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Drought Resistance Indices for Screening of Potato (*Solanum tuberosum* L.) Genotypes

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ABSTRACT

In breeding for drought tolerance, availability of precise, cheap and easy to apply selection tool is critical. The aim of the present study was to identify potential screening tools that are useful for selection of drought tolerant genotypes in potato and select drought resistant potato genotypes. The study assessed sixty clones arranged in a 10×6 alpha lattice design with two replicates in a managed stress experiment. Two irrigation treatments were applied: fully watered non-stress and terminal drought, where the irrigation water supply to the crop was withheld after 50 % flowering to induce post-flowering stress. Stress indices were calculated based on tuber yield of genotypes in both stressed and non-stressed conditions. Identification of drought tolerant genotypes based on a single index was less informative as different indices identified different genotypes as drought tolerant. Hence, to determine the most desirable drought tolerant clones rank sum of indices, correlation, and bi-plot display of the principal component analysis was employed. The indices modified stress tolerance index based on non-stressed yield, Men productivity, Geometric mean productivity, Stress tolerance index, Harmonic mean, modified stress tolerance index based on stressed yield and Yield index exhibited strong association with both yield under stressed and non-stressed yield. These indices discriminated drought tolerant genotypes with higher tuber yielding potential both under stress and non-stress conditions. Genotypes CIP-398180.612, CIP-397069.5, and CIP-304371.67 were identified as drought tolerant. These genotypes could be potentially grown both under drought prone and potential environments and these selection attributes could help to develop climate resilient potato varieties.

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Introduction

Potatoes are fairly cheaper and main part of dishes for peoples across the globe due to their high yield per unit of time, space and cost. It has also a promising prospect in improving the nutritional quality of the basic human diets in both rural and urban areas. There are evidences indicating that potatoes contain significant amounts of vitamins, macronutrients, micronutrients, and important antioxidants, including phenolic acids, flavonoids, ascorbic acid, carotenoids, and tocopherols which are essential in the human diet (Brown, 2005; Gumul et al., 2011). It delivers a high amount of energy per unit of land, water and time with wider consumer acceptance (Anderson et al., 2010). Such a crop is certainly imperative for Ethiopia, where inadequate supplies of protein and calories are the apparent nutritional problems.

In 2016/17, the area under potato production is about 66,923.35 hectares with 13.7 tha^{-1} average productivity (CSA, 2017). Despite the efforts made to improve its productivity level, yield at farmer level is still very low and is about one-fourth of achievable yields (34-47 tha^{-1}) at research stations (MOA, 2016), which is about 83 and 61% of the average African and global yields, respectively. Many diverse and complex biotic, abiotic, and anthropogenic factors have contributed to the gap between the attainable potential yield and the existing low productivity of potato in Ethiopia.

Among the abiotic stresses, drought is the most complex and serious danger to global agricultural production (Cattivelli, 2008, Pennisi, 2008). Potato regularly suffers a transient water deficit in most of the rain-fed growing regions due to erratic rainfall or inadequate supplemental irrigation techniques (Thiele, 2010). Cut-off rain late in the growing season is the main cause for potatoes to suffer from drought in the "Belg" (February to May) and "Belmehr" (March to August) season production practices in the major production ecologies in Ethiopia (Asredie et al., 2015). Moreover, drought tolerance is amongst the priority traits growers make choice for cultivars to plant with. The search for and development of drought tolerant varieties are utmost urgency. Therefore, this particular study was carried to address this high priority issue. The objective of this study was to evaluate selection indices en route for identifying drought resistant clones of potato.

Materials and Methods

Description of the Study Area

The study was conducted under irrigated condition in 2015/16 at Koga trial site of Adet Agricultural Research Center located in Amhara National Regional State, Ethiopia. It has got an elevation of 1960 meter above sea level. Its soil represents a heavy clay-textured red Nitosol. A detail of climatological and geographic descriptions of the study area are indicated below in Tables 1 and Figure 1, respectively.

Experimental Materials

The experiment was conducted using a total of 60 potato clones of which 52 are introduced from CIP (*Centero Internacionale de la Papa*), Lima, Peru, six are released varieties in Ethiopia, one introduced variety and one is a local check cultivar (Table 2).

Experimental Design and Management

The experiment was laid out in a 10 x 6 alpha lattice design with two replications and under two moisture regimes (stressed and non-stressed). Well-sprouted seed tubers were planted at a spacing of 75cm between rows and 30 cm between plants on a plot. All other standard agronomic operations such as earthing-up, weeding, and fertilization were uniformly carried-out over entire experimental plot irrespective of water regime.

Under non-stressed treatment, genotypes were regularly watered using surface furrow irrigation at a week interval until physiological maturity, while in the stressed treatment; the genotypes were regularly irrigated at a week interval till 50 % of the genotypes initiated flowering and then totally cut-off irrigation water supply till the end of maturity starting from 50% flowering stage of each treatment. The non-stress trial received 6-8 times irrigations between flowering and physiological maturity to ensure optimum crop growth. The stress plots were covered with a movable rain out shelter when the rain seems to shower.

Table 1 Metrological description of the study area during the cropping months

Parameters	January	February	March	April
Minimum temperature (°C)	7.40	8.73	10.44	12.17
Maximum temperature (°C)	28.60	31.32	30.89	30.56
Mean Rain fall (mm)	3.43	4.88	15.13	44.51
Relative humidity (%)	48.19	44.25	42.06	42.35
Sunshine hours (hr.)	9.51	8.99	8.78	8.73

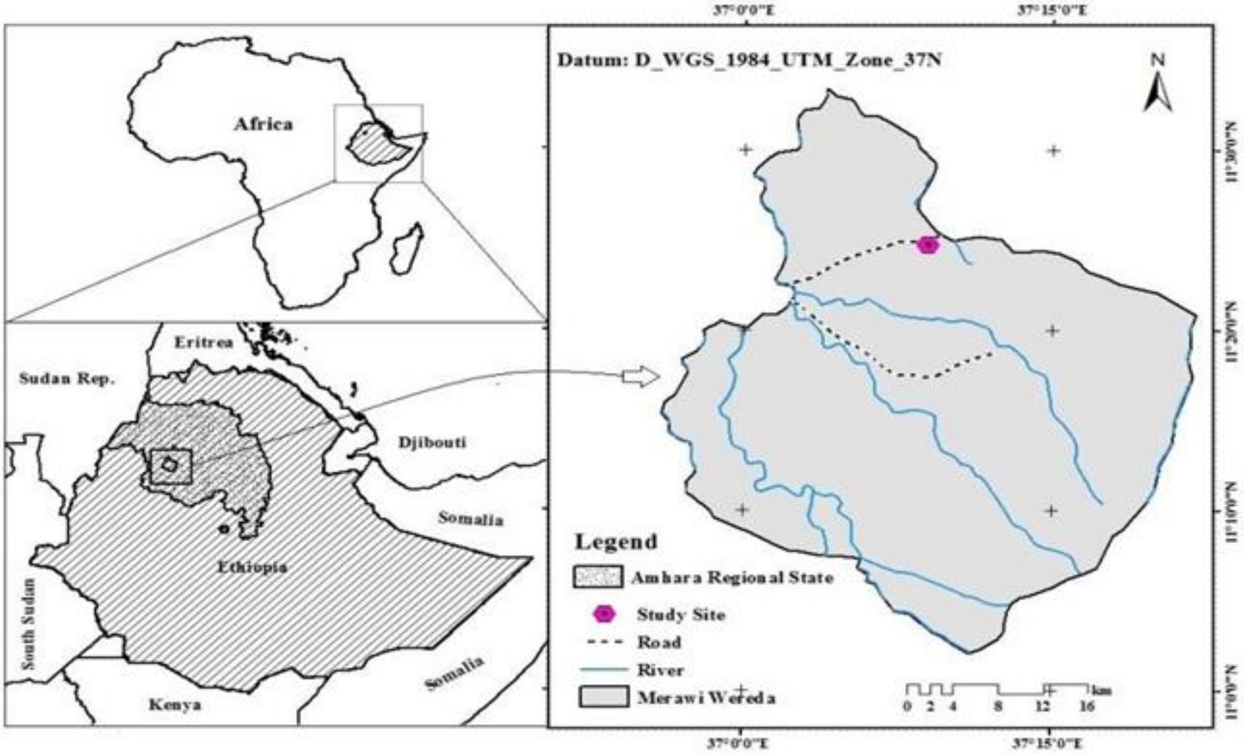

Figure 1 Map of the study area

Table 2 List of potato clones used in the study

Clone ID	Code	Clone ID	Code	Clone ID	Code
Guassa	1	CIP-381379.12	21	CIP-396004.225	41
CIP-304345.47	2	CIP-310135.14	22	CIP-398190.735	42
CIP-396038.101	3	CIP-395077.12	23	CIP-398193.65	43
Belete	4	CIP-301024.14	24	Granola	44
CIP-393077.54	5	CIP-301040.63	25	CIP-397054.3	45
CIP-391045.74	6	CIP-301024.95	26	CIP-396036.201	46
CIP-304356.32	7	Jallene	27	CIP-399048.24	47
CIP-395169.17	8	CIP-302498.7	28	CIP-399001.44	48
CIP-398089.119	9	CIP-396037.215	29	Gudene	49
CIP-396285.1	10	CIP-398192.41	30	CIP-397014.2	50
CIP-391533.1	11	CIP-398208.29	31	CIP-300054.29	51
CIP-392639.34	12	CIP-398190.53	32	CIP-395015.6	52
CIP-398190.605	13	CIP-397029.21	33	CIP-391580.3	53
CIP-380011.12	14	CIP-391011.17	34	CIP-399085.17	54
CIP-393227.66	15	CIP-396272.21	35	CIP-300099.22	55
CIP-301044.36	16	CIP-384866.5	36	CIP-304371.67	56
CIP-398180.612	17	CIP-398208.704	37	CIP-302499.3	57
CIP-397069.5	18	Gorebella	38	CIP-396272.37	58
CIP-396046.105	19	CIP-396027.205	39	Shenkolla	59
CIP-394898.13	20	CIP-391065.69	40	Ater abeba	60

NB: the respective entry codes represent the clone ID throughout the write-up.

Table 3 Drought resistance indices used in the study

Indices	Formula	References
Relative drought index (RDI)	((Ysi/Ypi)/(Ys/Yp))	(Fischer and Maurer, 1978)
Stress susceptibility index (SSI)	(1-(Ysi/Ypi))/(1-(Ys/Yp))	(Fischer and Maurer, 1978)
Tolerance (TOL)	Ypi-Ysi	(Rosielle and Hamblin, 1981)
Drought intensity index (DII)	1-(Ysi/Ypi)	(Fernandez, 1992)
Stress tolerance index (STI)	(Ypi x Ysi)/Yp2	(Fernandez, 1992)
Geometric mean productivity (GMP)	$\sqrt{\text{Ypi x Ysi}}$	(Fernandez, 1992)
Mean productivity (MP)	(Ypi + Ysi)/2	(Rosielle and Hamblin, 1981)
Yield index (YI)	Ysi/Ys	(Gavuzi et al. 1997)
Yield stability index (YSI)	Ysi/Ypi	(Bouslama and Schapaugh, 1984)
Drought resistance index(DRI)	Ysi x (Ysi/Ypi)/Ys	(Lan, 1998)
Abiotic stress tolerance index (ATI)	((Ypi-Ysi)/(Yp/Ys))x (Ypi x Ysi)0.5	(Moosavi, 2008)
Stress susceptibility percentage index (SSPI)	((Ypi-Ysi)/2Yp) x 100	(Moosavi, 2008)
Harmonic mean (HM)	2 (Ypi x Ysi) / (Ypi+Ysi)	(Kristin et al. 1997)
Stress non stress production index (SNPI)	$\left[\sqrt[3]{\frac{\text{(Ypi+Ysi)}}{\text{(Ypi-Ysi)}}}\right] \text{x} \left[\sqrt[3]{\text{Ypi x 2Ysi}}\ \right]$	(Moosavi, 2008)
Modified stress tolerance index (K1STI)	(Ypi2/Yp2)x STI	(Farshadfar and Sutka, 2002)
Modified stress tolerance index (K2STI)	(Ysi2/Ys2)x STI	(Farshadfar and Sutka, 2002)
Rank sum (RS)	Rank mean + Standard deviation of ranks	

Where, Ysi: Total tuber yield of individual genotype under stress condition, Ypi: Total tuber yield of individual genotype under non-stress condition, Ys: mean of all the genotypes under stress condition and Yp: Mean of all the genotypes under non-stress condition.

Soil Moisture Test

Soil moisture during the plant growth period was recorded by installing a Watermark Meter (Model 2000ss, IRROMETER Company, INC, USA) on 12 representative points across the stress and non-stress fields. Measurements were taken at a soil depth of 15, 30 and 45cm during various growth stages *i.e.* at full emergence, 50 % flowering, 15 days from the onset of the stress, 30 days from onset of the stress and at physiological maturity.

Evaluation of Drought Resistance and Susceptibility of The Genotypes

Stress tolerance index was used to identify genotypes with higher tuber yield and drought resistance. For every genotype, the sixteen drought resistance indices were calculated based on their tuber yield in non-stressed and stressed conditions. The drought resistance indices were calculated following a mathematical formula described in Table 3.

Statistical Analysis

Rank of genotypes was calculated for each of stress resistance indices. Correlation coefficient among drought resistance indices and tuber yield in two conditions was performed by SAS ver. 9.1 statistical software. Moreover, the bi-plot display of principal component analysis was used to identify stress-tolerant and high yielding genotypes and to study the interrelationship between the drought resistance attributes using Minitab ver. 14 software.

Results and Discussion

Soil Moisture Conditions

The soil water content was considerably reduced from flowering onward until physiological maturity in the stress trial (Figure 2). The intensity of drought increased with increase in time from which the stress was induced and is verified in terms of increment of tension force on the plant root to suck water. Variation in moisture content was recorded at different soil depths both under stress and non-stress conditions. The soil moisture depletion started at the top soil layer and moved gradually down to the deeper soil layer due to deep percolation and/or evaporation. The observed gradual soil moisture depletion trend across the soil depth significantly affected the potato plant that possesses a shallow root system. The shaded area is the range (60-90 KPa) whereby irrigation should be employed.

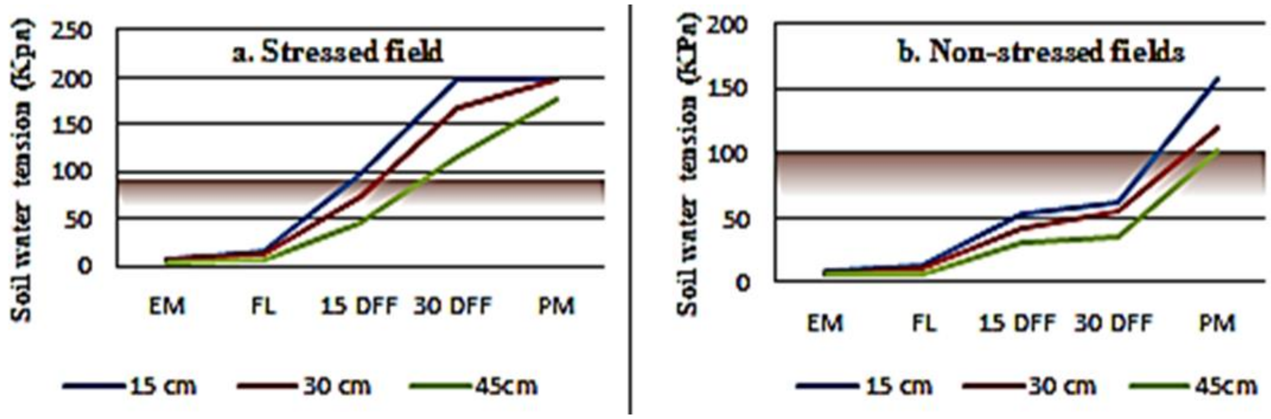

Figure 2 Soil moisture status of the experimental site

Table 4 Most resistant and susceptible genotypes based on rank sum of indices

Genotypes	Yp (tha^{-1})	Ys(tha^{-1})	MR	SDR	RS	Remark
CIP-398180.612	44.1	26.97	11	10.50	21.78	Resistant
CIP-397069.5	43.23	26.61	13	10.46	23.18	Resistant
CIP-304371.67	40.63	29.26	13	10.45	23.45	Resistant
CIP-399085.17	12.96	9.12	53	10.59	63.20	Susceptible
CIP-399048.24	16.12	8.93	51	10.54	61.65	Susceptible
Ater abeba	19.99	10.30	49	10.49	59.76	Susceptible

MR: mean rank; SDR: standard deviation of rank and RS: rank sum

Comparing Genotypes Based on Resistance Indices

To investigate suitable drought resistance indices for screening potato clones, different indices were calculated based on Yp and Ys (Table 4). The indices STI and GMP identified genotypes CIP-398180.612, CIP-304371.67 and CIP-397054.3 as the most drought tolerant and Ater abeba, CIP-399048.24 and CIP-399085.17 as the least drought adapted genotypes. TOL and SSPI identified CIP-395077.12, CIP-398208.29 and CIP-393077.54 as drought adapted genotypes, while as to the SSI and DII indices, CIP-396046.105, CIP-395077.12 and CIP-393077.54 were tolerant genotypes.

Though, the drought tolerance indices fail to judge consistently the drought tolerance level of the clones, STI, GMP, MP, YI, HM, K$_1$STI and K$_2$STI have ranked the genotypes more or less in similar fashion suggesting that these stress indices can be used interchangeably and this finding is in agreement with Gholinezhad et al. (2014) who reported as those indices are suitable for ranking of sunflower landraces based on their response for drought stress under mild stress condition.

The lack of consistency among the stress tolerance indices in discriminating the tolerant and susceptible genotypes warrants the use of multiple stress indices for selection of drought tolerant genotypes in potato. Hence, to determine the most desirable drought tolerant genotype based on multiple indices, the mean rank, standard deviation of ranks and rank sum of all drought tolerance criteria was calculated. Accordingly, genotypes CIP-398180.612, CIP-397069.5 and CIP-304371.67 exhibited the best mean rank, low standard deviation of ranks, and smaller rank sum, hence were the most drought tolerant genotypes. Similarly, genotypes CIP-399085.17, CIP-399048.24 and Ater abeba were identified as the most sensitive genotypes to drought.

Correlation among Stress resistance Indices

The correlation coefficients between Yp and Ys and other quantitative indices of stress tolerance were calculated (Table 5) to determine the most desirable drought tolerance criteria. According to Mitra (2001), a suitable index must have a significant correlation with yield under both conditions. STI, GMP, MP, YI, HM, K$_1$STI and K$_2$STI exhibited a strong and positive correlation with both Ys and Yp, suggesting that these parameters are suitable to discriminate drought tolerant genotypes with high tuber yield both under stress and non-stress conditions. A similar result was reported by Farshadfar et al. (2013), who found these parameters suitable for discriminating the landraces of bread wheat under stress and non-stress conditions.

Table 5 Correlation coefficient between Yp, Ys and drought resistance indices

	Yp	Ys	RDI	SSI	TOL	DII	STI	GMP	MP
Ys	0.67**								
RDI	-0.05	0.69**							
SSI	0.05	-0.70**	-0.99**						
TOL	0.50**	-0.30*	-0.88**	0.88**					
DII	0.05	-0.70**	-0.99**	0.99**	0.88**				
STI	0.86**	0.93**	0.42**	-0.42**	0.02	-0.42**			
GMP	0.89**	0.94**	0.41**	-0.41**	0.04	-0.42**	0.99**		
MP	0.92**	0.91**	0.33**	-0.33**	0.13	-0.33**	0.98**	0.99**	
YI	0.67**	0.99**	0.69**	-0.70**	-0.30*	-0.70**	0.93**	0.94**	0.91**
YSI	-0.05	0.70**	0.99**	-0.99**	-0.88**	-0.99**	0.42**	0.42**	0.33**
DRI	0.37**	0.93**	0.89**	-0.89**	-0.61**	-0.89**	0.76**	0.76**	0.70**
ATI	0.78**	0.08	-0.63**	0.63**	0.91**	0.63**	0.40**	0.41**	0.49**
SSPI	0.50**	-0.30*	-0.88**	0.88**	0.99**	0.88**	0.02	0.04	0.13
HM	0.84**	0.96**	0.48**	-0.48**	-0.04	-0.49**	0.99**	0.98**	0.98**
K_1STI	0.89**	0.77**	0.16	-0.16	0.25	-0.16	0.94**	0.90**	0.91**
K_2STI	0.68**	0.92**	0.56**	-0.56**	-0.21	-0.56**	0.94**	0.89**	0.87**
SNPI	0.35**	0.88**	0.85**	-0.85**	-0.57**	-0.85**	0.70**	0.71**	0.66**

	YI	YSI	DRI	ATI	SSPI	HM	K_1STI	K_2STI
Ys								
RDI								
SSI								
TOL								
DII								
STI								
GMP								
MP								
YI								
YSI	0.70**							
DRI	0.93**	0.89**						
ATI	0.08	-0.63**	-0.28*					
SSPI	-0.30*	-0.88**	-0.61**	0.91**				
HM	0.96**	0.49**	0.80**	0.34*	-0.04			
K_1STI	0.77**	0.16	0.53**	0.60**	0.25	0.88**		
K_2STI	0.92**	0.56**	0.84**	0.16	-0.21	0.91**	0.87**	
SNPI	0.88**	0.85**	0.96**	-0.28*	-0.57**	0.74**	0.48**	0.79**

* and ** represent significance at 5% and 1% probability levels, respectively

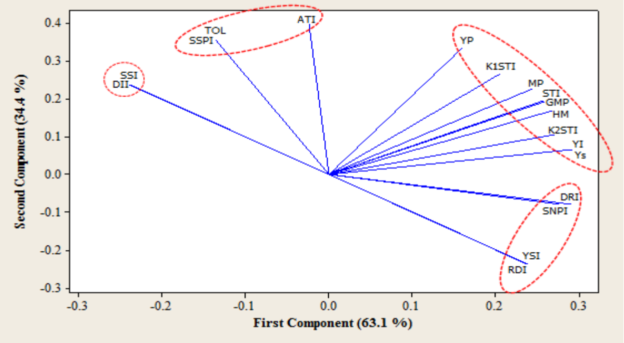

Figure 3 Loading plot of drought indices on potato

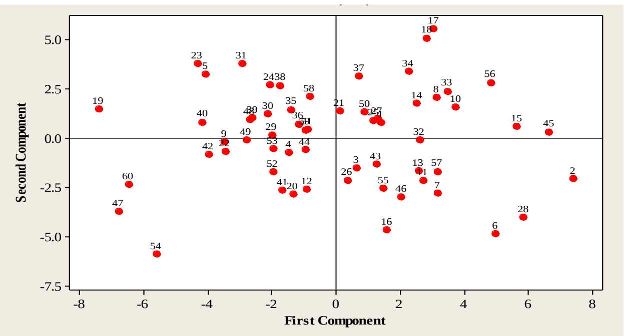

Figure 4 Score plot of potato genotypes for drought tolerance indices

Tuber yield under stress condition showed a negative and higher association with stress indices SSI and DII which is in agreement with Gholipouri et al. (2009). Therefore, SSI and DII indices are suitable to identify genotypes with low yield and susceptible to drought because under stress yield decreased with increasing SSI. Some other relationships revealed includes a strongly and positively correlation of GMP with STI, MP, HM, K_1STI, K_2STI and YI and amongst each other which is in accordance with the finding of Javed *et al.(2011)* on wheat. TOL and SSPI had a strong positive correlation with DII, SSI and ATI and amongst each other; RDI and YSI with DRI and SNPI and amongst each other. A strong negative correlation was found for RDI and YSI with DII, SSI, TOL, SSPI and ATI; DRI and SNPI with SSI, DII, SSPI and TOL; and YI with SSI and DII.

Principal Component Analysis (PCA)

PCA was performed to group drought tolerance indices based on their function as well as genotypes using their drought tolerance indices. The first two principal components contributing about 97.5% of the variance with eigenvalues of >1.0 were employed to draw a bi-plot graph. Provided that the bi-plot explained a sufficient amount of the total variation, the correlation coefficient among any two variables is approximated by the cosine of the angle between their vectors (Yan and Rajkan, 2002). Accordingly, acute angles indicate positive correlations, obtuse angles negative correlations and right angles no correlations.

In this study, the most prominent relations revealed by the bi-plot diagram (Figure 3 and 4) are:

- Bi-plot vectors for the indices K_1STI, MP, GMP, STI, HM, K_2STI, and YI remained in acute angle being in between the Yp and Ys vectors, signifying the presence of a strong positive association of these indices with tuber yield of potato in both conditions. These indices in cluster, therefore, could be used as selection criteria for screening of genotypes that are better adapted to environments with variable water availability. Similar results were reported between MP, GMP, STI and YI on Sorghum by Tesfamichael et al. (2015), and between GMP, STI, K_1STI, and K_2STI on maize by Kachapur et al. (2015). CIP-398180.612, CIP-397069.5, and CIP-304371.67 are superior and suitable for both environments.
- DRI and SNPI exhibited strong and positive association with Ys, therefore can be used to identify genotypes like CIP-304345.47, CIP-391045.74, CIP-301044.36 and CIP-302498.7, which were best performing only under drought prone environment.

Summary and Conclusion

Based on rank sum, correlation, and bi-plot display of principal component analysis, the indices K_1STI, MP, GMP, STI, HM, K_2STI, and YI exhibited strong association with both Ys and Yp, therefore, these indices can discriminate genotypes better adapted both under stressed and non-stress growing environments. Moreover, based on the stress indices genotypes CIP-398180.612, CIP-397069.5, and CIP-304371.67 were identified as drought tolerant. Therefore, they are recommended to be grown under drought prone areas and to be used as parents for improvement of drought tolerance in other cultivars.

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