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Lablab purpureus: Evaluation and Selection of Drought-tolerant - High-yielding Accessions in Dry Farming Systems Based on Drought Tolerance Indices and Multi-environmental Yield Trials

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ABSTRACT

Breeding for drought tolerance in crops requires responding knowledge on the moisture regimes of crops. This study was conducted to evaluate and select the drought tolerant - high yield Lablab accessions in the dry farming systems of Tanzania based on drought tolerance indices and field performance. Three sites from different agro-ecological conditions were selected for the study and each site involved trials with moisture stress-free (MSF) and early terminal moisture stress (TMS) conditions. The experimental design consisted of a randomized complete block design. The twelve accessions used in the study were the best genotypes selected from the former moisture screening experiment at the seedling stage. Data collections included days to 50% flowering and maturity, seed yield plant-1 and seed yield ha-1. The responses of the accessions to TMS conditions were quantified through ten developed indices whose correlation coefficients were computed from the mean of the seed yield plant-1 under MSF and TMS conditions. ANOVA and post-hoc tests were used to analyze the variation among the accessions and their field parameters as well as to compare their means, respectively. Based on this analysis, three indices; mean productivity, geometric mean productivity, and stress tolerance index were discovered with higher correlation coefficients (>0.5), and thus effective for selecting the TMS tolerant accessions with high seed yield plant-1 under both conditions. Through the combined rank mean method, D147, D363, HA4, D349, D352, D348, and D359 were generally selected as Lablab TMS tolerant accessions with high seed yield plant^{-1} across the evaluation sites. Although the significant difference ($p<0.05$) in field performance was noted among the accessions and across the sites, promising trends were found among the above selected TMS tolerant accessions. It is therefore suggested that, further evaluation of the above-selected accessions should involve farmers in their fields before releasing them as commercial varieties.

Keywords: *Lablab purpureus,* Field evaluation, Moisture regime, Stress tolerance indices, Terminal moisture stress

1. Introduction

Ever-increasing food demand is highly predictable over the world due to the rapid growth in the global population (UN 2019; Beltran-Pea et al. 2020). This high food demand is likewise projected in many areas due to drought stress (FAO 2017). The major effects of drought stress are likely to take place in Africa where farmers are more vulnerable to climate change (Muchuru & Nhamo 2019; Benjamin et al. 2021). Maintaining crops in such persisted conditions of climatic challenges is the most significant phase of production.

Since there are few crop species that perform well in harsh conditions, knowledge on their production in drought condition could enhance our effort to develop drought tolerant genotypes for the future sustainability of food security (Raza et al. 2019).

Lablab (*Lablab purpureus* L. Sweet) is a multi-purpose crop, useful for both human consumption and animal feeding (Naeem et al. 2020; Whitbread et al. 2011). Some essential food and nutritional materials have been found higher in Lablab compared to many other related crops. For instance, the protein content is higher in Lablab (302 g kg^{-1} in seed flour) than in other legumes (Venkatachalam & Sathe 2007). Lablab is also the best cover crop and green manure. Since it fixes more nitrogen (180-215 Kg N ha^{-1}) than other related crops (McDonald et al. 2001; Bell et al. 2017), farmers utilize it for conservation agriculture. Farmers rely on Lablab for food and income, especially during persistent drought condition when other legumes such as common beans (*Phaseolus vulgaris*), soybeans (*Glycine max*), cowpeas (*Vigna unguiculata),* and pigeon peas (*Cajanus cajan*) are no longer in the field. For this reason, Lablab is increasingly becoming an important food and cash crop (Raghu et al. 2018) particularly in rural areas in Eastern Africa (Karanja 2016; Nord et al. 2020).

Despite such potential, Lablab has been neglected in many areas in Africa, including Tanzania. This has caused fewer improved cultivars and the continual use of local landraces among farmers (Maass et al. 2010; Miller et al. 2018; D'Alessandro & Molina 2021). To enhance sustainable production of Lablab, especially in dry farming systems that dominate in many areas in the world, a need should be there to develop high-yield and drought-tolerant varieties which could accelerate its transformation to an industrial crop. Such types of varieties are highly needed in many African countries, including Tanzania, as they would serve as food and income security in large parts of their countries that produce very little food due to fewer and erratic rainfalls (FAO 2017; Mkonda & He 2017). A report by the Ministry of Agriculture and Food Security (MAFS 2015) in Tanzania has shown that about 300-600 mm of rainfall is experienced in many areas of the country to influence the production of several crops that farmers prefer to grow such as common beans, cowpeas, soybeans, maize, etc.

Since many crops suffer drought stress typically at the reproductive stages (Nadeem et al. 2019), breeding for drought-tolerant varieties in Lablab should focus on terminal moisture stress (TMS) (Susmitha & Ramesh 2020). This kind of stress is primarily due to insufficient rainfall (meteorological drought) that leads to soil moisture (SM) (agricultural drought) stress (Ding et al. 2021). MOA (2015) and Da Silva et al. (2019) reported that many crops experience drought stress when a percentage of SM drops to a range of 35-50%. This is different from Lablab which is capable of vigorous growth when provided with only little amount of SM (Miller et al. 2018). Lablab is able to grow in very low rainfalls of about 200 mm and high temperatures of around 35 ˚C (Maass et al. 2010). SM elicits drought stress in Lablab when it is below a range of 25-50% (Fening et al. 2009).

Since drought tolerance is organized by polygenes through a complex process (Wang et al. 2018; Missanga et al. 2021), the development of TMS tolerant cultivars has not been possible with many crops (Susmitha & Ramesh 2020). Field evaluation for TMS tolerant cultivars has mainly been performed to develop stress tolerant cultivars (Mitra 2001). The first approach involves genotypes evaluation for yield under moisture-stress free (MSF) or moisture stress (MS) environment. However, this method is proven ineffective due to low yield, significant interactions among accessions, and the MS environment, and low genetic heritability. The second approach focuses on the genetic manipulation of the crop. This method is also proven ineffective as knowledge on genetic mechanisms for crop transformation is still lacking in many crops such as Lablab. Based on such challenges, genotypes evaluation for TMS tolerant varieties at both MSF and TMS conditions is seen as the most suitable method (Susmitha & Ramesh 2020).

Ten drought tolerant indices (Table 1) generated to establish the relationship between yield under MS relative to MSF conditions are practical tools for drought tolerant studies (Talebi et al. 2009). These indices involve mean productivity (MP), geometric mean productivity (GMP), hormonic mean productivity (HMP), stress tolerance index (STI), abiotic tolerance index (ATI), stress non-stress production index (SNPI), yield index (YI), modified STI 1 and 2 (K_1STI and K_2STI), and drought susceptibility index (Susmitha & Ramesh 2020). The relationship between these indices and crop performance in the field such as days to 50% flowering, days to maturity, seed yield $plant^{-1}$ and seed yield hectare $(ha)^{-1}$ is essential for developing TMS tolerant genotypes (Bennani et al. 2017), however with limited information in Lablab. For this reason, this study aims to evaluate and select potential drought tolerant Lablab accessions in the dry farming systems based on drought tolerant indices and field parameters under MSF and early TMS conditions.

Table 1- Formerly developed indices used to quantify the accessions' responses to TMS experiments (Susmitha & Ramesh 2020; Gitore et al. 2021)

S/N	*Drought tolerance indices*	*Code reference*	*Formula*
1	Mean productivity	MP	$(Yp+Ys)/2$
2	Geometric mean productivity	GMP	$\sqrt{(Yp \times Ys)}$
3	Harmonic mean productivity	HMP	$2^* (Yp \times Ys) / (Yp+Ys)$
4	Stress tolerance index	STI	$(Yp \times Ys)/ \bar{Y}p^2)$
5	Abiotic tolerance index	ATI	$[(Yp-Ys)/(\bar{Y}p/\bar{Y}s) \times \sqrt{} (Yp \times Ys)]$
6	Stress non-stress production index	SNPI	$[\sqrt[3]{} Yp+Ys/(Yp -Ys)] \times [\sqrt[3]{} Yp \times Ys]$
7	Yield index	YI	$(Yp/\bar{Y}s)$
8	Modified STI 1	K1STI	$Yp^2/\bar{Y}s^2$
9	Modified STI 2	K2STI	$Ys^2/\bar{Y}s^2$
10	Drought resistance index	DI	$(Ys \times (Yp/Ys)/\bar{Y}s$

Yp and Ys: seed yield plant^{-1} of each accession under MSF and TMS conditions, respectively
$\bar{Y}p$ and $\bar{Y}s$: Mean seed yield plant^{-1} of all accession under MSF and TMS conditions, respectively. MSF: Moisture stress free, TMS: Terminal moisture stress

2. Material and Methods

2.1. Multi-location sites and Lablab accessions for field evaluation

This study was carried out at the three different agro-ecological production zones of Tanzania (Figure 1) in the 2021 production season. The sites were drylands and part of the Lablab production areas in the country. The village of Lengijave was the first evaluation site located (3°24'23.23" S; 36°42'1.78" E and altitude of 1794 masl) in the Arumeru district in Arusha region (in the upper side of the Northern highland zone). The second site; the village of Kavambughu (04°01'59.26" N, 37°41'44.03" E and altitude 928 masl) was located in the Same district in Kilimanjaro region (in the Northern arid zone). The Tanzania Agricultural Research Institute (TARI), Selian, in Arusha region (03°21'50.08" N and 36°38'06.29" E with an altitude of 1390 masl) was the third site (in the lower side of the Northern highland zone) (Figure 1). All three evaluation sites had rainfall predominantly taking place from March to May. A short rainfall period occurs between October and January. The field crops, including Lablab, are typically produced during the long rainfall period while few crops are produced during the short rainfall.

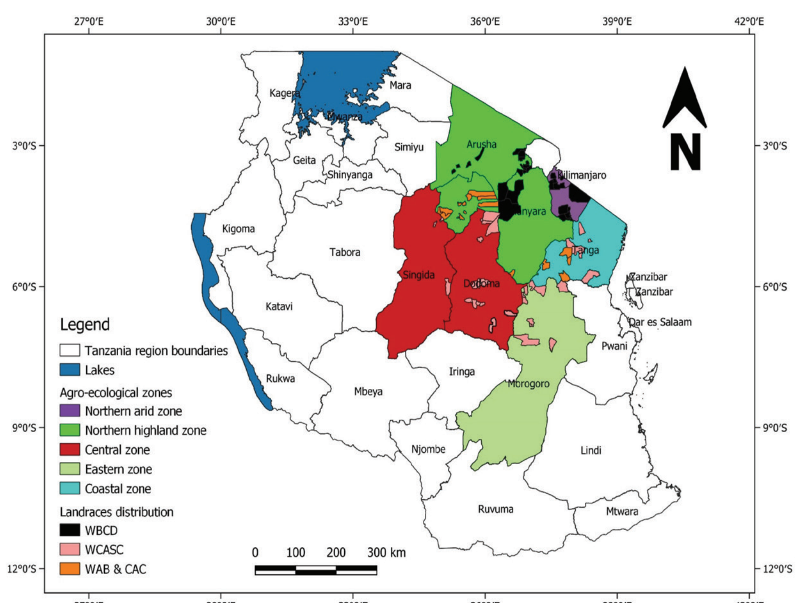

Figure 1- A map of Tanzania (mainland) showing five agro-ecological zones, wards and their villages potential in Lablab grain production along with seed color diversity in each production zone: there are wards with black seeded cultivars dominating (WBCD); wards with cultivars of all seed colors (WCASC); and wards with high availability of black cultivars and less of other cultivars (WAB & CAC)

The Lablab genotypes selected for evaluation consisted of 12 accessions (Table 2, Figure 2): 10 as drought tolerant accessions including Karamoja red and Eldoret Black-2 as recently evaluated for commercial release in Tanzania (Miller et al. 2018; Nord et al. 2020) and 2 as drought susceptible accessions. These 12 accessions were the best selections from the previous MS screening experiment in 2020 of about 300 Lablab accessions (local and exotic) performed at the seedling stage in the greenhouse (Missanga et al. 2021).

Table 2- Some characteristics of the Lablab accessions (12) selected from the moisture screening experiment at seedling stage in 2020 (Missanga et al. 2021) that have been used for high yielding and drought tolerant multi-location evaluation trials in Tanzania

S/N	*Ac- id*	*Accession name*	*Growth habit*	*Seed color*	*Flower color*	*Origin*
Drought tolerant accessions						
1	D 348	Eldoret KT Black-2*	Semi-determinate	Black	Purple	Kenya[c]
2	D 363	Karamoja Red*	Indeterminate	Red	Yellowish	Uganda (Karamoja)
3	HA4	-	Determinate	Cream	Yellowish	India[c]
4	D 352	Eldoret KT Cream	Semi-determinate	Reddish	White	Kenya[c]
5	D 349	Eldoret KT Maridadi	Semi-determinate	Black	Pink	Kenya[c]
6	D 359	ILRI. 14491[i]	Semi-determinate	Brown	White	ILRI, Kenya
7	D 311	Kondoa White	Indeterminate	White	White	Tanzania (Kondoa)
8	D 250	-	Indeterminate	Brownish-creamy	Yellow	India
9	D 55	-	Indeterminate	Brownish-creamy	White	Cambodia
10	D 147	-	Vigorous growth Indeterminate	Brown	Yellowish	Ethiopia
Drought susceptible accessions						
11	D 271	-	Indeterminate	Reddish	White	India
12	D 66	-	Indeterminate	Brownish	White	Uzbekistan

D: Dolichos lablab, Ac- id: Accession identification number, *Accessions used as checks/controls
[c]Already released as the commercial varieties; [i]Potential line at the International Livestock Research Institute

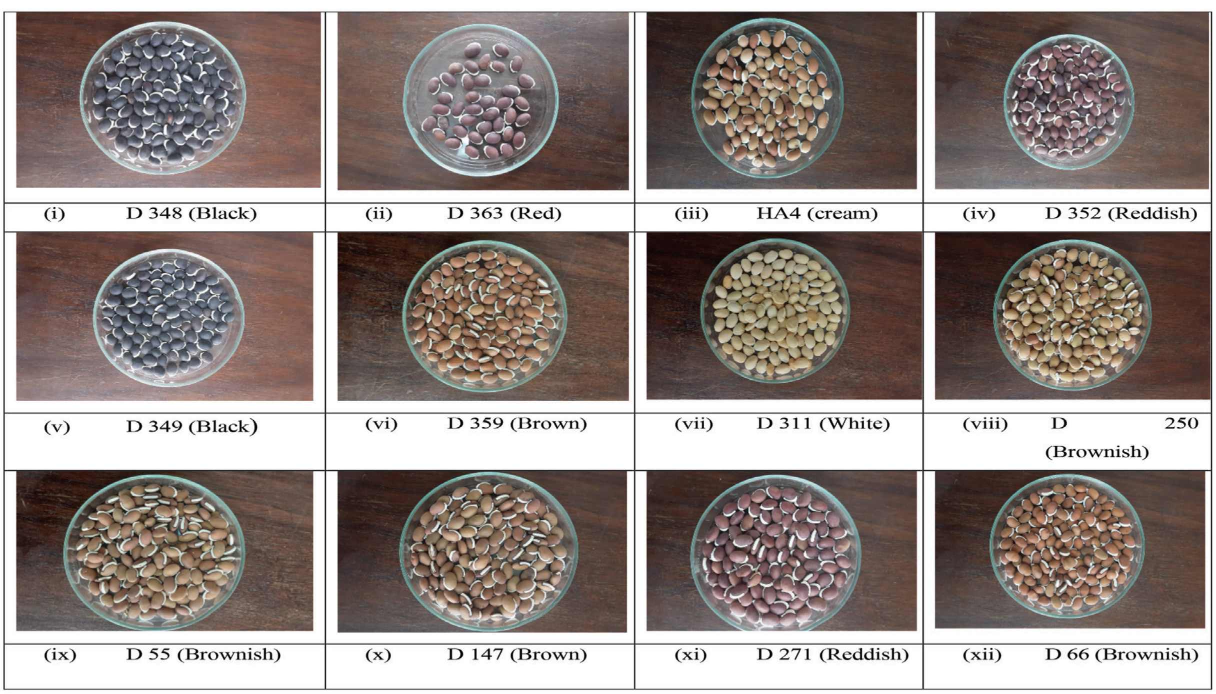

Figure 2a. Illustration of the variability of seed colors of different Lablab accessions (i-xii) that were selected from moisture screening experiment at seedling stage in 2020 and used for the high yielding and drought tolerant multi-location evalua-tion trials in dry farming systems of Tanzania (diameter of the Petri-dish: 65mm x 15mm)

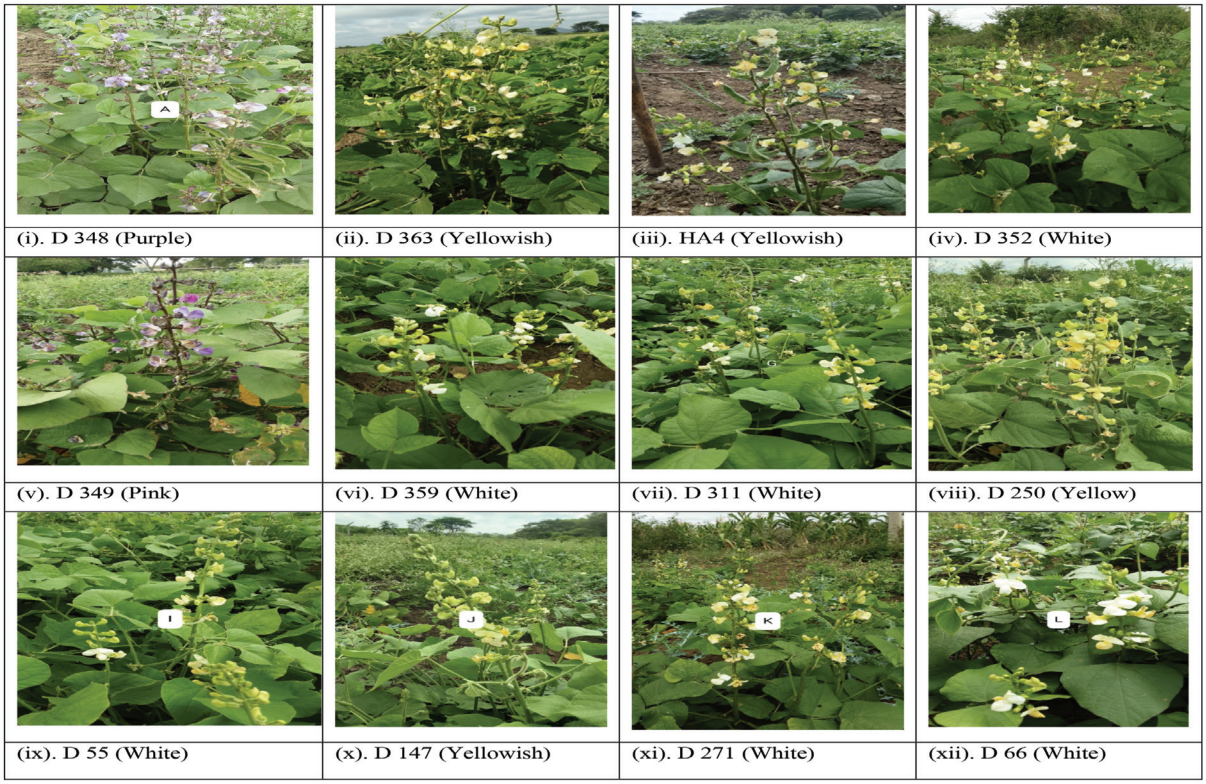

Figure 2b. Illustration of the variability of flower colors of different Lablab accessions (i-xii) that were selected from moisture screening experiment at seedling stage in 2020 and used for the high yielding and drought tolerant multi-location evaluation trials in dry farming systems of Tanzania (diameter of the Petri-dish: 65mm x 15mm)

2.2. Field experimental processes

2.2.1. Field establishment

The field experiments were initiated in early April 2021 through field cultivation using hand-hoe at the Lengijave site, and ploughing at the rest of the sites. The next was leveling and laying out of the experiments for the planting of seeds.

2.2.2. Soil physical properties, and soil nutrients

Soil from the study sites (0-30 cm) was evaluated for physical properties as well as micro and macro-nutrients (Table 3) before the experiment. The content of organic carbon (OC%) ranged from low at the Lengijave and TARI, Selian sites to medium at the Kavambughu site. Their soils were acidic (medium) and non-saline in nature. The total nitrogen (TN%) and exchangeable cations [cmol (+) kg^{-1}] for calcium (Ca), potassium (K), and magnesium (Mg) were very low at all the sites. The exchangeable cation for sodium (Na) ranged between low at the Kavambughu site and very low at the Lengijave and TARI, Selian sites. At all the sites, a high amount (mg kg^{-1}) of sulphur (S), manganese (Mn), and iron (Fe) and low level of available (mg kg^{-1}) phosphorus (P), zinc (Zn), and boron (B) were recorded. Aluminium (Al) (mg kg^{-1}) was elevated a bit at the Lengijave site compared to other sites. This classification of soil physical properties and micro and macro nutrients were established based on the soil guide by Msanya et al. (2001) and Sendhil et al. (2018).

Table 3- Soil physical properties, macro and micro-nutrients (0-30 cm) at the three evaluation sites

S/N	*Soil parameters*	*Unit*	*Evaluation sites*			*Properties*
			Lengijave	*Kavambughu*	*TARI, Selian*	
1	Organic carbon (OC)	%	1.05	1.67	1.25	Physical properties
2.	Soil pH		5.60	5.75	5.70	
3.	Electrical conductivity (EC)	dSm^{-1}	0.87	0.96	0.83	
4.	Total Nitrogen (TN)	%	0.04	0.059	0.039	Macro-nutrients
5.	Calcium (Ca)	cmol (+) kg^{-1}	0.09	0.31	0.15	
6.	Potassium (K)	cmol (+) kg^{-1}	0.02	0.021	0.013	
7.	Magnesium (Mg)	cmol (+) kg^{-1}	0.005	0.088	0.005	
8.	Sodium (Na)	cmol (+) kg^{-1}	0.048	0.292	0.046	
9.	Sulphur (S)	mg kg^{-1}	28.2	64.21	31.96	
10.	Phosphorus (P)	mg kg^{-1}	5.56	6.35	3.03	
11.	Manganese (Mn)	mg kg^{-1}	4.84	5.96	5.32	
12.	Zinc (Zn)	mg kg^{-1}	0.45	0.46	0.38	Micro-nutrients
13.	Iron (Fe)	mg kg^{-1}	41.75	38.18	37.15	
14.	Boron (B)	mg kg^{-1}	0.007	0.011	0.009	
15.	Aluminium (Al)	mg kg^{-1}	56.76	40.42	29.00	Element

2.2.3. Experimental design

The field experimental design at each site involved two separate trials that had different moisture regimes (MR) during the flowering and pod-filling stages i.e. an irrigated field that formed the moisture stress-free (MSF) experiment and a non-irrigated field that formed the early TMS experiment. Both experiments were set down under the randomized complete block design (RCBD) and each of them was laid down into three replications to make a total of 36 plots per experiment. The spacing for the experiments was 0.75 m between the rows and 0.45 m within the rows. One m was left unplanted to form a border space between the plots while 2.5 m was allowed for the space between MSF and TMS experiments.

2.2.4. Starting and management of the experiments

The seeds were sown on 16th April 2021 (Lengijave site) as well as on 19th and 22nd April, 2021 for the TARI, Selian, and Kavambughu sites, respectively. For 5 rows $plot^{-1}$ and 1 seed $hole^{-1}$, 25 seeds were sown into a single plot of 8.4 m^2 (8.4 x 10^{-4} ha). While all other agronomic processes such as weeding, insecticide application etc. were kept properly, no fertilizer was applied to the field during the experiment.

2.3. Data management

An early TMS condition was set to meet the flowering stage, and therefore weather data and the SM contents were recorded every month at all the three sites to establish the irrigation time for the MSF experiment.

2.3.1. Weather data

Rainfall was below the average and unevenly distributed during the production season (April - September) at all the evaluation sites. The levels of rainfall recorded during this period were 290.0 mm, 88.6 mm, and 503.2 mm at Lengijave (Figure 3a), Kavambughu (Figure 3b), and TARI, Selian (Figure 3c), respectively. Among the sites, the majority of rainfall occurred between April and May with little rainfall from June to September. Temperatures were also variable among the sites. The average maximum/minimum temperatures during Lablab growing period were higher at the Kavambughu site (26.7/16.9 ˚C) and lower at the Lengijave site (22.1/13.5 ˚C). The average maximum/minimum temperatures at TARI Selian were 23.3/14.8 ˚C. June and July were the coldest months, especially at Lengijave (21.1/12.2 ˚C and 20.2/12.0 ˚C), compared to TARI, Selian (22.2/14.0 ˚C and 22.0/13.2 ˚C) and Kavambughu (25.7/15.6 ˚C and 25.1/15.3 ˚C).

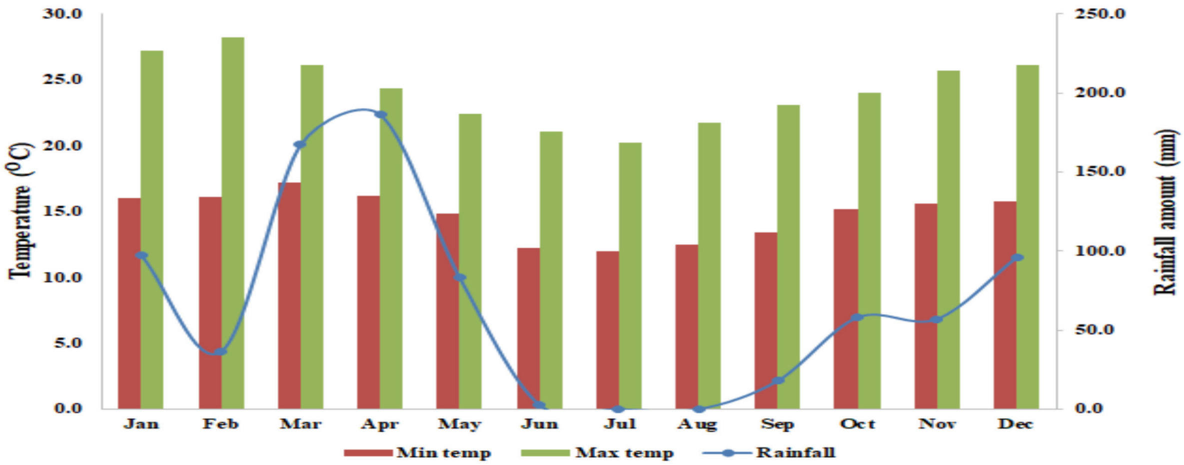

Figure 3a- Weather data (rainfall, maximum and minimum temperature) in 2021 collected from min-weather station (Korvofon seed company) closer to Lengijave evaluation site. Rainfalls dropped off from June to August to induce soil moisture stress in the field

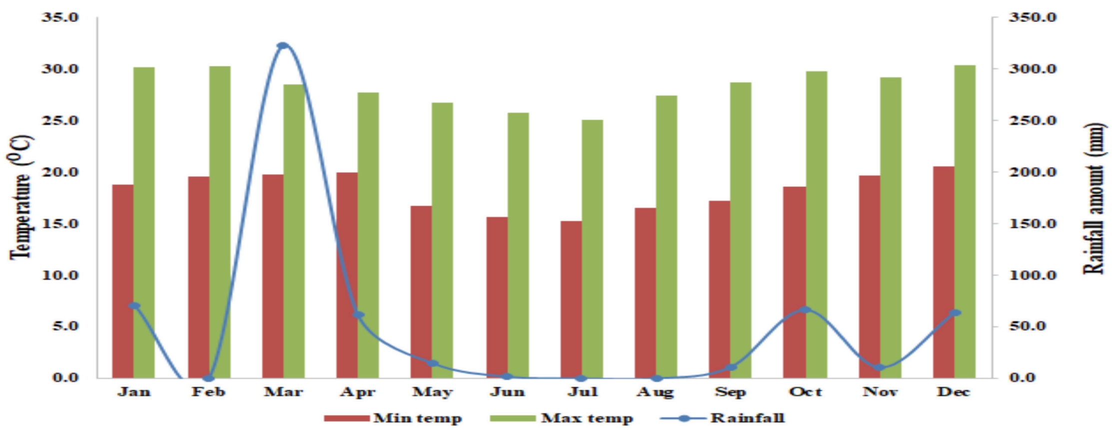

Figure 3b- Weather data (rainfall, maximum and minimum temperature) in 2021 collected from Same weather station. There was almost no rainfall from June to August that led into little moisture content in the field

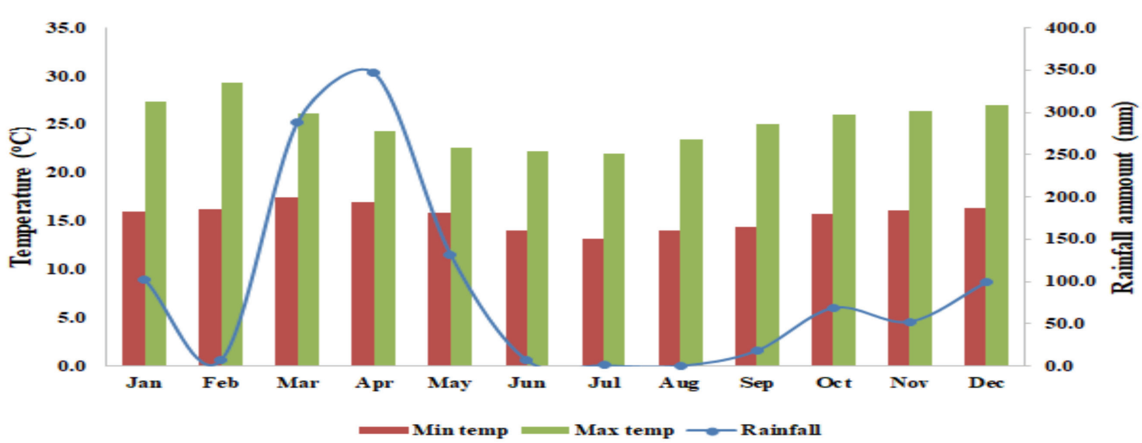

Figure 3c- Weather data (rainfall, maximum and minimum temperature) in 2021 collected from TARI, Selian mini-weather station (closer to the experiment). There was very little rainfall from June to August that caused loss of soil moisture to the experiment

2.3.2 Soil moisture content (%)

Changes in the amount of rainfall (Figure 3a-c) from June as per weather data collected from the nearby meteorological/min-weather stations altered the moisture content (MC) in the soil across all the experimental sites (Table 4). The soil MC in this month was slightly above 20% (at TARI, Selian) and below 20% for the rest of the sites. Since Lablab experiences drought stress when the soil content in below 25% (Fening et al. 2009), irrigation was initiated for the MSF experiments at the end of June (the 2nd month of the experiment).

Table 4- Monthly records of soil moisture content (%) at three evaluation sites

Month	*Lengijave*		*Kavambughu*		*TARI, Selian*		*Average*	
	MSF	***TMS***	***MSF***	***TMS***	***MSF***	***TMS***	***MSF***	***TMS***
1	35.6	34.2	30.7	32.4	37.8	38.2	34.7	34.9
2*	19.8	18.5	12.4	10.9	21.5	20.8	17.9	16.7
3	30.9	15.4	28.3	8.8	34.2	17.1	31.1	17.8
4	28.2	13.1	26.6	6.0	32.7	14.3	29.2	11.1

*Irrigation was initiated on the 2nd month of the experiment. Moisture stress is triggered in Lablab when its content is below 25%. To maintain the moisture to the MSF experiments, irrigation was also done monthly-wise. MSF: Moisture stress free, TMS: Terminal moisture stress

The amount of water [30 liters (L) plot^{-1}] to irrigate the MSF experiment at the beginning of flowering was attained through monitoring the soil absorption capacity as described in the irrigation protocols (number four) for vegetable crops at the University of Georgia, USA (Da Silva et al. 2019).

2.4 Data collection

Data collected from the experiments included different plant parameters related to production and yield including days to 50% flowering, days to maturity, seed yield (g) plant^{-1} and seed yield (kg) ha^{-1} for establishing the best high yielding and drought tolerant accessions. Seed yield plant^{-1} was used to establish drought tolerant indices for selecting the desirable accessions that would tolerate early TMS. The harvest involved hand-picking of dry pods that were thoroughly threshed and weighed for overall seed yield determination.

2.5 Statistical analysis

All the collected data were tested for normality by Bartlett's and Levene's tests and both showed $p>0.05$. Further testing for linearity by Cook's distance and collinearity ($p>0.05$) approved the normal distribution of the data. The equality of variance was tested by Shapiro-Wilk, and Kolmogorov-Smirnov tests and proved that p-values were >0.05.

2.5.1 Drought tolerance indices

Pooled (multi-way) ANOVA and post-hoc tests were performed to analyze the significance of the mean sum of the squares (MSS), F, and p-values attributable to MRs, genotypes (G), replications (R), as well as G and MR interactions (G × MR) for seed yield plant^{-1} at all the evaluation sites. The analysis was implemented using R-software version 4.1.1 (2021-08-10).

Quantification of the accessions' responses to TMS conditions: The responses of Lablab accessions to TMS conditions were quantified through the formerly 10 developed indices (Table 1) whose values were computed from the mean of the seed yield (g) plant^{-1}. The next was the correlation coefficients (Pearson) values of the indices with seed yield (g) plant^{-1} of the accessions evaluated under MSF and TMS conditions.

Desirable indices for selection of the TMS tolerant accessions: The indices that showed significant coefficient correlation (magnitude >0.5) with mean for seed yield plant^{-1} of all accessions evaluated under both MSF and TMS conditions were considered suitable for selection of TMS tolerant accessions from all the sites. Since more than one suitable index was recognized as suitable and the stress-tolerant accessions varied with the indices, the rank mean (RM) generated from the rank sum method of indices was used to identify TMS tolerant accessions at each site. The RM values on average from all the sites were combined into one index to produce the overall best TMS tolerant accessions (Farshadfar & Elyasi 2012; Susmitha & Ramesh 2020; Gitore et al. 2021).

2.5.2 Field parameters

The means and standard deviation (SD) of field parameters from all the Lablab accessions at each evaluation site were computed using Jamovi 1.2.25 for further statistical analysis. General analysis of variance and Post-hoc tests (by Gen Stat software version 12) were used to explore variations among the accessions and their selected parameters: days to 50% flowering, days to maturity, seed yield plant^{-1}, and seed yield ha^{-1} to compare their established means. The compared means and established differences were presented as "mean ± SD". Boxplots generated from statistical software (Minitab 14) were used to visualize the variation among the accessions and between the MR irrespective of the evaluation sites. In all the analyses, a significant difference was considered when p<0.05.

3. Results

3.1 Drought tolerance indices

3.1.1 Multi-way analysis of variance

Table 5 shows multi-way ANOVA for MR, G, R, and G x MR evaluated for seed yield plant^{-1} under MSF and TMS conditions at all three evaluation sites. Overall G at each site varied significantly for seed yield plant^{-1} as indicated from MSS, F, and p-values (significant *at p=0.05; **p=0.01; **p=0.001) attributable to accessions evaluated under two MR. Furthermore, G at all the sites performed differentially across the MSF and TMS conditions for seed yield plant^{-1} as revealed by significant MSS, F, and p-values attributable to G in interaction with MR (G x MR) and genotypes in the non-stressed experiment (G_1).

Table 5- Multi-way ANOVA for accessions evaluated under MSF and TMS conditions at the three sites for seed yield (g) plant-1

Source of effects	***Df***	***Lengijave, Arumeru***			***Kavambughu, Same***			***TARI, Selian, Arusha***		
		MSS	***F-value***	***p-value***	***MSS***	***F-value***	***p-value***	***MSS***	***F-value***	***p-value***
Moisture regime (MR)	1	0.28	2.19	0.143	0.08	0.39	0.5350	0.15	0.004	0.9495
Genotypes (G)	11	0.27**	2.69	0.0059	0.46**	2.88	0.0034	7.64***	3.595	0.0008
Replication (R)	2	0.01	0.051	0.9500	0.02	0.032	0.9680	0.63	0.082	0.9220
G x MR	23	0.14	1.57	0.1350	0.37**	3.44	0.0012	6.15**	3.181	0.0023
G_1	11	0.30***	26.69	<0.001	0.61***	281.7	<0.001	1.23**	99.39	<0.001
G_2	11	0.11	0.69	0.7430	0.21	0.99	0.4850	0.56	1.09	0.4120
R_1	2	0.004	0.04	0.9630	0.006	0.027	0.9730	0.028	0.063	0.9390
R_2	2	0.03	0.185	0.832	0.002	0.008	0.9920	0.019	0.033	0.967

Df: Degrees of freedom, MSS: Mean sum of squares, Statistically significant difference avails, MSF: Moisture stress free, TMS: Terminal moisture stress. *p=0.05, **p=0.01, ***p=0.001.
G: Overall genotypes at each station; G_1: Genotypes at non stressed experiment (MSF); G_2: Genotypes at stressed experiment (TMS)
R: Overall replications at each station; R_1: Replications at non stressed experiment (MSF); R_2: Replications at stressed experiment (TMS)

3.1.2 Desirable indices based on significant correlation of drought indices with seed yield plant-1 under MSF and MF conditions

The correlation coefficients of drought indices with seed yield plant^{-1} under MSF and TMS conditions in the three sites are displayed in Table 6. The significant indices that exhibit high (>0.5) and positive magnitude of correlation with seed yield plant^{-1} under two MR were counted as desirable for the selection of TMS tolerant accessions. From this basis, three (MP, GMP, and STI), six (MP, GMP, HMP, STI, YI, and ATI), and five (MP, GMP, HMP, STI, and ATI) indices expressing a high magnitude (>0.5) of significant correlation with seed yield plant^{-1} were considered valuable for selecting TMS tolerant accessions at Lengijave, Kavambughu, and TARI, Selian, respectively. Finally, three common indices i.e. MP, GMP, and STI were found as desirable indices for the selection of the TMS tolerant accessions from all the evaluation sites.

Table 6- Correlation coefficients of drought tolerant indices with seed yield (g) plant-1 under MSF and TMS condition in the three evaluation sites

S/N	*Drought tolerant Index*	*Lengijave*		*Kavambughu*		*TARI, Selian*	
		MSF	*TMS*	*MSF*	*TMS*	*MSF*	*TMS*
1	Mean productivity (MP)	0.55**	0.58**	0.72**	0.65**	0.66**	0.75**
2	Geometric mean productivity (GMP)	0.51**	0.61**	0.74**	0.61**	0.69**	0.68**
3	Harmonic mean productivity (HMP)	0.44	0.62**	0.75**	0.57**	0.69**	0.63**
4	Stress tolerance index (STI)	0.51**	0.60**	0.74**	0.59**	0.68**	0.65**
5	Abiotic Tolerance Index (ATI)	0.84**	-0.79**	0.83**	0.59**	0.65**	0.74**
6	Stress non-stress production index (SNPI)	0.34	-0.04	0.76**	0.17	0.35	0.13
7	Yield index (YI)	0.87**	-0.74**	0.59**	0.79**	0.48	0.76**
8	Modified STI (K1STI)	0.99**	-0.32	0.99**	0.05	0.99**	0.07
9	Modified ST2 (K2STI)	-0.37	1.00**	-0.06	0.99**	0.00	0.98**
10	Drought resistance index (DI)	1.00**	-0.36	1.00**	-0.05	1.00**	-0.01

Pearson correlation analysis at 5%, *p=0.05; **p=0.01. MSF: Moisture stress free, TMS: Terminal moisture stress

3.1.3 Selection of TMS tolerant accessions based on recognized indices

The TMS tolerant accessions were not the same under three (MP, GMP, and STI) recognized indices. Therefore, through the combined RM method i.e. an effective combination of the selective indices into a single index, HA4, D363, D147, D348, D349, D352, and D271 from Lengijave (site 1); D147, D363, D349, HA4, D311, D352, and D359 from Kavambughu (site 2); and D147, D363, D348, D352, D359, HA4, and D349 from TARI, Selian (site 3) (Table 7) were recommended as TMS tolerant accessions.

Table 7- Selection of TMS tolerant accessions based on combined RM method of desirable indices at Lengijave (Site 1), Kavambughu (Site 2) and TARI - Selian (Site 3) evaluation sites

S/N	*Indices*	*MP*			*RS*			*GMP*			*RS*			*STI*			*RS*			*Combined RM*		
	Site	*1**	*2**	*3**	*1**	*2**	*3**	*1**	*2**	*3**	*1**	*2**	*3**	*1**	*2**	*3**	*1**	*2**	*3**	*1**	*2**	*3**
1	D 348	11.32	40.96	56.74	4	9	3	10.46	37.15	56.38	4	11	3	1.09	0.51	1.879	4	11	3	4	10	3
2	D 363	12.28	74.29	68.37	2	2	2	11.94	74.16	68.37	2	2	2	1.42	2.04	2.75	1	2	2	2	2	2
3	HA4	12.50	51.15	41.22	1	4	6	11.08	45.63	31.18	1	4	6	1.22	0.77	0.57	3	4	6	1	4	6
4	D 352	9.30	44.70	43.42	6	8	4	9.29	43.36	41.72	6	6	4	0.86	0.70	1.02	6	6	4	6	6	4
5	D 349	10.05	63.25	40.84	5	3	7	9.29	62.67	30.42	5	3	8	0.86	1.47	0.56	5	3	7	5	3	7
6	D 359	7.80	44.84	42.00	9	7	5	7.76	42.93	40.96	9	7	5	0.60	0.69	0.99	9	7	5	9	7	5
7	D 311	7.15	51.12	27.60	11	5	11	6.99	44.07	24.55	11	5	11	0.48	0.72	0.35	11	5	11	11	5	11
8	D 250	7.25	26.5	12.35	10	12	12	7.18	26.36	12.32	10	12	12	0.51	0.26	0.09	10	12	12	10	12	12
9	D 55	6.84	40.49	32.22	12	10	9	6.84	38.61	29.37	12	9	8	0.46	0.55	0.51	12	9	9	12	9	9
10	D 147	12.01	77.72	70.32	3	1	1	11.52	77.38	70.10	3	1	1	1.32	2.23	2.89	2	1	1	3	1	1
11	D 271	8.87	46.00	39.04	8	6	8	8.62	40.87	30.98	7	8	7	0.74	0.62	0.56	7	8	8	7	8	8
12	D 66	8.97	40.24	31.91	7	11	10	8.45	37.88	24.73	8	10	10	0.71	0.53	0.36	8	10	10	8	11	10

MP: Mean productivity, GMP: Geometric mean productivity, STI: Stress tolerance index, RS: Rank sum, RM: Rank mean
1*, 2* and 3 imply to evaluation site number 1 (Lengijave), 2 (Kavambughu) and 3 (TARI - Selian), respectively

3.1.4 The best TMS accessions based on the combined RM method of desirable indices from all the evaluation sites

The best TMS tolerant accessions generated by the combined RM methods of desirable indices from all three evaluation sites (Table 8) involved D147, D363, HA4, D349, D352, D348, and D359.

Table 8- Overall best TMS tolerant accessions generated from combined RM method of desirable indices from for the three evaluation sites

S/N	*Ac- ID*	*RM method*			*Average positions*	*Combined RM method*
		Lengijave	*Kavambughu*	*TARI, Selian*		
1	D 348	4	10	3	5.67	6
2	D 363	2	2	2	2	2
3	HA4	1	4	6	3.67	3
4	D 352	6	6	4	5.33	5
5	D 349	5	3	7	5	4
6	D 359	9	7	5	7	7
7	D 311	11	5	11	9	9
8	D 250	10	12	12	11.33	12
9	D 55	12	9	9	10	11
10	D 147	3	1	1	1.67	1
11	D 271	7	8	8	7.67	8
12	D 66	8	11	10	9.67	10

Combined rank mean (RM) method of desirable indices to recommend the best TMS tolerant accessions

3.2 Field parameters

The Lablab accessions evaluated for high yield and drought tolerance in the present study had a wide range of genetic diversity (Table 2, Figure 2a,b). These accessions were significantly varied ($p<0.05$) when evaluated for field parameters at the three agro-ecological sub-zones under MSF and TMS conditions (Table 9a-d, Figure 4). Descriptions of the selected parameters for the specific accession at each evaluation site and each MR were as follows:

3.2.1. Days to 50% flowering

Days to 50% flowering were significantly varied among the Lablab accessions and between MSF and TMS conditions (Table 9a, Figure 4). HA4 had fewer days (56.9) of 50% flowering irrespective of the evaluation sites and MR. The next accessions with few (68-70.7) days of 50% flowering were D349, D352, D348, D147, and D359 while the rest of the accessions had longer (73.3-81.1) days of 50% flowering. Respective to the MR, almost all the accessions generally had 50% flowering earlier in TMS than in MSF conditions, except in HA4, D271, and D66 which did not show any significant variation. Moreover, concerning the evaluation sites, days to 50% flowering among all accessions were overall shorter (63 days) at the Kavambughu site in Same and longer (88 days) at the Lengijave sites in Arumeru (Table 10).

Table 9a. Variations of Lablab accessions on days to 50% flowering as compared across the evaluation sites in MSF and TMS water regimes

S/N	*Ac-Id*	*Lengijave*		*Kavambughu*		*TARI, Selian*		*Average*	
		MSF	*TMS*	*MSF*	*TMS*	*MSF*	*TMS*	*MSF*	*TMS*
1	D 348	84.0±2.00 r-u	81.0±1.00 rs	62.3±1.53 l-k	60.0±1.73 l-g	67.3±1.53 j-o	64.0±1.00 e-i	71.2±9.93 b-d	68.3±9.72 b
2	D 363	94.7±3.21 x-z	91.7±2.08 v-x	63.0±1.00 d-k	60.3±2.08 c-h	66.0±1.00 h-m	63.7±1.53 d-l	74.6±15.20 c-f	71.9±15.00 b-d
3	HA4	64.3±0.58 j-o	64.0±1.00 e-l	49.7±1.53 ab	49.7±1.53 ab	56.7±1.53 bc	56.7±1.53 bc	56.9±6.45 a	56.8±6.32 a
4	D 352	82.0±1.00 r-t	80.3±1.53 g-r	63.0±2.65 d-k	60.0±1.73 c-g	67.0±1.00 i-n	64.3±1.53 f-h	70.7±8.80 b-d	68.2±9.38 b
5	D 349	83.7±2.08 r-u	81.0±1.00 rs	60.3±1.15 c-h	58.0±1.00 b-d	63.3±1.53 d-k	61.3±2.08 e-l	69.1±11.10 bc	66.8±10.80 b
6	D 359	87.0±1.00 t-v	84.0±3.00 r-u	61.0±1.73 l-h	58.3±0.58 l-e	68.0±2.65 k-o	66.0±1.00 h-m	72.0±11.80 b-d	69.4±11.50 bc
7	D 311	100.0±2.65 zA	98.0±1.00 yzA	71.0±1.73 m-p	68.0±1.00 k-o	75.0±2.00 pq	72.7±0.58 n-p	82.0±13.70 h	79.6±14.00 f-h
8	D 250	97.0±1.00 y-zA	94.0±1.00 w-y	65.0±2.65 g-l	62.7±1.53 d-k	71.0±1.73 m-p	67.0±1.00 l-n	77.7±14.80 e-h	74.6±14.70 c-f
9	D 55	95.3±1.15 x-z	92.0±2.65 v-x	67.0±1.00 l-n	65.0±2.65 g-l	73.0±2.00 op	71.3±1.53 m-p	78.4±13.00 e-h	76.1±12.40 d-g
10	D 147	86.1±1.53 u-w	84.0±1.00 s-v	63.0±1.00 d-l	60.0±1.00 c-j	65.2±1.53 l-p	63.0±2.00 l-n	71.4±11.40 b-d	69.0±11.20 c-e
11	D 271	99.0±1.00 yzA	94.0±2.65 w-y	67.0±1.00 l-n	68.0±1.00 k-o	71.7±2.08 m-p	71.0±1.73 m-p	79.2±15.00 e-h	77.7±12.40 e-h
12	D 66	102.0±1.00 A	99.0±1.73 yzA	68.0±1.73 k-o	69.3±0.58 l-p	74.3±2.08 p	74.0±1.00 p	81.4±15.70 gh	80.8±13.90 gh

Table 9b. Variations of Lablab accessions on days to maturity as compared across the evaluation sites in MSF and TMS water regimes

S/N	*Ac-Id*	*Lengijave*		*Kavambughu*		*TARI, Selian*		*Average*	
		MSF	*TMS*	*MSF*	*TMS*	*MSF*	*TMS*	*MSF*	*TMS*
1	D 348	129.0±1.73 x-zA	127.0±0.58 t-y	114.0±0.58 h-m	111.0±0.58 e-i	119.0±2.00 op	116.0±1.00 j-o	121.0±6.63 b-e	118.0±6.84 bc
2	D 363	134.0±1.00 B-D	132.0±0.58 A-C	114.0±1.73 g-l	112.0±1.00 f-i	118.0±1.00 m-p	116.0±1.00 j-o	122.0±9.23 c-g	120.0±9.03 b-d
3	HA4	107.0±1.00 b-d	105.0±0.58 bc	99.0±1.00 a	97.3±0.58 a	107.0±1.00 b-d	104.0±1.00 b	104.0±4.09 a	102.0±3.57 a
4	D 352	128.0±1.53 w-zA	126.0±1.00 t-y	116.0±1.00 j-o	112.0±0.58 f-j	119.0±0.58 o-q	116.0±0.58 k-o	121.0±5.61 b-f	118.0±6.12 b-d
5	D 349	128.0±2.65 v-zA	126.0±1.15 t-y	111.0±1.73 e-h	109.0±1.00 d-f	115.0±1.00 i-n	114.0±0.58 g-l	118.0±7.87 bc	116.0±7.81 b
6	D 359	131.0±1.15 AB	130.0±0.58 yzA	110.0±0.58 d-g	108.0±1.00 c-e	120.0±0.58 o-r	118.0±1.00 m-p	120.0±9.14 b-e	119.0±9.42 b-d
7	D 311	139.0±1.73 E-G	135.0±0.58 C-E	119.0±1.00 op	116.0±0.58 k-o	127.0±2.31 t-y	124.0±1.00 s-u	128.0±8.87 h-j	125.0±8.30 e-i
8	D 250	142.0±1.00 GH	138.0±1.15 D-F	115.0±1.00 l-n	113.0±1.53 g-l	123.0±1.00 q-l	119.0±1.00 op	127.0±12.00 g-j	123.0±11.10 d-h
9	D 55	141.0±1.53 F-H	138.0±0.58 E-G	117.0±0.58 l-o	114.0±1.00 g-l	125.0±1.00 t-w	123.0±0.58 r-t	127.0±10.60 h-j	125.0±10.70 e-i
10	D 147	131.0±1.15 zAB	127.0±0.58 u-z	113.0±0.58 f-k	110.0±0.58 d-g	121.0±1.15 p-s	119.0±1.15 n-p	121.0±7.86 b-f	119.0±7.40 b-d
11	D 271	144.0±1.00 HI	141.0±0.58 F-H	116.0±1.00 j-o	114.0±0.58 h-m	124.0±0.58 s-v	123.0±1.15 r-t	128.0±12.50 h-j	126.0±11.60 f-j
12	D 66	147.0±1.00 I	144.0±0.58 HI	119.0±0.58 n-p	116.0±1.73 j-o	126.0±1.00 t-y	126.0±0.58 t-x	131.0±12.80 j	129.0±12.50 ij

Table 9c. Variations of Lablab accessions on seed yield (g) plant-1 as compared across the evaluation sites in MSF and TMS water regimes

S/N	Ac-Id	Lengijave		Kavambughu		TARI, Selian		Average	
		MSF	TMS	MSF	TMS	MSF	TMS	MSF	TMS
1	D 348	11.0±0.76 a-f	15.7±1.61 d-i	71.8±2.46 w-z	67.1±2.61 u-x	63.1±6.42 s-w	68.2±1.70 w-y	48.6±28.70 e-h	50.3±26.00 e-h
2	D 363	9.4±0.50 a-e	8.6±0.27 a-d	78.6±4.01 zA	70.4±1.65 w-z	69.4±1.80 w-z	75.9±4.11 x-zA	52.5±32.70 f-h	51.7±32.50 e-h
3	HA4	14.3±1.42 a-f	11.2±0.80 a-d	68.9±4.89 t-v	64.6±2.44 r-t	57.8±1.72 p-s	63.0±3.78 q-t	47.0±2.78 fg	40.3±2.35 f
4	D 352	8.9±0.78 a-e	7.1±1.33 a-d	33.8±0.45 no	31.9±1.64 l-o	31.4±2.32 l-o	32.7±0.76 m-o	24.7±12.00 a-d	23.9±12.70 a-d
5	D 349	12.0±0.40 a-f	10.7±0.40 a-f	58.2±3.22 r-v	55.6±1.98 r-t	52.1±2.19 qr	54.0±2.63 q-s	40.8±21.80 d-h	40.1±22.10 d-h
6	D 359	8.6±0.61 a-d	6.8±0.45 a-d	57.8±3.07 r-u	54.9±1.21 q-s	51.3±14.20 qr	50.5±6.82 qr	39.2±24.30 d-h	37.4±23.30 d-g
7	D 311	8.7±1.25 a-d	7.0±0.42 a-d	53.8±3.14 q-s	52.7±1.59 qv	40.2±2.99 op	45.5±0.82 pq	34.2±20.20 b-e	35.0±21.30 c-f
8	D 250	8.3±0.50 a-d	6.7±1.65 a-d	30.5±0.76 l-n	28.0±0.68 k-n	13.1±0.23 a-f	15.3±1.84 b-h	17.3±10.10 ab	16.7±9.38 ab
9	D 55	6.7±1.04 a-d	5.6±0.38 a	28.3±0.59 k-n	26.7±0.85 j-n	19.0±3.71 f-k	15.0±1.67 a-h	18.0±9.55 a-c	15.8±9.19 a
10	D 147	15.4±1.37 b-g	13.9±1.35 a-e	85.1±4.67 A	77.0±2.06 yzA	64.7±1.93 t-w	68.1±1.97 w-y	53.1±31.10 h	53.0±29.60 gh
11	D 271	7.0±0.86 a-d	5.9±0.15 ab	24.9±1.71 i-n	23.7±0.70 h-m	14.3±1.14 a-h	11.7±0.58 a-f	15.4±7.89 a	13.8±7.86 a
12	D 66	6.3±1.03 a-d	6.2±1.67 a-c	25.2±1.00 j-n	22.8±1.14 g-l	13.6±0.89 a-g	11.6±1.14 a-f	15.0±8.31 a	13.5±7.42 a

Table 9d. Variations of Lablab accessions on seed yield (kg) ha-1 as compared across the evaluation sites in MSF and TMS water regimes

S/N	Ac-Id	Lengijave		Kavambughu		TARI, Selian		Average	
		MSF	TMS	MSF	TMS	MSF	TMS	MSF	TMS
1	D 348	327.4±22.5 a-d	467.3±47.9 c-h	2137.9±73.2 t-w	1997.0±77.2 s-u	1878.0±191.0 q-t	2029.8±50.6 t-v	1447.8±854.0 f-h	1498.0±775.0 f-i
2	D 363	278.8±15.0 a-c	256.0±7.9 a-c	2340.3±119.0 wz	2096.2±49.1 t-w	2066.5±53.7 t-w	2259.9±122.0u-x	1561.8±672.0 hi	1537.4±966.0 g-i
3	HA4	425.6±42.2 a-f	333.3±23.8 a-d	2051.6±146.0 t-v	1922.6±72.7 r-t	1721.2±51.1 p-s	1874.0±112.0 q-t	1399.5±749.0 fg	1376.7±786.0 f
4	D 352	264.9±23.2 a-c	210.3±39.5 a-c	935.5±13.4 j-m	949.0±48.7 j-m	935.5±69.0 k-n	973.2±22.50 l-n	735.8±356.0 b	711.0±377.0 b
5	D 349	357.1±11.9 a-d	1006.9±12.0 lm	1732.1±95.9 p-s	1653.8±58.8 p-r	1549.6±65.3 op	1606.2±78.2 o-q	1213.0±649.0 e	1192.5±658.0 e
6	D 359	254.0±18.2 a-c	201.4±13.4 a-c	1719.2±91.5 p-s	1633.9±36.1 o-q	1526.8±423.0 op	1503.0±203.0 op	1166.7±723.0 de	1112.8±694.0 c-f
7	D 311	258.9±37.30 a-c	207.3±12.4 a-c	1567.2±93.5 op	1601.2±47.5 o-q	1196.4±88.9 mn	1354.0±24.4 no	1018.8±600.0 c	1043.0±634.0 cd
8	D 250	247.0±14.9 a-c	199.4±49.2 a-c	907.7±22.5 j-l	834.3±20.3 i-l	388.9±6.9 a-d	455.4±54.6 b-f	514.6±302.0 a	496.4±279.0 a
9	D 55	200.4±31.00 a-c	167.7±11.30 a	841.3±17.40 i-l	794.6±25.40 i-l	564.5±110.00 d-i	446.4±49.7 a-f	534.4±284.0 a	469.0±274.0 a
10	D 147	459.3±40.60 b-g	413.7±22.40.30 a-e	2531.7±139.00 x	2292.7±61.30 v-x	1925.6±57.50 r-t	2026.8±58.60 t-v	1638.9±926.00 i	1577.7±882.00 hi
11	D 271	207.3±25.70 a-c	176.6±4.55 ab	741.1±50.90 g-l	705.4±20.80 f-k	424.6±33.80 a-f	349.2±17.20 a-d	457.7±235.00 a	410.4±234.00 a
12	D 66	186.5±30.50 a-c	184.5±49.70 a-c	750.0±29.80 h-i	678.6±33.80 e-j	404.8±26.50 a-e	345.2±33.80 a-d	447.1±247.00 a	402.8±221.00 a

Ac-Id: Accession Identification number, MR: Moisture regime, Changes in alphabets refer to the significant difference at p<0.05

Table 10- Comparison of the values obtained from field parameters at the three evaluation sites

S/N	***Evaluation site***	***Lengijave***		***Kavambughu***		***TARI, Selian***		****Average***	
	Moisture regime (MR)	***MSF***	***TMS***	***MSF***	***TMS***	***MSF***	***TMS***	***MSF***	***TMS***
1	Days to 50% flowering	90.0	86.9	63.5	61.5	68.2	66.1	73.9	71.5
3	Days to maturity	133.5	130.9	113.6	111.1	120.4	118.1	122.5	120.1
3	Seed yield plant-1	9.7	8.8	51.4	48.0	40.8	42.7	34.0	33.1
4	Seed yield in kg ha-1	288.7	261.2	1531.0	1427.3	1215.0	1270.3	1011.6	986.3

This table compares the data values obtained from the field parameters for MSF and TMS experiments at each evaluation site. *Average data values obtained from the field parameters for all evaluation sites

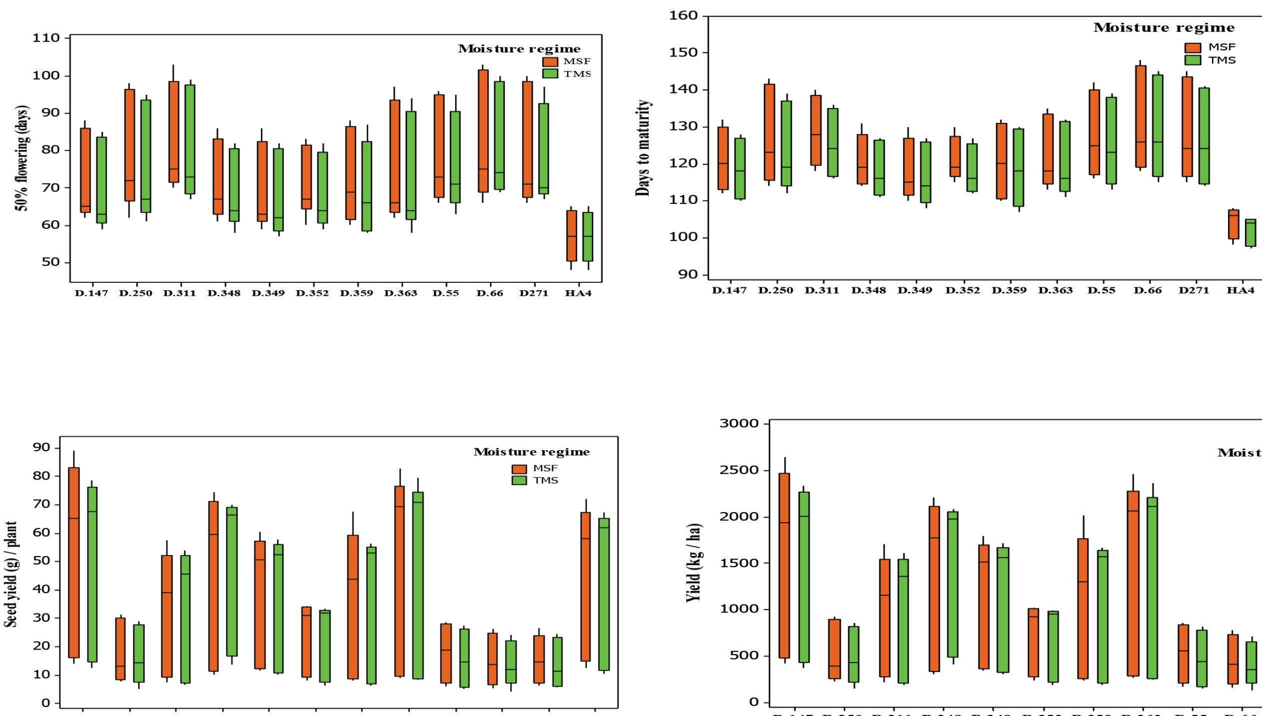

Figure 4. Sameness and variations in some field parameters; days to 50% flowering, days to maturity, seed yield (g) plant-1 and seed yield (kg) ha-1 as compared among the Lablab accessions irrespective of the evaluation sites and between MSF and TMS moisture regimes

3.2.2. Days to maturity

Table 9b and Figure 4 show days to maturity varied significantly among Lablab accessions and between MSF and TMS experiments. HA4 matured earlier (103 days) compared to the rest of the accessions irrespective of the evaluation sites. The next early (117-121 days) maturing accessions involved D349, D348, D352, D359, D147, and D363. The rest of the accessions had longer days (125-130) to maturity. Concerning the MR, most of the accessions generally matured earlier in TMS than in MSF conditions except in HA4 which showed no significant variation. Concerning the evaluation sites, the accessions generally matured earlier (112.4 days) at the Kavambughu site, in Same while taking longer (132.2 days) at the Lengijave site in Arumeru (Table 10).

3.2.3 Seed yield parameters: seed yield plant^{-1} and seed yield ha^{-1}

Seed yield plant^{-1} (Table 9c, Figure 4) and seed yield ha^{-1} (Table 9d, Figure 4) also differed significantly among Lablab accessions and between MSF and TMS conditions. Irrespective of the evaluation sites, D147, D363, D348, HA4, D349, D359, and D311 had the greatest (53.1 - 34.6 g plant^{-1} or 1608.3 – 1030.9 kg ha^{-1}) seed yield values. The low (24.3-14.3 g plant-1 or 723.4-425.0 kg ha^{-1}) seed yield values involved the rest of the accessions. Regarding the moisture conditions, a significant variation in the seed yield parameters was observed among half of all accessions. Generally, the values were higher in the MSF experiments than in the TMS experiments for D363, HA4, D359, and D147 and the opposite of it for D348, and D311 accessions. This kind of trend where seed yield is produced higher in TMS conditions than in MSF conditions was more noticeable at TARI, Selian than at the other two sites. However, no significant variation was generally noted between MSF and TMS experiments for the other half of accessions i.e. D352, D349, D250, D55, D271, and D66. With respect to the evaluation sites, the low (9.3 g plant^{-1} or 275 kg ha-^{1}) seed yield values were noted at the Lengijave site, in Arumeru while the large (49.7 g plant^{-1} or 1479.2 kg ha-^{1}) seed yield value was obtained at the Kavambughu site in Same (Table 10).

4. Discussion

4.1. Lablab genetic resources for evaluation studies

A wide genetic diversity in crops is essential for enhanced breeding programs. Lablab is a leguminous crop with a wide range of genetic diversity (Venkatesha et al. 2007; Maass et al. 2010). The accessions selected for the present study (Table 2, Figure 2a,b) have shown morphological diversity that plays an important role in the theme of the study. The growth habits of the crop i.e. determinate and indeterminate are useful traits to determine the harvesting and long utilization of the crop in the field (Keerthi et al. 2018; Basanagouda et al. 2022). Seed characteristics in Lablab especially the color influence the consumption and marketing of the crop. Kenya has more consumers of Lablab, especially the black seeded cultivars, than Tanzania. Lablab production in Tanzania is mainly for marketing. The consumers of this crop in Tanzania are very few and they mostly prefer white or cream colored seeds. For this reason, the production of Lablab in Tanzania is focused more on Northern zone in order to seek the market in Kenya (Miller et al. 2018). Lablab flowers have not received much discussion as a production means in East Africa. However, the use of Lablab as an ornamental crop can take a further step towards utilizing their morphology and colors in future business. The results in Table 5 justify the use of the selected accessions for the planned study.

The genetic potential in Lablab has enabled its wide distribution over a range of agro-ecological zones (Vidigal et al. 2018) similarly to the landraces cultivation in five agro-ecological production zones of Tanzania (Figure 1). Farmers producing Lablab in Tanzania have been depending on their own landraces due to the unavailability of improved varieties. Rongai (black seeds), and white seeds (Kilosa, Gairo, Dodoma, Kondoa, and Karatu whites) are some of the Lablab cultivars that farmers have been growing in Tanzania. Among African countries, Kenya released its commercial varieties earlier than other countries. Through the Kirk-house Trust funded Stress Tolerant Orphan Legume project (Kirkhouse Trust 2019), and United States Agency for International Development, Canadian Food-grains Bank sponsored ECHO project (Nord et al. 2020), Lablab exotic germplasm was collected from various Lablab growing countries to enhance breeding activities in Tanzania and the rest of Africa. Such genetic resources were supplemented with local collections made by the authors of the present study in Tanzania. All these resources were screened for drought stress at the seedling stage in 2020 (Missanga et al. 2021) to obtain drought-tolerant and susceptible accessions (Table 2) for the present field evaluation study.

4.2. Drought tolerant indices: selection for desirable accessions

The ability of crops to tolerate drought stress as evaluated in different stressed conditions based on grain yield is a heritable trait controlled by the genes (Farshadfar & Elyasi 2012). The mean dry seed yield plant-1 of twelve selected Lablab accessions in the present study established different drought indices (Table 6) at the three sites under both MSF and TMS conditions. Since the selection of TMS tolerant genotypes from both MR considers the indices with high magnitude (Susmitha & Ramesh 2020), MP, GMP, and STI were selected as the overall desirable indices that established the TMS tolerant accessions in this study. These three types of indices were reported by Ferdandez (1992) and Guendouz et al. (2012) as the special drought tolerant indices that breeders use to select high-yielding cultivars under stress and non-stress conditions. The criteria and indices similar to those obtained in this study for Lablab were only reported in India (Susmitha & Ramesh 2020). However, further similar reports were found in soybean (Seyyed et al. 2014), chickpea (Uday et al. 2016), barley (Zare 2012), cowpeas (Ajayi 2020), common wheat (Moosavi et al. 2008; Farshadfar & Elyasi 2012; Bennani et al. 2017), and durum wheat (Talebi et al. 2009; Guendouz et al. 2012).

As farmers' selection for drought tolerant varieties (Table 7,8) considers high yielding cultivars in different moisture conditions (Ramesh & Byregowda 2016) i.e. accessions with the high average number of desirable indices in combination especially in MP, GMP, and STI (Golabadi et al. 2006; Guendouz et al. 2012; Susmitha & Ramesh 2020), D147, D363, HA4, D349, D352, D348, and D359 were recommended in the present study as drought tolerant and high yielding Lablab varieties.

Most of the Lablab accessions evaluated and selected in this study as overall high yielding and TMS tolerant accession (Table 8) have been widely used in production and considered in some research studies. They were already released as commercial varieties in India (HA4) (Ramesh et al. 2018), and Kenya [D349 (Eldoret KT Maridadi), D352 (Eldoret KT Cream), D348 (Eldoret KT Black-2)] (Kirkhouse Trust., 2015; KEPHIS, 2017; Cook et al. 2020). D363 (Karamoja red) and D348 (Eldoret Black-2) were recently evaluated for commercial release in Tanzania (Miller et al. 2018; Nord et al. 2020). D359 was the potential line (ILRI 14491) in the series of Lablab lines at the I*nternational Livestock Research Institute* (ILRI), Kenya (Cook et al. 2020).

4.3. Field performance evaluation in Lablab genotypes

A wide variation in Lablab growth parameters similar to this work (Table 9a-d, Figure 4) affirms the potential of this crop among smallholder farmers (Pengelly & Maass 2001; Whitbread et al. 2011). Serving as a multi-purpose crop (Naeem et al. 2020; Raghu et al. 2018), Lablab has been used for human consumption especially as tender leaves, immature pods, green seeds, and dry grains (D'Alessandro & Molina 2021) or as forage for livestock (Ewansiha & Singh 2006). The major factors that lead to the underutilization of Lablab in Tanzania and other African countries is primarily due to the unavailability of improved varieties. Many farmers' landraces in Tanzania have indeterminate growth habits taking longer to flower and mature. Harvests from these indeterminate cultivars are repetitive with low yield (Huyghe 1998; Sultana et al. 2001).

The breeders' targets similar to the goals of this study (Table 9a,b) have been to select early flowering Lablab accessions that would tolerate drought stress and provide them with early harvesting. Furthermore, other important goals have been to achieve high-yielding accessions (Table 9c,d) which can provide farmers with a good economic return. Some early flowering accessions as per this study (HA4, D349, D352, D348, D147, and D359) (Table 9a) were also early maturing cultivars (Table 9b) as well as high yielding accessions (Table 9c,d) as reflected in other studies. While no MSF and TMS experiments were conducted before to compare Lablab genotypes in East Africa including Tanzania, Miller et al. (2018) and Nord et al. (2020) from northern Tanzania only evaluated some Lablab genotypes in the field, including some accessions used in this study. Similar trends in their field performance were also discovered in this study. Ewansiha et al. (2007) from Nigeria reported 40-60 days as the early flowering period in Lablab, similar to days taken by HA4 to accomplish 50% flowering in this study (Table 9a). The rest of the accessions were classified into the second group with intermediate days of flowering. Ranges of days from 51-160 days and 90-197 days were reported by Whitbread et al. (2011) in South Africa as days to 50% flowering and days to maturity in Lablab, respectively. In Uganda, Kankwatsa and Muzira (2018) have reported 52-69 days (first year) and 56-108 days (second year) as days to 50% flowering. In her Lablab evaluation study by Kamotho et al. (2016) in Kenya, the grand mean in days to 50% flowering, and days to maturity were 98.79, and 143.45, respectively. The minimum and maximum days for maturity and seed yield (g) plant^{-1} were 117.8 and 186.4 as well as 19.7 and 126.9, respectively. Such information has a close relation to the findings obtained from this study. Although improved Lablab varieties can produce 2.5-5.0 tons (t) of green pods or 1.5-2.0 t of dry seeds per ha (Heuzé et al. 2016; Nord et al. 2020), most of their cultivars have long production cycles compared to other legumes. Early-maturing varieties in common bean and cowpeas involve an average of 60 and 90 days, respectively. Yield production in common bean is 0.88 t ha^{-1} while that of cowpeas ranges from 1.3 to 1.5 t ha^{-1}) (CIAT; World Bank 2017; Njonjo et al. 2019).

One important criteria to select for drought-resilient cultivars in crops is their similar performance in both stress and non-stress conditions. However, their selection should further consider the genotypes with desirable performance (Mehraban et al. 2019). Based on this criteria, Figure 4 displays some accessions (D147, D363, D348, HA4, D349, D352, and D359) that were generally performing well in the entire area of the study. Their minor variations between MSF and TMS condition in some accessions (Figure 4) were due to drought resilience abilities in Lablab (Robotham & Chapman 2015) and the relationship that Lablab shows between rainfall and grain production (Bakari & Pauline 2020). Zinzala et al. (2016) reported that stressful environments tend to lower plant physiological parameters in many crops. Unclear trends in Lablab performance and grain productivity (Table 10) along the three evaluation sites were triggered by rainfall variations (Figure 3a-c). Since, Lablab is a drought resilient and photoperiodic sensitive crop (Ramtekey et al. 2019), it does not need much rainfall to raise production (Nord et al. 2020). The low temperature (Figure 3a) particularly during reproduction season and soil factors (Table 3) especially a raised amount of Aluminium seem to be the limiting factors for Lablab production at the Lengijave site in the upper side of the northern highland zone. This site was not suited for Lablab grain production in the selected period of the present study. As mentioned by Forsythe (2019), some areas in Tanzania are better suited to grow Lablab from December in order to utilize early rainfall and avoid the drop in temperature from April that would influence the production.

5. Conclusion

Some potential Lablab accessions were evaluated for high yielding and drought tolerance at multi-locational field trials in the dry farming systems of Tanzania. The evaluation was completed under MSF and TMS conditions. Based on correlation criteria, three drought tolerant indices i.e. MP, GMP, and STI were discovered as the effective indices in the selection of the TMS tolerant accessions with high seed yield under the stipulated conditions. Through the combined RM method, D147, D363, HA4, D349, D352, D348, and D359 were selected as Lablab TMS tolerant accessions with high seed yield under both conditions. Moreover, their performance in multi-locational field evaluation trials showed promising trends. The field performance involved days to 50% flowering, days to maturity, and seed yield parameters i.e. seed yield plant^{-1} and seed yield ha^{-1}. Based on these findings, it was suggested that, the selected high yield - drought tolerant Lablab accessions from the present study should be further evaluated by farmers in their fields before releasing them as commercial varieties. Furthermore, the breeding programs can start to utilize these resourceful accessions to generate variability among Lablab cultivars both inside and outside of the country.

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