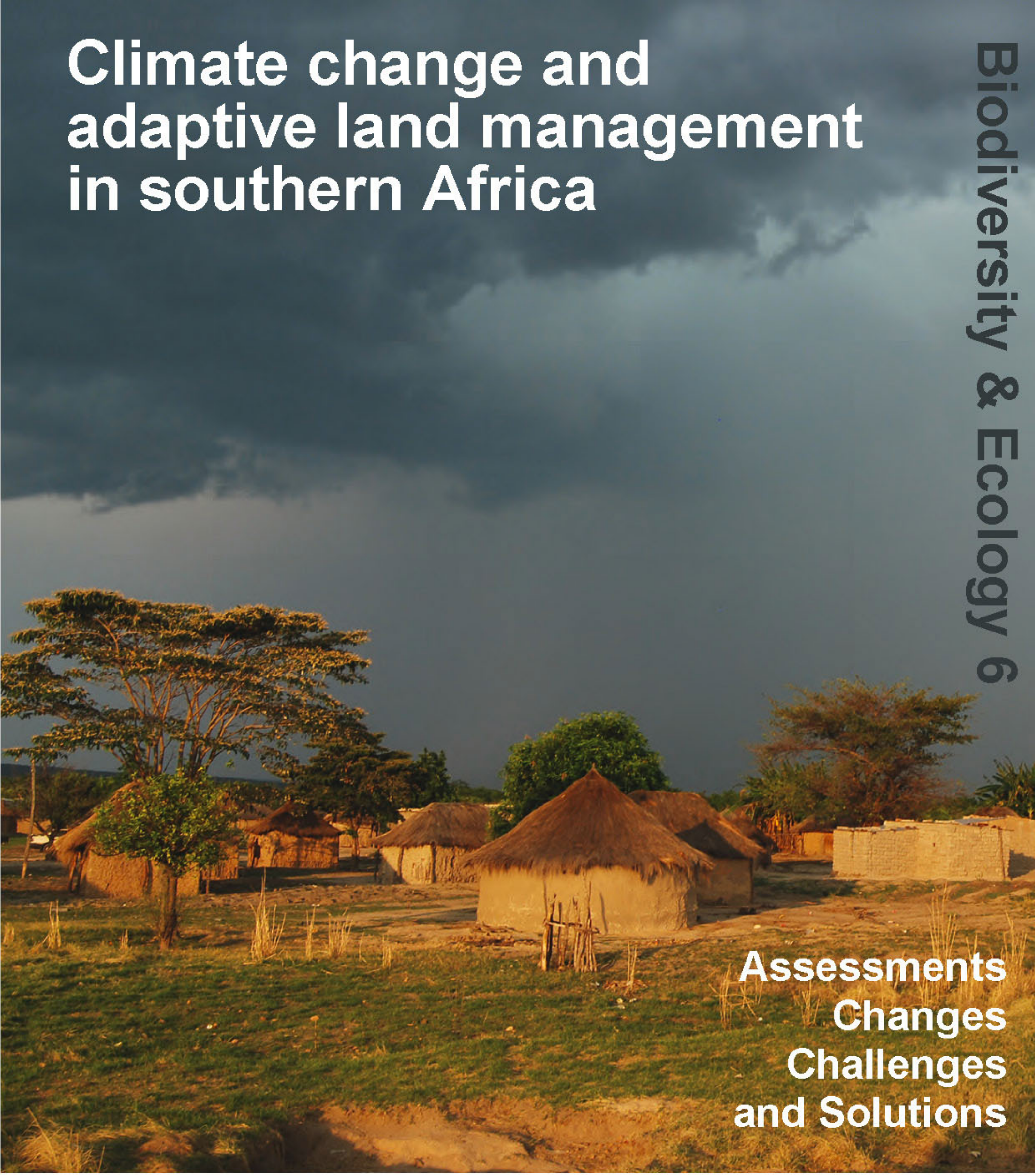
Climate change and adaptive land management in southern Africa

Biodiversity & Ecology 6



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Changes
Challenges
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Climate change and adaptive land management in southern Africa

Assessments, changes, challenges, and solutions

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Germplasm evaluation for climate adaptation and drought tolerance: The cases of local varieties of maize in Zambia and cowpea in Botswana

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Abstract: Water shortages as a result of changes in rainfall patterns and increases in temperatures are associated with climate change. Rising temperatures and evaporation rates exacerbate water scarcity problems primarily affecting dry-land crop production systems in southern Africa. Thus, the search for drought-tolerant crop varieties becomes necessary to mitigate climate change and to achieve food security in the region. Fifty maize germplasm accessions obtained from the Zambian gene bank were characterized at Mount Makulu Research Station in Zambia to identify suitable varieties for on-farm evaluation. In that regard, data was collected on days to 50% tasselling, days to silking, plant height, ear height, number of leaves above leaf ear, tillering index, tassel type, number of kernel rows, kernel type, and kernel colour. Furthermore, we carried out on-farm participatory evaluation of 20 local varieties of maize at two representative sites. Farmers selected six crop varieties on the basis of their early maturity, high yielding ability, drought tolerance, and tolerance to field pests and diseases. The selected maize varieties are suitable for large-scale production or variety development for the targeted sites or areas with similar agro-ecological conditions.

In Botswana, greenhouse and field studies were conducted to characterise 20 cowpea genotypes based on different drought tolerance indices. Results showed that stress tolerance index (STI) and drought resistance index (DI) were the most suitable indices for selecting cowpea genotypes for drought tolerance. Six cowpea collections were tested in a field study at Hukuntsi, situated in the Kalahari Desert, in 2014-15. Analysis of variance and regression analysis showed that three accessions [BCA001 (Blackeye), BCA009 (Mahutohuto), BCA016 (Speckled brown] were promising drought-tolerant varieties displaying a higher plant drought survival (PDS%) rate under field conditions. Significant correlations were detected between PDS% and STI, indicating the usefulness of the two parameters in selecting drought-tolerant cowpea genotypes. The two selected cowpea genotypes are recommended for cultivar development or production under drought-prone and rain-fed farming systems in southern Africa.

Resumo: A escassez de água, resultante das alterações nos padrões de precipitação e do aumento da temperatura, está associada às alterações climáticas. O aumento da temperatura e das taxas de evaporação exacerbam os problemas de escassez de água, principalmente nos sistemas de produção de culturas de sequeiro no Sul de África. Assim, a procura de variedades de culturas tolerantes à seca torna-se necessária para mitigar as alterações climáticas e alcançar segurança alimentar na região. Cinquenta acessos de germoplasma de milho, obtidos do banco de genes Zambiano, foram caracterizados na Estação de Investigação de Mount Makulu na Zâmbia, de modo a identificar variedades adequadas para avaliação em quintas. Nesse contexto, foram recolhidos dados sobre o número de dias que demora a crescer 50% do pendão, o número de dias que demora a crescer as estigmas, a altura da planta, a altura da espiga, o número de folhas acima da folha da espiga, o índice de perfilhamento, o tipo de pendão, o número de filas de grãos e o tipo e cor do grão. Para além disso, realizámos avaliações participativas no terreno de 20 variedades locais de milho em dois locais representativos. Os agricultores seleccionaram seis variedades de culturas com base na sua maturidade precoce, alta capacidade de rendimento, tolerância à seca e tolerância a pragas e doenças no campo. As variedades de milho seleccionadas são adequadas para a produção em grande escala ou desenvolvimento de variedades para locais específicos ou áreas com condiçoes agro-ecológicas semelhantes.

No Botswana, foram realizados estudos de campo e em estufas para caracterizar 20 genótipos de feijão-frade com base em diferentes indíces de tolerância à seca. Os resultados mostraram que o índice de tolerância ao stress (STI) e o índice de resistência à seca (DI) foram os mais adequados para a selecção de feijão-frade com tolerância à seca. Seis colecções de feijão-frade foram testadas num estudo de campo em Hukuntsi, situado no Deserto do Kalahari, em 2014/15. A análise da variância e a análise da regressão mostraram que três acessos [BCA001 (*Blackeye*), BCA009 (*Mahutohuto*), BCA016 (*Speckled brown*] eram variedades tolerantes à seca promissoras, apresentando uma maior taxa de sobrevivência à seca (PSD%) em condições de campo. Correlações significativas foram detectadas entre PDS% e STI, indicando a utilidade dos dois parâmetros na selecção de genótipos de feijão-frade tolerantes à seca. Os dois genótipos de feijão-frade seleccionados são recomendados para o desenvolvimento ou produção de culturas em sistemas agrícolas de sequeiro, ou susceptíveis à seca, no Sul de África.

Introduction

Climate change in many parts of the developing world brings about water shortages as a result of changes in rainfall patterns and increases in temperatures. Rising temperatures and evaporation rates may exacerbate water scarcity problems affecting dry-land crop production systems as a result of drought. Drought, also known as water deficit, can result from the presence of insufficient moisture for a plant to grow adequately and complete its life cycle. Insufficient moisture can be the consequence of water shortage, coarsely textured soils that retain little water in the root zone, or drying winds. Both droughts and heat waves are predicted to occur more frequently and become more problematic in many areas (Lindner et al., 2010)

Southern Africa is described as a hotspot of climate change, experiencing increased frequency of heat and drought stress (Tubiello et al., 2007; Stringer et al., 2009; Archer et al., 2018). The situation will be worsened by soil erosion and degradation, as well as a decline in the availability of water. Evidence suggests that in this region, climate change may decrease the yields of many crops by shortening the growing season and amplifying water stress, among other factors. The key vulnerable sectors identified by the Intergovernmental Panel on Climate Change (IPCC, 2007b) include agriculture, food, and water. This part of Sub-Saharan Africa is expected to suffer the most not only in terms of reduced agricultural productivity and increased water insecurity, but also through increased exposure to extreme climatic events. The region's vulnerability to climate change is exacerbated by a number of non-climatic factors, including low levels of development and low adaptive capacity. To adapt crop germplasm to climate change scientists look for genetic resources with traits supporting drought adaptation. The ability to develop new varieties depends on their access to genetic resources with traits of economic interest, as well as their technical ability to incorporate these traits into breeding materials and subsequently into commercial varieties.

Crops such as maize, sorghum, pearl millets, cassava, yam, banana, coffee (Ramirez-Villegas & Thornton, 2015) and various legumes (Foyer et al., 2016) are critical for food security in southern Africa. The importance of legumes such as cowpea for food security and sustainable cropping systems has been extensively documented (Sidique et al., 2012). Maize is the most important source of dietary protein and the second most important source of calories in southern Africa. In Zambia, local maize populations have been cultivated for a long time and therefore have been subjected to natural and human selection in different agro-ecological regions and production environments. Such successful adaptation to local growing conditions explains why most traditional farmers prefer local and traditional varieties, which are usually differentiated by a number of specific morphological and agronomic traits. Recently, however, it has become apparent that diversity of local germplasm is declining as a result of the influence of national policy on agriculture, promoting improved varieties (Langyintuo & Mungoma, 2008).

In Botswana, cowpea production is practiced in rain-fed agricultural systems. The latest Agricultural Census Report (CSO, 2013) indicated that cowpea is among the most cultivated crops after maize and sorghum, contributing 10% to the total agricultural production. However, a recent crop census indicated a significant drop in production and productivity of cowpea agriculture, attributed to low and erratic rainfalls (MoA, 2010). Production is more dominant in the eastern part of the country and there are efforts by authorities to promote cowpea production in the Kalahari and Ghanzi Districts (Kalahari Desert), where conditions are generally unfavourable for crop production. Cowpea is a relatively drought-tolerant crop, has adapted to high temperatures and other stresses such as low soil fertility, and can cope with a wide range of soil pH, making it a crop of interest for the changing environmental conditions associated with climate change. Traits to be considered as potential selection targets for improving yield under water-limited conditions must be genetically correlated with yield and should have a greater heritability. Measurements of target trait such as yield should be rapid, accurate, and inexpensive (Tuberosa, 2012).

In light of impending climate change in the SASSCAL region, maize and cowpea varieties grown by farmers may not withstand the projected stresses, with resultant losses in productivity and potentially negative consequences for food security. One strategy for responding to this situation is to identify drought-adapted germplasm from farmers, gene banks, and research organizations that can withstand similar climatic conditions elsewhere. Therefore, two case studies were undertaken with the following objectives: (i) to evaluate and select maize germplasm obtained from the national gene bank in Zambia; (ii) to assess the effectiveness of drought tolerance indices as indicators for drought tolerance in cowpea; and (iii) to identify drought-tolerant cowpea genotypes from a large population growing under field conditions in Botswana. The selected local varieties can be useful genetic resources for direct production or may have their traits incorporated via plant breeding programs.

Case Study I. Agro-morphological evaluation of maize germplasm in Zambia

Field experiments

Two field studies were undertaken to identify and assess maize germplasm accessions held in the gene bank at Mount Makulu Research Station. The first field study was conducted on station to assess the agro-morphological diversity of the germplasm accessions and identify accessions with inherent characteristics such as early maturing that enable the crop to survive drought occurring later in the season. The second study involved participatory evaluation of 20 varieties grown in farmers' fields in the Rufunsa and Shiwuyunji districts.

Plant materials

A total of 50 maize germplasm accessions originally collected from Rufunsa, Shiwuyunji, and other regions with similar agro-ecological conditions and conserved in the Zambian national gene bank were involved in the on-station field trial.

Study sites

Agro-morphological characterisation of maize germplasm accessions in a single season involved one experimental site at Mount Makulu Research Station (15°33´S; 28°11´E). Participatory evaluation and selection of maize varieties involving farmers was undertaken on farmers' fields at sites in Rufunsa (15°04´S; 29°40´E) and Shiwuyunji (15°23´21.2″S; 27°42´9.3″E) situated in the Lusaka and Central Provinces of Zambia.

Experimental design and agronomic management at the research station

The germplasm accessions were grown in a single plot without replication. The maize germplasm accessions were planted at interrow spacing of 90 cm and intrarow spacing of 30 cm, providing a spacing of 2 m between accessions.

Agro-morphological data at the vegetative and reproductive growth stages of the crop were recorded for 10 randomly selected plants for each accession according to the International Board for Plant Genetic Resources descriptor list for maize (IBPGR ROME, 1991). We measured the following morphological characteristics: days to tassel (DTT), days to silking (DTS), plant height (PH), ear height (EH), number of leaves (NLL), tillering index (TI), stem colour (SC), tassel type (TT), number of kernel rows (NKR), kernel type (KT), and kernel colour (KC). Qualitative data were scored as binary data (present/absent). The agro-morphological traits measured on the 50 germplasm accessions of maize were subjected to principal component analysis using NTSYSpc 2.21 (Rohlf, 1998).

Experimental design of field experiments and participatory evaluation

We carried out participatory selection of the maize varieties at two sites in Zambia using farmers' own criteria in order to enhance adoption of the selected varieties. A total of 20 out of the 50 local maize varieties were involved in participatory evaluation at each of the two study sites (Tab. 1). The maize varieties involved in the study met the criteria of suitability for the target sites involved.

The field experimental design used for on-farm evaluation of the maize varieties was randomised complete block design (RCBD) with three blocks or replicates. A total of three fields of different farmers were involved at each of the two sites and each field represented one replicate or experimental block. Each field held a total of 20 maize accessions. At each study site, we included maize accessions that had previously been collected in the area. The accessions were: ZMB8172, ZMB4429, ZMB4436, and ZMB8196 at Rufunsa and ZMB8160, ZMB5205, and ZMB6846 at Shiwuyunji. Maize accessions were planted in four rows, each 5 m long, at interrow spacing of 90 cm and intrarow spacing of 30 cm. The plot dimensions were 2.7 m x 5 m, and in order to

Table 1: Maize germplasm accessions used in the participatory evaluation; accessions were collected from Rufunsa, Shiwuyunji, other regions, and the National Gene Bank in Zambia.

Serial No.	Accession	Local name	Site of evaluation
1	ZMB5045	Chilala	Rufunsa
2	ZMB8262	Chilala	Rufunsa
3	ZMB8217	Kafwamba	Rufunsa
4	ZMB8214	Local	Rufunsa
5	ZMB4429	Kafwamba	Rufunsa
6	ZMB8154	Sesheke	Rufunsa
7	ZMB8174	Mboni ya sintu	Rufunsa
8	ZMB8215	Kangalingali	Rufunsa
9	ZMB4745	Chulu chitu	Rufunsa
10	ZMB8212	Chilala	Rufunsa
11	ZMB8172	Chilala	Rufunsa
12	ZMB8213	Chilala	Rufunsa
13	ZMB8216	Chilala	Rufunsa
14	ZMB8165	Akansalika	Rufunsa
15	ZMB6611	Chiyongoli	Rufunsa
16	ZMB7476	Kampala	Rufunsa
17	ZMB4436	Gankata	Rufunsa
18	ZMB8196	Kanjele	Rufunsa
19	ZMB8256	Kanjele	Rufunsa
20	ZMB6653	Yachisi	Rufunsa
21	ZMB7456	Kanjele	Shiwuyunji
22	ZMB5203	Gankanta	Shiwuyunji
23	ZMB6639	Kafwamba	Shiwuyunji
24	ZMB6866	Gankata	Shiwuyunji
25	ZMB5195	Gankata	Shiwuyunji
26	ZMB5194	Kafwamba	Shiwuyunji
27	ZMB8260	Kafwamba	Shiwuyunji
28	ZMB6614	Gankata	Shiwuyunji
29	ZMB6863	Gankata	Shiwuyunji
30	ZMB6628	Gankata	Shiwuyunji
31	ZMB5205	Gankata	Shiwuyunji
32	ZMB6623	Jereman	Shiwuyunji
33	ZMB4231	Kafwamba	Shiwuyunji
34	ZMB8259	Kafwamba	Shiwuyunji
35	ZMB6843	Kapyapya	Shiwuyunji
36	ZMB4445	Gankata	Shiwuyunji
37	ZMB8160	Gankata	Shiwuyunji
38	ZMB6846	Gankata	Shiwuyunji
39	ZMB6656	Kasenga	Shiwuyunji
40	ZMB6653	Kafumbushi	Shiwuyunji

allow sufficient space between varieties, the distance between adjacent plots was maintained at 2 m.

Process of participatory selection of maize varieties

When the maize crop growth stage was nearing physiological maturity, farmers were invited to evaluate the performance of the maize varieties (Fig. 1). Prior to field evaluation of the varieties, farmers selected their own criteria to be used in the assessment. The traits of importance to farmers that formed the basis for selecting maize varieties were early maturity, high yielding ability, drought tolerance, and tolerance to field pests and diseases. Farmers were then asked to walk through the trial field and record the plot(s) containing the maize varieties they liked most based on their set criteria. Note that early maturity was considered an important criterion by farmers at both sites for two main reasons. First, early maturing varieties allowed farmers to harvest their crop earlier in the season in consideration of changed rainfall patterns; additionally, the trait permits the crop to escape drought periods which occur after fertilization. Both factors help ensure early and quick provision of cash and food to farmers' households to alleviate hunger.

Figure 1: A group of farmers involved in participatory evaluation of maize germplasm accessions on farm at one of the three sites in Rufunsa District.

Table 2: Principal components (PC), eigenvalues, proportion, and cumulative variance attributed to the 10 traits of maize germplasm

PC	Variable	Eigenvalue	Percent	Cumulative
1	Days to 50% Tasseling (DTT)	2.46680897	24.6681	24.6681
2	Days to Silking (DTS)	1.89682003	18.9682	43.6363
3	Plant Height (PH)	1.26775672	12.6776	56.3139
4	Ear Height (EH)	1.16708705	11.6709	67.9847
5	Number of leaves above upper ear (NLUE)	1.10279524	11.028	79.0127
6	Tassel Type (TT)	0.82457977	8.2458	87.2585
7	Number of Kernel Rows (NKR)	0.64926709	6.4927	93.7511
8	Kernel Type (KT)	0.41567904	4.1568	97.9079
9	Kernel colour (KC)	0.17830817	1.7831	99.691
10	1000 Kernel weight (1000KW)	0.03089793	0.309	100

Results

Principal component analysis (PCA) yielded five significant principal components with significant Eigen value > 1.0: days to 50% tasseling (DTT), days to silking (DTS), plant height (PH), ear height (EH), and number of leaves above upper ear (NLUE), with each explaining 24.7%, 19.0%, 12.7%, 11.7%, and 11.0% of the total observed variation respectively (Tab. 2). Cumulatively, these five principal components explained a total of 79.1% of the observed variation.

The plot of the first two components of the PCA of the maize varieties and the 10 traits yielded a pattern in which traits days to tassel (DTT) and days to silking (DTS) enabled grouping of the following genotypes: ZMB8178, ZMB8244, ZMB7442, and ZMB7283 (Fig. 2). In a similar manner, ear height (EH), plant height (PH),

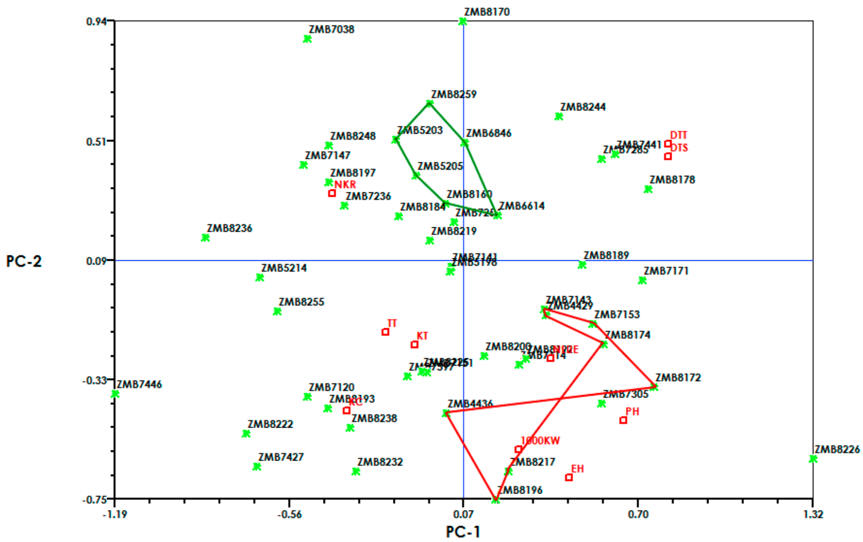

Figure 2: A two-dimensional plot of the 50 maize germplasm accessions and 11 traits studied. The traits used in the analysis were days to 50% tassel (DTT), days to silking (DTS), plant height (PH), ear height (EH), number of leaves (NLL), tillering index (TI), stem colour (SC), tassel type (TT), number of kernel rows (NKR), kernel type (KT), and kernel colour (KC). Principal Component 1 (PC1) explains 25% and PC2 explains 19% of the observed variation. Preferred maize varieties in Shiwuyunji and Rufunsa are in green and red boxes respectively.

thousand-kernel weight (1 000 KW), and number of leaves above upper ear (NLUE) allocated ZMB7305, ZMB8172, ZMB8217, ZMB8196, ZMB7235, ZMB7153, and ZMB7171 into one group. Similarity among tassel type (TT), kernel type (KT), and kernel colour (KC) enabled us to allocate ZMB8232, ZMB8238, ZMB7120, ZMB7427, ZMB8222, ZMB4436, and ZMB8255 to another group.

Through this analysis and farmers' own selection criteria, six maize varieties were selected in Shiwuyunji and Rufunsa. The six maize varieties (ZM8259, ZM6614, ZM8160, ZM5205, ZM6846, and ZM5203) scored high in Shiwuyunji. Of the six selected maize varieties, ZM8259 and ZM6614 were the most preferred by farmers. In Rufunsa, the maize varieties that ranked highly during farmer evaluation were ZM8217, ZM8196, ZM8172, ZM4429, ZM4436, and ZM8174, of which ZM8217 and ZM8196 were outstanding. The preferred maize varieties were superior with respect to earlier maturity, higher grain yield, increased cob size, and increased grain size.

Discussion

The analysis of agro-morphological data in this study indicates that there was significant variation among the maize varieties; their grouping patterns seem to conform to the geographic origin of the collections, suggesting that they could be adapted to specific regions. Based on morphological and reproductive traits, Llaurado and Moreno-Gonzalez (1993) and Ruiz de Galarreta and Alvarez (2001) screened and measured variability of maize germplasm accessions and clustered them into separate groups. PCA indicates that days to 50% tasseling, days to silking, plant height, ear height, and number of leaves above upper ear are the most important descriptors, accounting for more than 50% of the phenotypic variation expressed in the maize accessions; these are therefore the most useful traits for studying the variability of maize populations. Our results suggest the possibility of agro-morphological variation in the maize accessions under study being influenced by specific environmental factors. The results from this study also seem to demonstrate that in addition to the open-pollinated nature of the crop, the role of farmers in the selection process and the crop's adaptation to climatic and environmental conditions may perhaps explain the observed variation in the maize populations (Llaurado & Moreno-Gonzalez, 1993). In a similar manner, Ng'uni et al. (2011) reported the influence of geographical locality for close similarity of sorghum accessions, attributing this pattern to the existence of variety exchange patterns. Categorising germplasm accessions into morphologically similar and, presumably, genetically similar groups (Souza & Sorrells, 1991) is useful for selecting parents for crossing. Crossing germplasm accessions belonging to different groupings could maximize opportunities for transgressive segregation. Considering the higher probability that unrelated genotypes would contribute unique desirable alleles at different loci (Peeters & Martinell, 1989; Beer et al., 1993), the grouping of maize accessions in the present study would be of practical value to breeders in selecting representative accessions for crossing programmes.

Given that climate change and increased genetic erosion due to both natural and human-driven factors seem to be evident and irreversible trends, initiatives focusing on restoration of local germplasm obtained from the national gene bank become necessary. Local crop varieties in farmers' fields evolve with changing climate and are therefore less prone to environmental stresses such as drought. As observed by other authors (Teshome et al. 2001; Newton et al. 2010), genetic variation for stress tolerance is broadly explained by differences among and within traditional crop varieties. The involvement of local farmers through participatory variety selection becomes critical to increasing the chances of acceptance and adoption of crop varieties suitable for specific agro-ecological regions. The selected maize varieties in this study were subsequently involved in the guided participatory seed multiplication programme for distribution to other households in the two areas. Conserved samples of these varieties are readily available to breeders for use in their breeding programmes.

Case Study II: Evaluation of cowpea germplasm for drought tolerance in Botswana

Greenhouse experiment

Plant materials

Twenty cowpea genotypes were obtained from farmers in Hukuntsi (Kalahari Desert), Lecheng, and Makoro (Eastern Central District) and the National Plant Genetic Resources Centre at the Department of Agricultural Research, Ministry of Agricultural Development and Food Security (NPGRC-DAR) in Botswana (Tab. 3). Further, six of the genotypes were tested for drought tolerance in the Kalahari Desert under its adverse environmental conditions.

Study site

The greenhouse experiment at Botswana University of Agriculture and Natural Resources site (24° 38′ 41.5″ S, 25° 54′ 26.46″ E, and 983 m elevation) was conducted from December 2013 through January 2014, where the following average environmental conditions were recorded: 11 hours sunshine duration, 17/31°C minimum and maximum temperatures, and 50% relative humidity. However, the greenhouse temperature was modulated at 20°C minimum and 30°C maximum.

Experimental design and agronomic management

Twenty cowpea genotypes were planted in wooden boxes measuring 117 cm (length) by 85 cm (width) and 12 cm (depth). Seeds were planted at distances of 10 cm between rows and 5 cm between plants. Plants were raised under well-watered conditions until the first trifoliate leaf was fully expanded after about four weeks. Half of the plants were then exposed to mild drought stress by withdrawing irrigation after soil moisture content had reached 50% of field capacity. The other half of the plants were maintained at field capacity moisture content until sampling. Soil moisture was monitored with the MpKit portable soil moisture sensor kit (ICT International, Armidale, New South Wales, Australia) following manufacturer protocol. The experimental design was randomised complete block design (RCBD) and each treatment was replicated four times.

Table 3: Description of 20 cowpea genotypes used for drought tolerance evaluation; germplasm was collected from various sources in Botswana

Serial No	ID No	Genotypes	Source
1	BCA001	Blackeye	NPGRC-DAR
2	BCA002	Speckled Grey-1	Farmer-Hukuntsi
3	BCA003	Makoro	Farmer-Makoro
4	BCA004	Speckled brown-1	Famer-Lecheng
5	BCA005	B 212	NPGRC-DAR
6	BCA006	B069 E	NPGRC-DAR
7	BCA007	B079-C	NPGRC-DAR
8	BCA008	B020-A	NPGRC-DAR
9	BCA009	Mahutohuto	Farmer-Hukuntsi
10	BCA010	B 505A	NPGRC-DAR
11	BCA011	B 500	NPGRC-DAR
12	BCA012	B111-B	NPGRC-DAR
13	BCA013	Tswana	Farmer-Hukuntsi
14	BCA014	E 129	NPGRC-DAR
15	BCA015	E 129 (2)	NPGRC-DAR
16	BCA016	Speckled brown	Farmer-Tshane
17	BCA017	Tswana Red	Farmer-Hukuntsi
18	BCA018	Bo11-A 7	NPGRC-DAR
19	BCA019	Lecheng	Farmer-Lecheng
20	BCA020	E7	NPGRC-DAR

Data collection and analysis

After 11 days, plants were harvested to determine above-ground biomass yield for well-watered controls (BYW) and drought-stressed treatment (BYD). The following indices were calculated as described in Tab. 4: biomass stress susceptibility index (BSSI), relative drought index (RDI), stress tolerance index (STI), tolerance (TOL), mean production (MP), drought resistance index (DI), and biomass reduction (BR). Pearson's correlation coefficients (*r*) between BYW, BYD, and drought tolerance indices were calculated to determine the most suitable index for monitoring drought.

Field experiment

Plant materials

The field experiment involved six genotypes (BCA001, BCA002, BCA004, BCA009, BCA013, BCA016, BCA019). The genotypes underwent the greenhouse test and were preferred by local farmers; two of them, BCA001 (Blackeye) and BCA013 (Tswana), were varieties released by the Department of Agricultural Research for production and are the most prominent among pulses in the Botswana Agriculture Marketing Board retail shops.

Study site

The Hukuntsi Site (24° 1′ 1″ S, 21° 52′ 8″ E, and 1118 m elevation) is located in the heart of the Kalahari Desert. The soils are characterised as deep sand, generally

Food security

Table 4 Description of drought tolerance indices and their definitions used in the study. BYW: biomass yield under well-watered conditions; BYD: biomass yield under drought stress conditions; TOL: tolerance; MP: biomass mean productivity; STI: biomass stress tolerance index; SSI: biomass stress susceptibility index; DI: drought index; and BR: biomass reduction

No.	Index and abbreviation	Formula	Description	Reference
1	Tolerance (TOL)	$BYW - BYD$	A larger value of TOL represents greater sensitivity to drought	Rosielle and Hamblin, (1981)
2	Mean Productivity (MP).	$\frac{BYD + BYW}{2}$	High MP indicate drought tolerance.	Fernandez *et al.*, (1992)
3	Stress tolerance index (STI). High STI indicate more tolerance	$\frac{(BYD \times BYW)}{(B\bar{Y}s^2)}$	High STI indicate more tolerance	Fischer and Maurer, (1978)
4	Stress Susceptibility Index (SSI).	$\frac{1-(BYD/BYW)}{1-(B\bar{Y}D/\,B\bar{Y}W}$	SSI<1 indicate more resistance to drought	Fischer and Maurer, (1978)
5	Drought Resistance Index (DI).	$[(BYWxBYD)/BYW/B\bar{Y}D]$	High DI indicate drought tolerance	Fischer and Maurer, (1978)
6	Biomass Reduction (BR).	$\frac{(BYW - BYD]}{BYW}$	Low BR indicates drought tolerance	Harb *et al.*, (2010)

exceeding 60 metres; they are low in organic matter and could be extremely dry. During the December 2013 through May 2014 experimental period, an on-site rain gauge recorded a total precipitation of 132 mm. A weather station located 2 km away from the farm site recorded averages of 10 hours sunshine duration, 18°C minimum and 31°C maximum air temperature, and 68% average humidity during the period.

Experimental design and agronomic management

The experiment was planted in a farmer's field on 15 December 2014 in Hukuntsi (Kalahari Desert). The experimental design was randomised complete block design (RCBD) and each treatment was replicated four times. Weeding was carried out 30 days after sowing. In the months of January and February 2015, an extended period of lack of rainfall and high heat imposed severe drought stress and plant death was observed at the vegetative stage.

Table 6: Correlation coefficient between biomass yield and tolerance indices measured from 20 cowpea genotypes tested in the greenhouse. * and ** significant at 0.05 and 0.01 levels. BYW: biomass yield under well-watered conditions; BYD: biomass yield under drought stress conditions; TOL: tolerance; MP: biomass mean productivity; STI: biomass stress tolerance index; SSI: biomass stress susceptibility index; DI: drought index; and BR: biomass reduction (see Tab. 4).

	BYW	BYD	TOL	MP	STI	SSI	DI	BR
BYW	1							
BYD	0.506*	1						
TOL	0.970**	0.28	1					
BMP	0.980**	0.660*	0.90**	1				
BSTI	-0.660**	0.540*	-0.81**	-0.52*	1			
BSSI	-0.430*	0.25	-0.55*	-0.31	0.84**	1		
DI	-0.660**	0.25	-0.81**	-0.52*	1.00**	0.84**	1	
BR	0.700**	- 0.180*	0.83**	0.57**	-0.99**	-0.85**	-0.99**	1

Data collection and analysis

At approximately 55 days after sowing, data on plant survival was scored as the ratio of dead to total plants in a plot. This was expressed as plant drought survival percentage (PDS%). We used ANOVA with Fisher's LSD post-hoc test to analyse data. Means were considered significantly different when $p \leq 0.05$. To determine relationships between individual drought indices and PDS%, linear response models were fitted and relationships were considered statistically significant at $p \leq 0.05$.

Table 5: Drought tolerance indices of 20 cowpea genotype under stress and non-stress conditions in a greenhouse. BYW: biomass yield under well-watered conditions; BYD: biomass yield under drought stress conditions; TOL: tolerance; MP: biomass mean productivity; STI: biomass stress tolerance index; SSI: biomass stress susceptibility index; DI: drought index; and BR: biomass reduction

Genotypes	BYW	BYD	TOL	MP	STI	SSI	DI	BR
BCA001	8.098	2.29	5.808	5.194	16.086	0.546	3.016	0.637
BCA002	6.664	2.434	4.23	4.549	5.844	0.288	1.096	0.519
BCA003	7.718	2.725	4.993	5.222	5.649	0.333	1.059	0.545
BCA004	4.823	1.672	3.151	3.248	5.547	0.355	1.04	0.552
BCA005	1.891	2.223	-0.332	2.057	18.809	3.072	3.527	-0.337
BCA006	6.549	1.867	4.682	4.208	4.561	0.54	0.855	0.602
BCA007	4.446	1.03	3.416	2.738	3.707	0.665	0.695	0.627
BCA008	2.224	2.236	-0.012	2.23	4.525	3.952	0.848	-0.333
BCA009	5.53	2.528	3.002	4.029	7.314	0.5	1.371	0.505
BCA010	2.814	1.305	1.509	2.06	7.42	-0.215	1.391	0.337
BCA011	4.185	1.641	2.544	2.913	6.274	0.178	1.176	0.496
BCA012	3.86	1.529	2.331	2.695	6.338	0.161	1.188	0.472
BCA013	5.953	1.939	4.014	3.946	5.211	0.424	0.977	0.566
BCA014	3.163	1.488	1.675	2.326	7.527	-0.262	1.411	0.341
BCA015	4.59	1.57	3.02	3.08	5.473	0.371	1.026	0.571
BCA016	6.542	2.288	4.254	4.415	5.596	0.345	1.049	0.512
BCA017	3.952	1.569	2.293	2.806	6.717	0.424	1.259	0.416
BCA018	6.173	1.879	4.294	4.026	4.87	0.488	0.913	0.599
BCA019	6.518	2.165	4.353	4.342	5.315	0.404	0.996	0.56
BCA020	4.174	1.339	2.835	2.757	5.133	0.439	0.962	0.594

Results

Drought tolerance indices for cowpea

Biomass yield under both well-watered (BYW) and drought stress (BYD) conditions were used to calculate the drought indices (Tab. 5). There was a positive and significant correlation between BYW and BYD ($r^2 = 0.50$). Significant correlations were observed between BYW and all indices (TOL, MP, STI, SSI, DI, and BR), whereas BYD was correlated with MP only (Tab. 5). Correlation analysis between the indices showed that that TOL was significantly correlated with all other indices; MP significantly correlated with TOL, STI, and DI, but not with SSI. The STI index significantly correlated with all other indices (Tab. 6). The SSI significantly correlated with TOL, STI, DI, and BR, but not with MP. The DI index significantly correlated with all other indices. A strong positive correlation between STI and DI was observed.

Performance of cowpea genotypes under greenhouse conditions

The genotypes with high values of STI and DI were considered tolerant to drought stress under greenhouse conditions. Drought-tolerant genotypes were (Blackeye), BCA009 (Mahutohuto), and BCA005 (B212), whereas BCA006 (B069), BCA007 (B079-C), BCA008 (B020-A), and BCA013 (Tswana) were drought sensitive.

Performance of cowpea genotypes under field conditions

Under severe drought stress in the field, there was a mean survival of 71%. The highest survival rates were attained by BCA001 (Blackeye) (96.4%), BCA009 (Mahutohuto) (96.2%), and BCA016 (Speckled brown) (90.6%), while the lowest survival rates were recorded for (BCA019) (38.8%) and BCA002 (Speckled grey-1) (42.9%) (Fig. 3). The genotypes with the highest survival rates under field conditions were considered drought tolerant.

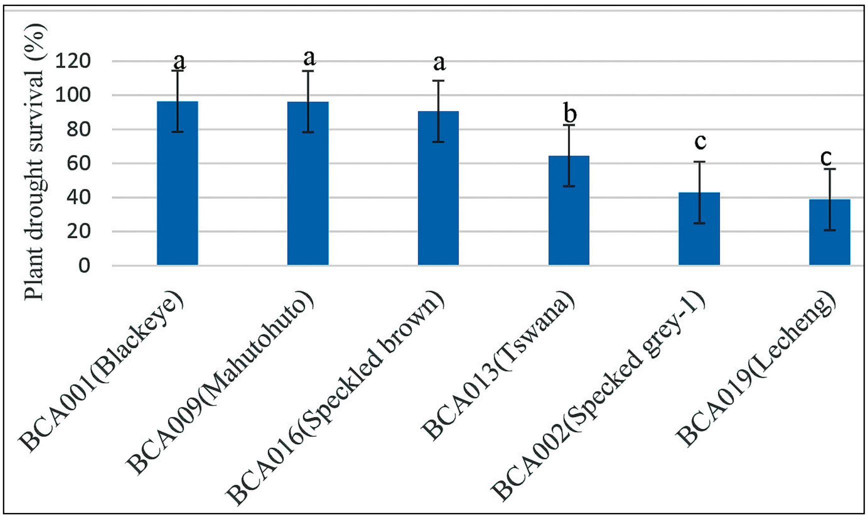

Figure 3: Effects of severe drought stress on the survival of six cowpea genotypes in the field in Hukuntsi (Kalahari Desert). At 55 days after planting, total number of plants was scored and survival (%) was calculated as the proportion of living to total number plants in a sampled row.

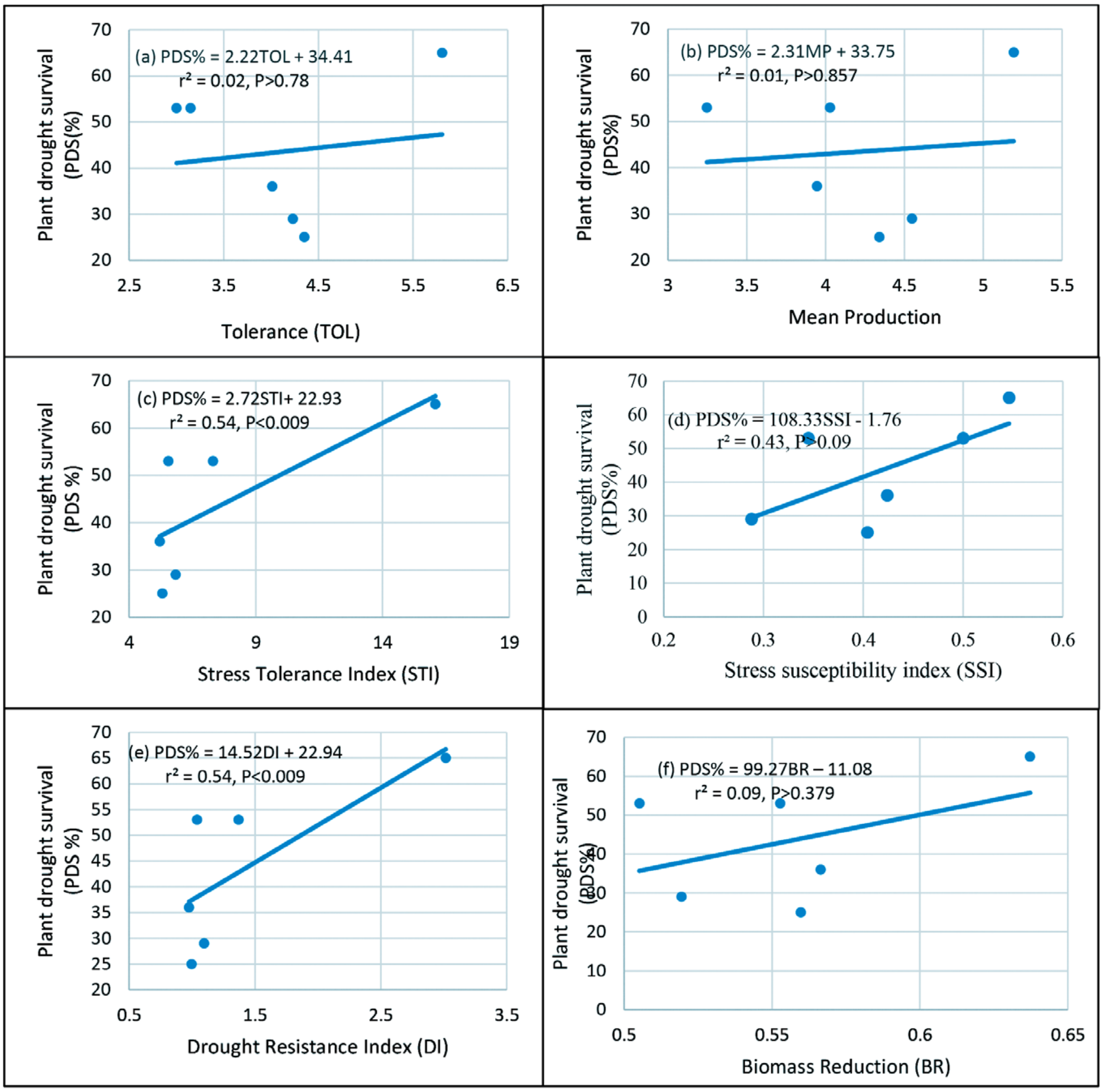

Figure 4: Relationships between drought tolerance indices and plant survival (%) in the field. Plants were exposed to drought stress for 11 days and drought tolerance indices were calculated and described as section 5.4.

Correlation between greenhouse and field data on plant survival under severe drought

A cross-check of the response of the genotypes to mild drought stress in the greenhouse study with the severe drought stress under field conditions confirmed that BCA001 (Blackeye), BCA009 (Mahutohuto), and BCA016 (Speckled brown) were more drought-tolerant than BCA013 (Tswana), BCA019 (Lecheng), and BCA002 (Speckled grey-1) (Fig. 4). PDS% was significantly correlated with STI ($r^2 = 0.54$, $p < 0.009$) and DI ($r^2 = 54$, $p < 0.009$) and not with TOL, MP, SSI, or BR.

Discussion

The greenhouse study indicated a high correlation between TOL and STI; moreover, it indicated that the two indices significantly correlated with all other indices. STI was also correlated with BYW and BYD, which showed its reliability and suggested that it may be the most suitable selection index for cowpea under greenhouse conditions. A suitable index must have a significant correlation with yield under both conditions (Mitra, 2001), which suggests that it can select genotypes under either drought or well-watered conditions. Other studies have identified STI to be a suitable index for drought tolerance selection for cowpea (Belko et al., 2014, Batieno et al., 2016) and for wheat (Naghavi et al., 2013).

The Kalahari Desert environment presented an opportunity to select cowpea for drought tolerance, where plant death occurred as a result of low rainfall and high temperatures in the months of January 2014. The survival rate (PDS%) of the different genotypes ranged from 38% to 96%, indicating that there is genetic variability for drought tolerance among the tested germplasm. Further, the PDS% results showed that the BCA001 (Blackeye), BCA009 (Mahutohuto), and BCA016 (Speckled brown) genotypes were more drought tolerant than BCA013 (Tswana), BC002 (Speckled grey-1), and BCA019 (Lecheng). It is worth noting that the two landraces, BCA009 (Mahutohuto) and BCA016 (Speckled brown), were collected from farmers in Hukuntsi (Kalahari Desert) and are popular among the local farmers for production, which indicates their adaptability. The variety BCA001 (Blackeye) was selected for Botswana's local arid environment by the Department of Agricultural Research.

Regression analysis between the greenhouse study and PDS% revealed significant association between STI and DI, which indicates the reliability of the two in selecting cowpea genotypes for the more hostile field environment. The results further confirm the utility of STI as the index most suitable for cowpea drought tolerance selection. The STI index has also been suggested for heat temperature tolerance selection (Porch, 2006; Porch et al., 2009), which is characteristic of the study area.

General conclusions and recommendations

Participatory evaluation of germplasm is important to assess plants' specific area suitability and to encourage farmer adoption of varieties perceived to be suitable for local conditions. Maize varieties that were selected by farmers due to their early maturation and perceived hardy grain type for withstanding postharvest storage pests in Shiwuyunji and Rufunsa have the potential to be suitable for other areas with similar agro-ecological characteristics. The cowpea study in Botswana has identified three genotypes, BCA001 (Blackeye), BCA009 (Mahutohuto), and BCA016 (Speckled brown) as on-farm drought tolerant. These can be recommended for production in the Hukuntsi (Kalahari Desert) environment to mitigate recurring drought, which is a permanent feature of the area and likely to increase in the future. The maize and cowpea genetic materials that were identified as suitable for production in Zambia and Botswana could be also be used for crop improvement programs in the SASSCAL region or parts of Sub-Saharan Africa with similar agro-ecologies. Involvement of smallholder farmers through participatory variety selection of promising crop varieties increases chances of adoption of better-performing candidate varieties that meet farmers' specific criteria in their specific localities.

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