B yielded well under diverse environmental conditions, its bitter taste, undesirable texture, and dark appearance resulted in poor preference ratings among the communities consulted in this study. The registration of the lablab accessions Karamoja Red and Eldoret Black 2 (named NMD19 and NMD20, respectively) provides a pathway for improved lablab cultivation in northern Tanzania (Gazeti, 2022). Further research into cooking characteristics, post-harvest processing, and sustainable pest management strategies will be crucial in enhancing lablab's role in food security and economic development amidst climate change challenges.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Reviving Lablab (*Lablab purpureus* (L.)) with agronomically superior, market-attractive accessions in northern Tanzania.

Supplemental Figures and Tables

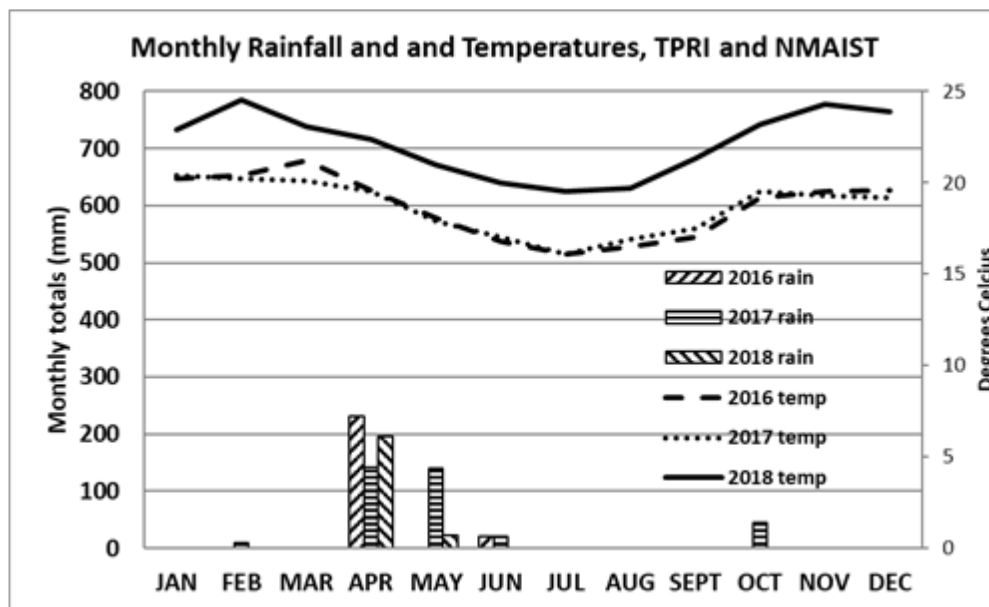


Figure S1. Monthly rainfall and temperatures at TPRI 2016 and 2017 and NM-AIST 2018.

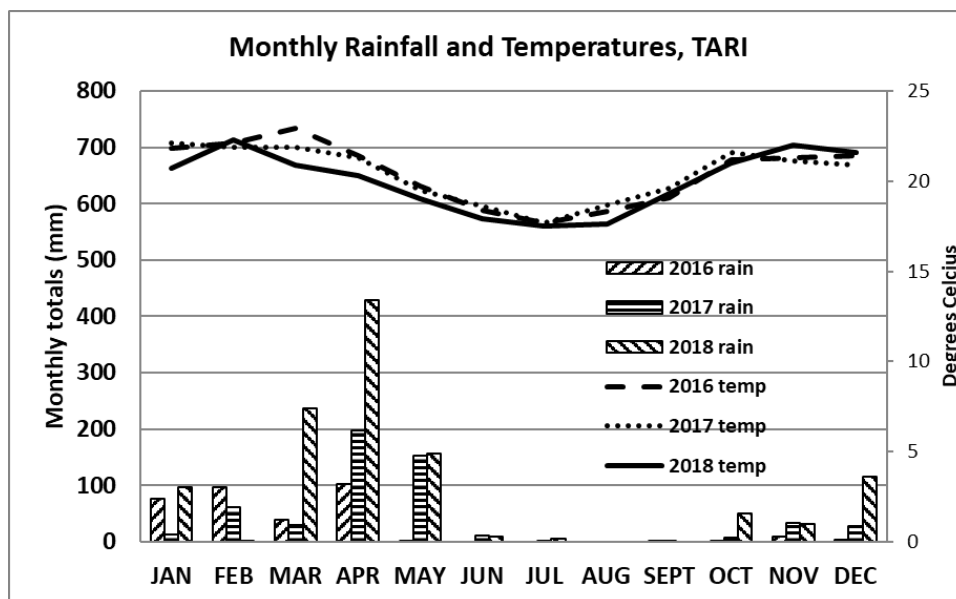


Figure S2. Monthly rainfall and temperatures at the TARI environment between 2016-2018.

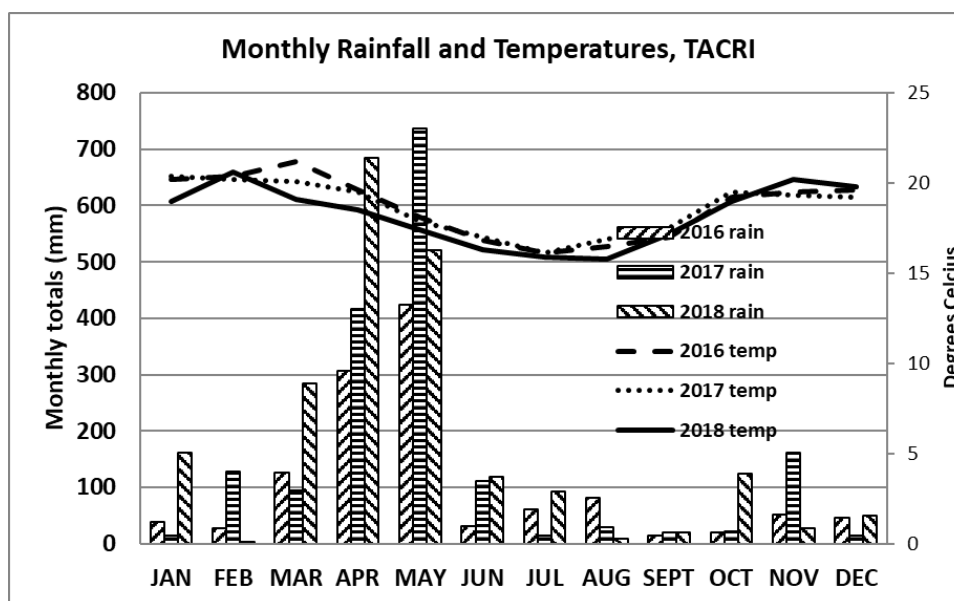


Figure S3. Monthly rainfall and temperatures at the TACRI location between 2016-2017.

Table S1. Combined early season soil cover means and analysis of variance comparing 26 lablab accessions and 2 reference cowpea varieties across four environments in Northern Tanzania from 2016-2017.

Accession (A)	Mean	TARI 2016	TPRI 2016	TARI 2017	TPRI 2017
	Soil cover (%)				
CIAT 22759	56	79	62	8	74
CPI 81364	38	71	15	7	61
DL1001	46	72	49	13	51
DL1002	57	77	72	13	66
Dodoma white	56	64	57	13	89
Echo Cream	53	69	51	7	84
Eldoret Black 2	54	74	55	8	80
Eldoret Cream	58	74	64	10	84
Eldoret Maridadi	48	68	44	5	75
HA-4	55	66	50	15	89
Highworth	49	71	48	8	68
ILRI 10979	45	67	44	5	63
ILRI 11630	44	61	39	7	69
ILRI 13700	54	79	61	7	69
ILRI 14411	51	82	52	8	62
ILRI 14437	49	67	46	12	70
ILRI 6536	48	65	36	12	79
ILRI 6930	48	74	53	7	61
Karamoja Red	60	86	59	7	89
Karatu Black	55	78	58	8	77
Kola Black	58	89	54	7	82
PI 195851	43	70	46	5	52
Q 6880B	55	69	66	17	70
Rongai	53	72	43	12	84
TARI Chungu	62	85	74	8	82
TARI Nyeupe	54	85	62	5	65

Table S1. Contd.

TARI Rongai	64	85	70	13	86
Mean Value	52	74	53	9	73
CV (%)	20	10	17	42	13
LSD	16	16	18	8	20
Accession $P > F^{a,b}$	0.04	0.046	0.6912	0.112	0.002
Fadhari Cowpea ^b	71	88	69	55	71
Vuli 2 Cowpea ^b	78	83	93	43	91

a: Means are considered significantly different at (>0.05)

b: Cowpea cultivars were not included in the ANOVA

Table S2. Combined late season soil cover means and analysis of variance comparing 26 lablab accessions and 2 reference cowpea varieties across four environments in Northern Tanzania from 2016-2017.

Accession (A)	Mean	TARI 2016	TPRI 2016	TARI 2017	TPRI 2017
	Soil Cover (%)				
CIAT 22759	21	32	8	20	25
CPI 81364	27	60	2	17	30
DL1001	23	37	15	23	18
DL1002	18	25	3	28	17
Dodoma white	17	27	10	15	17
Echo Cream	24	38	8	23	27
Eldoret Black 2	15	38	3	5	13
Eldoret Cream	20	32	8	10	30
Eldoret Maridadi	20	38	8	12	20
HA-4	16	30	2	15	18
Highworth	20	33	2	23	23
ILRI 10979	22	43	5	14	27
ILRI 11630	18	40	8	17	8
ILRI 13700	19	47	7	8	15
ILRI 14411	16	33	7	8	15
ILRI 14437	19	38	5	20	13
ILRI 6536	37	62	8	47	30
ILRI 6930	23	58	7	7	22
Karamoja Red	17	37	7	10	16
Karatu Black	20	40	7	20	14
Kola Black	23	53	5	15	20
PI 195851	29	80	3	15	17
Q 6880B	16	25	3	22	13
Rongai	35	60	10	42	28
TARI Chungu	17	33	7	12	15
TARI Nyeupe	22	47	5	27	10
TARI Rongai	15	18	5	17	22
Mean Value	22	41	6	18	19
CV (%)	44	38	63	59	48
LSD	0.06	0.03	0.16	0.15	0.15
Accession P>F ^{a,b}	<.0001	<.0001	<.0001	<.0001	0.156
Fadhari Cowpea ^b	4	10	0	2.5	3
Vuli 2 Cowpea ^b	0	0.25	0	0	0

a: Means are considered significantly different at (>0.05)

b: Cowpea cultivars were not included in the ANOVA

Table S3. Combined survivability means and analysis of variance comparing 27 lablab accessions and 2 reference cowpea varieties across four environments in Northern Tanzania from 2016-2017.

Accession (A)	Mean	TARI 2016	TPRI 2016	TARI 2017	TPRI 2017
Soil Cover (%)					
CIAT 22759	13	9	9	11	21
CPI 81364	5	3	9	5	2
DL1001	12	14	12	10	14
DL1002	15	31	13	17	4
Dodoma white	10	17	2	7	15
Echo Cream	20	38	7	7	31
Eldoret Black 2	12	33	7	9	5
Eldoret Cream	10	5	25	5	4
Eldoret Maridadi	9	16	6	7	8
HA-4	9	9	9	15	2
Highworth	16	21	25	9	13
ILRI 10979	11	8	8	4	23
ILRI 11630	11	12	7	7	20
ILRI 13700	4	2	7	7	0
ILRI 14411	18	35	9	6	29
ILRI 14437	12	20	14	9	9
ILRI 6536	24	54	18	14	19
ILRI 6930	8	19	9	2	4
Karamoja Red	4	7	4	1	5
Karatu Black	8	22	7	5	3
Kola Black	13	38	4	9	11
PI 195851	10	19	8	2	15
Q 6880B	26	19	16	39	27
Rongai	18	46	11	11	11
TARI Chungu	10	17	11	6	7
TARI Nyeupe	19	44	7	14	17
TARI Rongai	5	8	1	8	3
Mean Value	20	21	9.7	9	11
CV (%)	71	48	75	87	71
LSD	9	29	15	16	17
Accession P>F ^{a,b}	<.0001	0.051	0.256	0.099	0.01
Fadhari Cowpea ^b	2.3	0	0	0	8.6
Vuli 2 Cowpea ^b	0	0	0	0	0

a: Means are considered significantly different at (>0.05)

b: Cowpea cultivars were not included in the ANOVA

Table S4. Aphid susceptibility, as measured by % positive aphid presence per 10 plants at TARI and TACRI 2017 combined.

Accession (A)	%
CIAT 22759	0
CPI 81364	0
DL1001	0
DL1002	0
Dodoma white	0
Echo Cream	0
Eldoret Black 2	0.17
Eldoret Cream	0
Eldoret Maridadi	5
HA-4	0
Highworth	0.17
ILRI 10979	0
ILRI 11630	0
ILRI 13700	3.33
ILRI 14411	2.17
ILRI 14437	0
ILRI 6536	0
ILRI 6930	0
Karatu Black	4
Kola Black	2.17
PI 195851	0
Q 6880B	0.17
Rongai	0
TARI Chungu	0
TARI Nyeupe	0
TARI Rongai	0.17
CIAT 22759	0

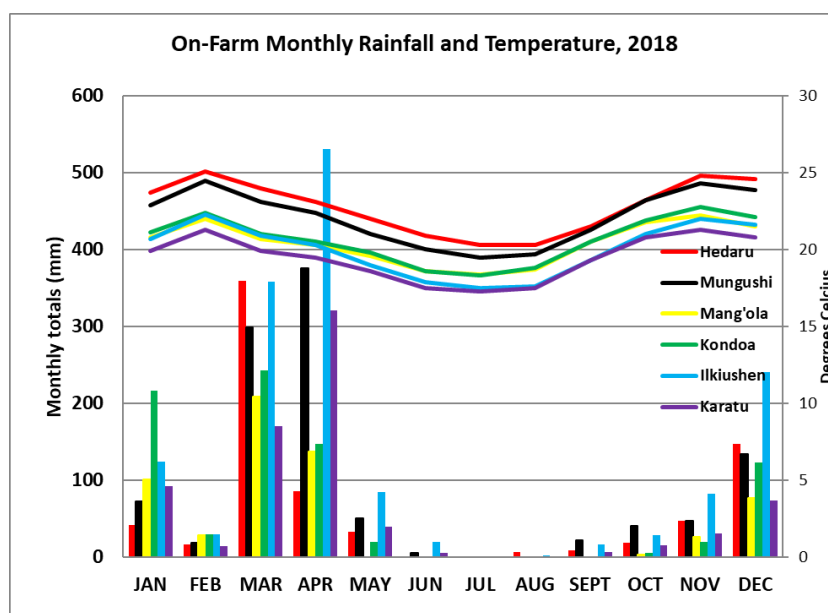


Figure S4. Monthly rainfall and temperatures at the on-farm environments in 2018

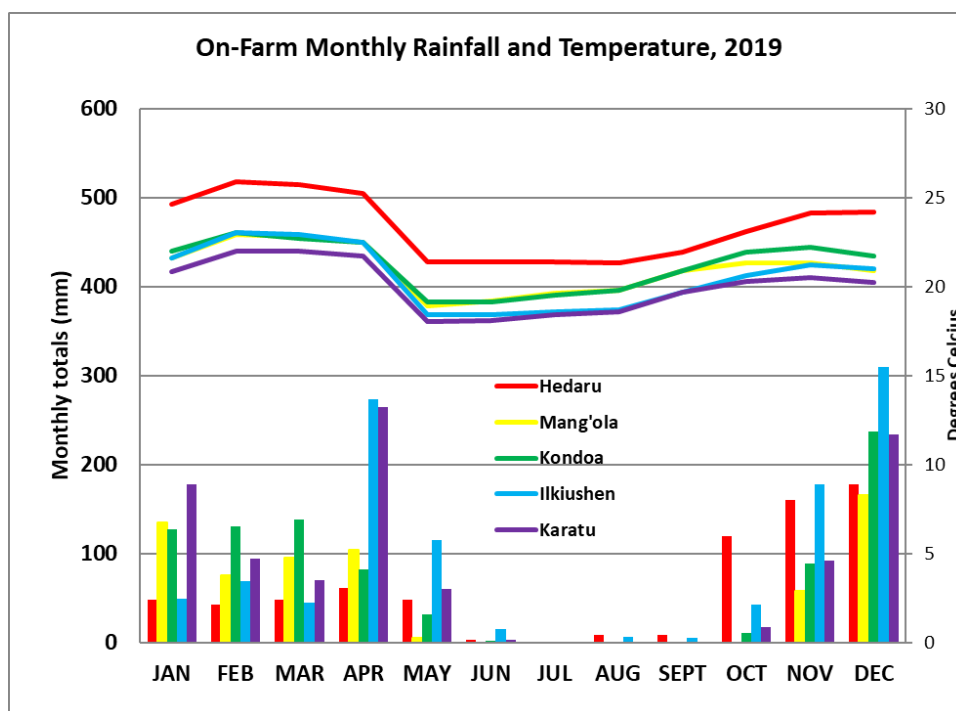


Figure S5. Monthly rainfall and temperature at the on-farm environments in 2019.

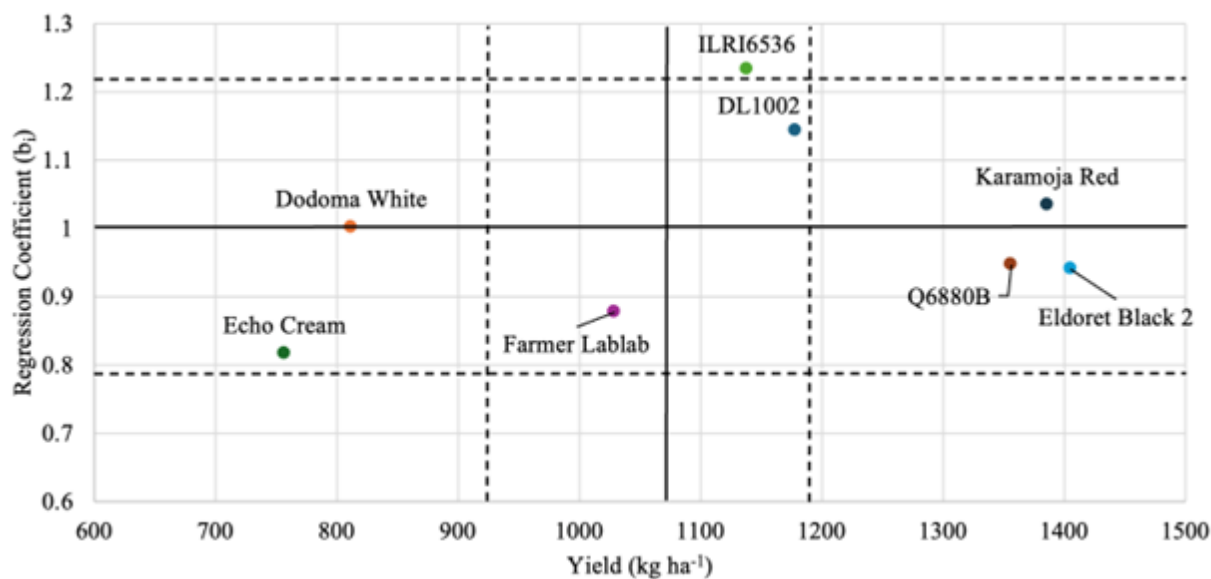


Figure S6. Finlay-Wilkinson yield stability model of eight lablab accessions tested in 11 farm environments in 2018 and 2019 in Northern Tanzania. The vertical line represents the mean yield of all accessions across 11 environments, and the horizontal line represents the mean regression coefficient. The dotted lines are one standard error above and below the regression coefficient and mean yield.

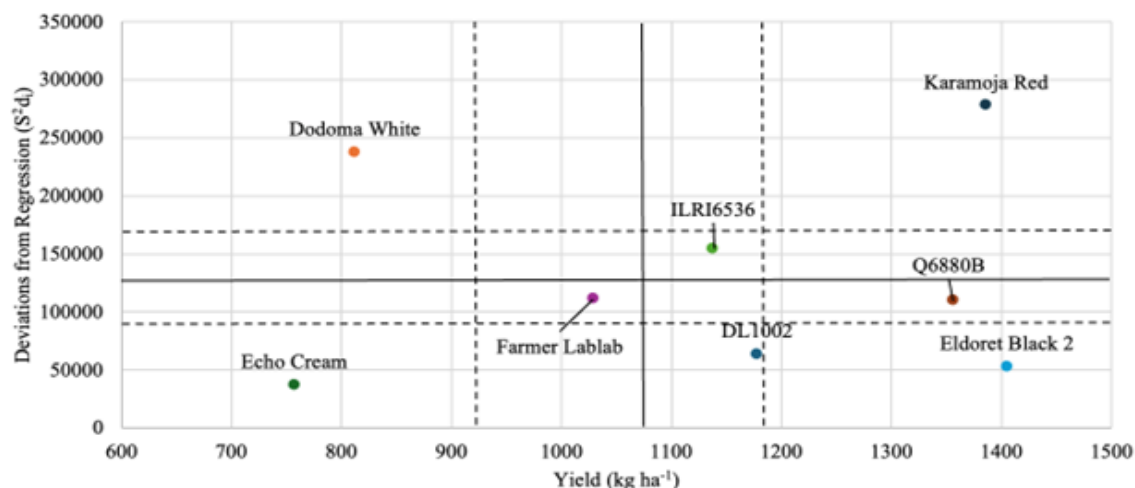


Figure S7. Eberhart-Russell yield stability model of eight lablab accessions tested in 11 farm environments in 2018 and 2019 in Northern Tanzania. The vertical line represents the mean yield of all accessions across 11 environments, and the horizontal line represents the deviations from the regression line of each accession. The dotted lines are one standard error above and below the deviations from the regression line and mean yield.

Table S5. Five sensory ratings from six communities in Northern Tanzania evaluating eight lablab accession in 2018

<i>Appearance^{yr}</i>	Accession Mean	Hedaru	Ilkiushin	Karatu	Kondoa	Mang'ola	Mungushi
		<i>n</i> =7	<i>n</i> =11	<i>n</i> =11	<i>n</i> =11	<i>n</i> =12	<i>n</i> =14
DL1002	3.0	2.9	2.8	3.0	3.1	2.7	3.4
Dodoma White	3.0	2.6	3.3	3.1	3.3	2.1	3.8
Echo Cream	3.4	3.6	3.7	3.8	2.6	3.9	2.9
Eldoret Black 2	3.3	3.9	2.5	2.7	3.8	3.5	3.6
Farmer Lablab	3.3	3.5	2.7	2.9	4.4	2.7	3.5
ILRI 6536	3.0	2.1	3.7	2.7	3.4	2.9	3.1
Karamoja Red	3.6	4.1	3.2	3.5	4.5	3.3	3.1
Q 6880B	2.8	2.6	2.9	2.3	3.6	2.7	2.5
Accession Mean	3.2	3.2	3.1	3.0	3.6	3.0	3.2
SE ±	0.174	0.3	0.6	0.4	0.37	0.43	0.38
CV (%)	41	32	43	43	32	45	44
<i>P>F^a</i>							
Accession (A)	0.0355	0.0119	0.2868	0.2590	0.0094	0.0775	0.3015
Community (C)	0.0074						
A x C	0.0148						
<i>Smell</i>							
DL1002	3.0	3.1	2.9	3.2	3.1	2.7	3.1
Dodoma White	3.0	2.6	3.2	3.8	3.2	2.6	2.8
Echo Cream	3.3	3.3	3.8	3.5	3.4	3.2	2.5
Eldoret Black 2	3.2	4.0	2.7	2.5	3.6	3.7	2.9
Farmer Lablab	3.2	3.2	4.1	2.7	3.1	2.2	4.6
ILRI 6536	3.1	2.1	3.9	3.3	3.2	3.1	3.2
Karamoja Red	3.5	3.9	3.3	3.4	3.6	3.9	3.4
Q 6880B	2.8	2.6	3.5	2.6	3.3	2.2	3.1
Accession Mean	3.2	3.1	3.4	3.1	3.3	2.9	3.2
CV(%) ^b	39	36	35	43	39	36	43
SE ±	0.13	0.42	0.36	0.4	0.41	0.3276	0.37

Table S5. Contd.

<i>P>F</i>							
Accession (A) ^a	0.1190	0.0747	0.1243	0.3025	0.9681	0.0001	0.015
Community (C)	0.2184						
A x C	0.0031						
<i>Taste</i>							
DL1002	3.0	3.2	2.8	3.1	3.0	2.7	3.1
Dodoma White	3.4	3.2	3.2	3.2	3.3	3.7	3.9
Echo Cream	3.6	4.2	3.4	3.6	3.8	3.4	3.5
Eldoret Black 2	3.4	3.2	2.8	3.3	3.0	3.7	4.5
Farmer Lablab	3.2	3.5	3.8	2.7	3.6	2.9	2.6
ILRI 6536	3.3	3.0	3.5	3.1	3.7	3.2	3.2
Karamoja Red	3.7	3.4	3.9	4.0	4.1	3.9	3.4
Q 6880B	2.6	2.5	4.0	2.1	3.4	1.7	1.8
Accession Mean	3.3	3.3	3.4	3.2	3.5	3.2	3.3
CV(%) ^b	38	39	40	36	33	40	38
SE ±	0.16	0.48	0.42	0.36	0.39	0.39	0.34
<i>P>F</i>							
Accession (A) ^a	<.0001	0.6054	0.2522	0.067	0.3327	0.0014	<.0001
Community (C)	0.3888						
A x C	0.0086						
<i>Texture</i>							
DL1002	3.3	3.1	3.5	3.2	2.9	3.5	3.4
Dodoma White	3.0	2.5	2.7	3.0	3.7	2.4	3.6
Echo Cream	3.5	3.5	3.8	3.5	3	3.8	3.5
Eldoret Black 2	3.4	3.5	2.5	3.6	2.5	3.9	4.2
Farmer Lablab	2.9	2.7	3.5	2.2	4.0	2.8	2.1
ILRI 6536	3.4	3.0	3.4	3.9	3.9	3.2	3.2
Karamoja Red	3.7	3.6	4.0	3.4	4.5	3.5	3.3
Q 6880B	2.5	2.3	2.7	2.5	3.4	2.1	2.0
Accession Mean	3.2	3.1	3.3	3.2	3.5	3.2	3.2
CV(%) ^b	38	41	29	37	34	42	38
SE ±	0.17	0.42	0.42	0.45	0.38	0.44	0.35
<i>P>F</i>							
Accession (A) ^a	<.0001	0.3525	0.08	0.0319	0.003	0.0513	0.0002
Community (C)	0.2934						
A x C	0.003						
<i>Marketability</i>							
DL1002	3.7	3.2	4.0	3.6	3.6	4.4	3.5
Dodoma White	2.8	2.5	2.8	2.8	2.8	2.7	2.4
Echo Cream	3.2	4.0	2.7	3.1	3.1	3.6	2.5
Eldoret Black 2	3.7	3.7	3.0	3.4	3.4	4.2	4.9
Farmer Lablab	3.7	3.8	4.1	2.7	3.0	3.6	4.1
ILRI 6536	3.1	2.8	2.7	4.2	3.2	2.9	2.5
Karamoja Red	3.5	3.1	3.1	3.4	4.5	3.6	2.8
Q 6880B	3.1	3.7	3.1	2.7	3.2	2.7	3.3
Accession Mean	3.4	3.4	3.2	3.2	3.6	3.6	3.3
CV (%) ^b	36	39	44	34	33	29	38
SE ±	0.18	0.49	0.48	0.39	0.42	0.33	0.36