Genetic diversity of 33 forage cactus pear accessions based on principal component analysis

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ABSTRACT

The present research was undertaken to assess genetic diversity of 33 forage cactus pear accessions introduced from different countries for their suitability in the existing fodder production system in Arabian Peninsula countries including Oman. These accessions were evaluated in randomized complete block design with four replications for two consecutive years 2014 and 2015 at Agriculture Research Center, Rumais in Oman. The characters cladode green and dry matter yields and their related traits plant height (cm), number of cladodes and cladode weight were considered for study. The results of principal component analysis (PCA) indicated that of the total four components, the first two components PC1 and PC2 accounted for 97.65 and 2.27%, respectively which in combination contributed to 99.92% of the total variation among characters studied in fodder cactus pear accessions whereas remaining two components PC3 (0.06%) and PC4 (0.02 %) contributed a meagre 0.08% to the total variation. The first principal component had high positive loading for only green matter yield with the highest value of 0.993 whereas second principal component had highest loading for plant height (0.998) in contributing to the diversity. However, PC3 and PC4 were accounted by higher positive loading in respect of dry matter yield (0.853) and number of cladodes (0.855). The results of correlation analysis indicated that of 10 possible correlations from five characters studied, seven correlations which were found significant ($p<0.05$) were also positive in nature of association. The scatter of accessions based on PC1 and PC2 scores resulted in grouping them into six clusters consisting of accession ranging from 1 to 9. These results could be applied in either selecting higher green matter yielding accessions from high yielding groups to recommend for either general cultivation or planning and execution of future breeding program for higher forage productivity in cactus by selecting accessions from different clusters as parents for hybridization.

Keywords: Cactus pear, cladodes, fodder yield, principal component analysis.

INTRODUCTION

Forage cactus pear is in general considered as an alternate fodder in arid areas of the world, as it is tolerant to drought (Nobel, 2009; Sony *et al.* 2015) and extreme heat (Guevara *et al*. 2011; Nefzaoui *et al*. 2014). It is highly efficient in water use (Snyman, 2005; Nobel, 2009) and moderately tolerant to salinity (Gajendra *et al.* 2014). Forage cactus could form a new diversified crop component of existing forage production system like fodder beet (Nadaf *et al.* 1999, 2000) in Arabian Peninsula in particular and West Asia and North African region; in general along with traditional perennial forage crops like alfalfa (*Medicago sativa* L.), Rhodes grass (*Chloris gayana* L.) and Buffel grass (*Cenchrus ciliaris* L.) species (Nadaf *et al*. 2004).

The forage cactus cannot replace already existing annual forage crops species. Cactus contains very low crude protein (1.4 - 4.0%) and hence can be used to feed livestock as supplementary feed as mixture of cactus with other forage having high protein source like alfalfa, Rhodes grass and annual forages like cowpea, and maize in appropriate proportions (Nefzaoui and Ben Salem, 2001; Nefzaoui *et al*. 2014).

Annual forage cactus green cladode (green matter) of 108 to 226 t ha^{-1} and dry matter yields of 13.9 to 40 t ha^{-1} were reported under irrigated conditions (Nefzaoui and Ben Salem, 2001; Sharafi *et al.* 2012). Principal component analysis (PCA) being multivariate analysis helps researchers to differentiate significant relationship between the characters studied and explains the correlation between a large set of variables in terms of a small number of independent components.

The cluster analysis via PCA is also an appropriate method for determining family relationships and genetic diversity (Mohammadi, 2002). Only few studies in cactus pear accessions utilized PCA for either morphological characterization and distribution (Peña-Valdivia *et al.* 2008; Chougui *et al.* 2016; Omweri *et al.* 2016) or for classifying the germplasm based on quantitative, qualitative and quality traits in fruiting cactus pear germplasm (Parker, 1988; Gutiérrez-Acosta *et al.* 2002; Karaba *et al.* 2004; Gallegos-Vázquez *et al.* 2012; El Finti *et al.* 2013;Chalak *et al.* 2014; Perez-Loredo, 2016) while there are not studies conducted so far in forage cacti applying PCA.

The main objective of this study was to assess the potential genetic diversity among forage cactus pear accessions by using cluster analysis through PCA-based method for selection of parents in hybridization program to obtain desirable segregants in advanced generation. In view of the above, 33 elite forage spineless cactus pear accessions introduced from various cactus growing countries like Tunisia, Morocco, South Africa, USA, were investigated for three years from December 2011 to December 2014 for their variability and productivity under irrigation with saline water (around 6 dSm^{-1}) in order to select promising high productivity cactus accessions and also to identify suitable accession for the rehabilitation of degraded rangelands of the arid countries like Oman.

MATERIALS AND METHODS

The two attached cladodes each of 33 spineless cactus pear accessions were planted erect under plant density of 40,000 plants ha^{-1} in December 2011 in randomized complete block design in the plots of 3m × 3m with three replications on a sandy loam site under drip irrigation at Livestock Research Center of the Directorate General of Agriculture & Livestock Research of the Ministry of Agriculture & Fisheries located at Rumais in Oman. Standard agronomic practices were followed as per worldwide recommendations for cactus cultivation with organic manure (1.6% N) and compound fertilizer application 1 kg $plant^{-1}$ and 50:50:50 kg of NPK ha^{-1}, respectively (FAO, 2001). The plots were irrigated initially irrigated at 3-day interval for 10 days and at week interval for four months for half hour to enable regeneration of cladodes and establishment of cactus pear plants. Subsequently, irrigation was done once in 15 days for 15 minutes throughout growth period of the plants, which were subjected to three harvests annually leaving two basal attached cladodes. The irrigation water EC was 5.37 dSm^{-1} at the beginning of the experiment while it was 6.01, 10.45 and 14.75 $dSm^{-1,}$ respectively at the annual harvests in December of 2012, 2013 and 2014.

The observations on plant height (cm) at harvest, number of cladodes per plant, weight per cladode, fresh or green weight of cladode, fresh or green weight m^{-2}, were recorded, at harvest. Two fresh cladode samples of each accession were taken to laboratory for computing dry matter percentage (AOAC, 2004) and dry matter yield (t ha^{-1}). The principal component analysis method (Chatfield and Collis, 1980) was followed in the extraction of the components using correlated matrix from the aggregate mean data of three years for 33 accessions studied. Principal component analysis (PCA) was performed using M-Stat C software (M-Stat C, 2016).

RESULTS AND DISCUSSION

Principal component analysis, one of the multivariate analyses is known to provide the information on the largest contributor´s among the characters/variables to the total variation at every axis of differentiation (Sharma, 1998). Table 1 presents the contribution to the variation that reflects diversity among the accessions in percentage by the four components of PCA.

Table 1. Percent of variance of principal components to total variation

Principal Components (PC' s)	% Variance	Cumulative variance (%)
PC 1	97.65	97.65
PC 2	2.27	99.92
PC 2	0.06	99.98
PC 4	0.02	100.00

These four principal components PC1 to PC4, which were extracted from the original data and having latent roots greater than one accounted 100% of the total variation indicating these principal component scores could be used to summarize the original five variables in any further

analysis of the data. Of the four principal components extracted, PC1 and PC2 with values of 97.65 and 2.27%, respectively, interesting contributed to 99.92 % of the total variation.

The character´s with largest absolute value of each principal component closer to unity within the first principal component would influence the clustering more than those with lower absolute value closer to zero (Tabachnik and Fiddel, 1996). Therefore, in the present study, differentiation of the genotypes into different clusters was because of relatively high contribution of one or few characters rather than small contribution from each character. Table 2 presents the principal component values or loadings of five characters studied.

Table 2. The principal component values of five characters in 33 forage cactus pear accessions

Variables/Characters	PC 1	PC 2	PC 3	PC 4
Plant height (cm)	0.061	0.998	0.022	0.011
Number of cladodes plant^{-1}	0.028	0.000	-0.517	0.855
Weight/cladode (kg)	0.001	0.004	0.010	-0.019
Green matter yield (t ha^{-1})	0.993	-0.058	-0.069	-0.074
Dry matter yield (t ha^{-1})	0.096	-0.031	0.853	0.512

The positive and negative loading indicates the presence of positive and negative correlation trends between the components and the characters. Accordingly, the first principal component had highest positive component loading or value from only one character i.e. green matter yield (0.993) and is the one that differentiated the clusters. Similarly, contributing character for the diversity in the second principal component (PC2) was plant height with PC values of 0.998 whereas in PC4, number of cladodes and dry matter weight positively contributed respectively the most with PC values of 0.855 and 0.512 (Table 2).

On the contrary, PC3 was steadily and positively influenced by dry matter weight with PC value of 0.853 on one hand while it was negatively influenced with PC values of -0.517 by number of cladodes, on the other. These findings revealed that first three principal components were related respectively to three characters in forage cactus pear viz. green matter yield, plant height and dry matter yield that were directly associated with cladode productivity. This fact was further strengthened by their significant associations among themselves in the form of strong correlation coefficients (r) ($p<0.05$) (Table 3).

Of 10 possible correlations from five characters studied, seven correlations were found to be significant ($p<0.05$) or highly significant ($p<0.01$) and they were interestingly positive in nature of association. The strong positive associations of plant height, number of cladodes and their weight *per se* with green and/or dry matter yields indicated that either of them could be used as selection criterion among the populations of forage cactus for improvement for higher productivity.

Table 3. Correlation coefficients between yield and growth characters in forage cactus pear.

	Plant height (cm)	Number of cladodes plant^{-1}	Weight/ cladode (kg)	Green matter yield (t/ha)	Dry matter yield (t/ha)
Plant height (cm)	1	0.329	0.629**	0.364*	0.319
Number of cladodes plant^{-1}		1	0.237	0.861**	0.770**
Weight/ cladode (kg)			1	0.469**	0.469**
Green matter yield (t/ha)				1	0.972***

The scatter of 33 forage pear cactus accessions studied in biplot graph of the first two principle components as X and Y –axes clearly separated into six clusters where the accessions belonging to the same cluster closely positioned due to their similarities in distinct grids on both axes (Fig 1).

Such information on clustering pattern of either highly productive accessions or of the accessions superior for one or few characters in respect of whether they belong to the same or different clusters would be useful in crop improvement. The accessions belonging to different clusters would be genetically different or diverse for their exploitation in crossing program by the plant breeders to obtain F_2 segregants of diverse range in all growth and yield attributes (Allard, 1999; Acquuah, 2012).

The second cluster (II) was consisted of the highest number of nine accessions belonging to Tunisia (4), Algeria (2), Morocco (1), Madagascar (1) and New Mexico (1). Similarly, clusters III, V, IV and I consisted respectively of eight, seven, five and three accessions from same and different countries. The cluster VI was represented by single accession with number 74112 of Mexico, which was found to be highest yielder and hence could be recommended for general cultivation.

Similarly, productive accessions like accessions with numbers 4321 (Tunisia), 75018 (Morocco) and 68247 (Algeria) from cluster V could be also considered for general cultivation for rehabilitation of degraded farm and rangelands. Alternatively, the diverse genotypes belonging to different clusters like accessions with numbers 73054 from Africa of cluster I and 69199 from Algeria of cluster II could be employed in hybridization program with accessions belonging to other clusters like V and VI for improvement of forage cactus pear.

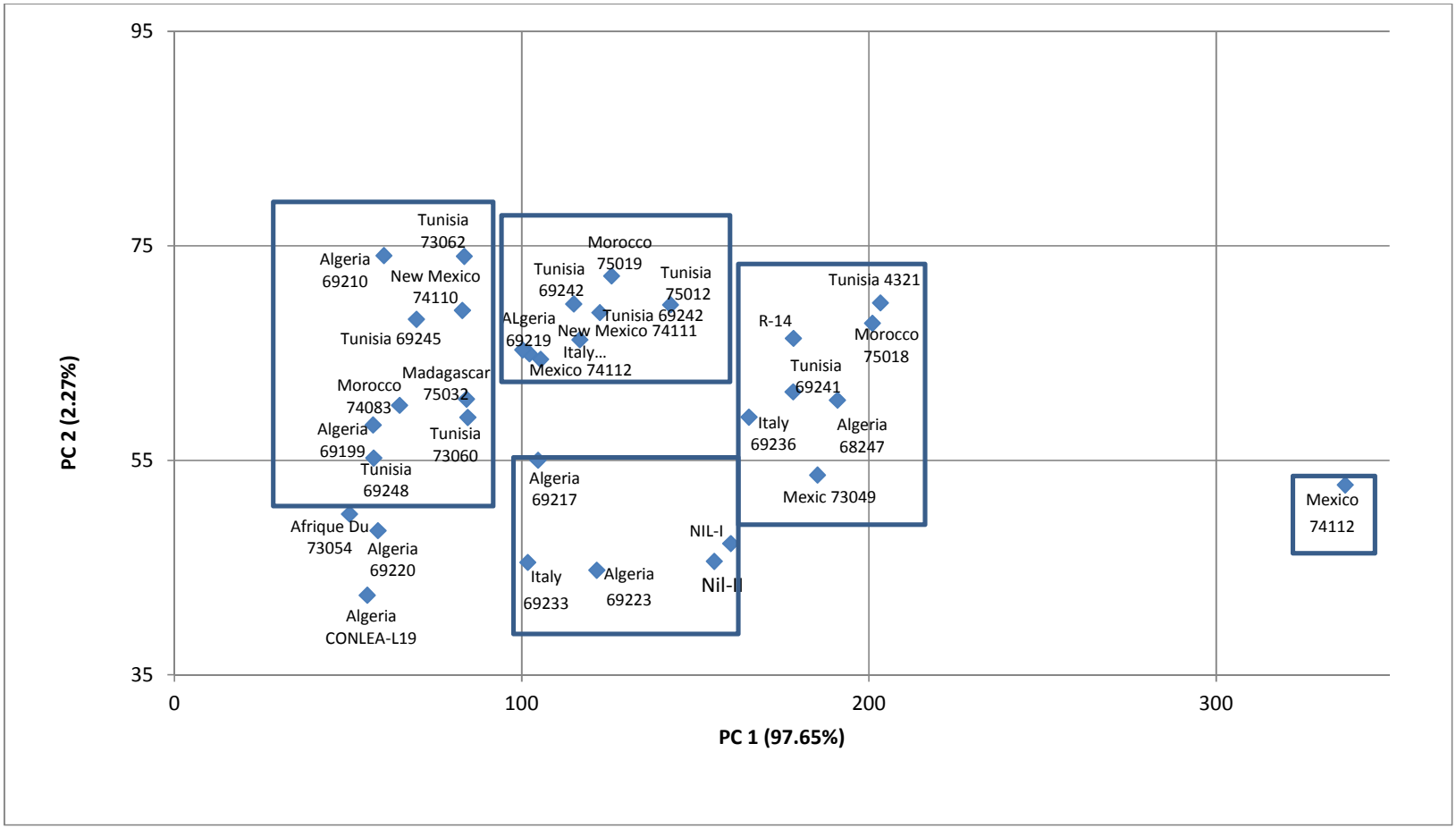

Figure 1. Plot of PC1and PC2 showing scatter of 33 forage cactus pear accessions of different countries (origin) and six clusters formed.

CONCLUSIONS

The cluster analysis via principal component analysis (PCA) was an appropriate method to assess the potential genetic diversity among forage cactus pear accessions, since PCA indicated that the first two components PC1 and PC2 accounted for 97.65 and 2.27%, respectively which in combination contributed to 99.92% of the total variation among characters studied in fodder cactus pear accessions. The first principal component had high positive loading for green matter yield with the highest value of 0.993 whereas second principal component had highest loading for plant height (0.998). The results of this study could be applied to select promising high productivity cactus accessions and also to identify suitable accession for the rehabilitation of degraded rangelands of the arid countries.

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