Electronic Journal of Plant Breeding, 5(4): 743-751 (Sep 2014)
ISSN 0975-928X

Research Article

Phenotypic Diversity and Genetic Variation within a Collection of Onion (*Allium cepa* L.) Germplasm from Peninsular India

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(Received: 23 June 2014; Accepted: 13 Aug 2014)

Abstract
Twenty three diverse germplasm lines collected from varying agro-ecological regions of Peninsular India during 2007-08 were characterized and evaluated along with three controls *viz.* Nasik Red, Light Red and White Marglobe, in an augmented block design during *kharif* 2009-10, at NBPGR Regional Station, Rajendranagar, Hyderabad. The accessions exhibited good variation for qualitative traits like early seedling vigour, leaf cross section, leaf arrangement, stem shape, bulb shape, bulb skin color, bulb size, bulb hearting and bulb flesh colour and quantitative traits like plant height, number of leaves per plant, leaf length, leaf girth, number of scales per bulb, total soluble solids (TSS) (°Brix), bulb weight and bulb yield per plant. Correlation study revealed that high significant positive correlation was recorded between number of scales per bulb and bulb weight (r=0.71) and significant negative correlation was observed between leaf length and leaf girth (r= -0.88), leaf length and bolting (-0.63) among others. Principal component analysis (PCA) revealed that the first four principal components explained 99.76% of the total variation among the 23 accessions and three controls. PCA I accounted for 97.04% of variation, had maximum influence on bulb weight followed by plant height. The PCA II traits were leaf length and plant height which accounted for 1.97 % of the variance. The PCA III and PCA IV have contributed for 0.39 and 0.39% of total variance. The cluster analysis revealed that dendrogram formed four distinct clusters and cluster III was found to be the largest including controls. The promising accessions for bulb weight were IC 571959, IC 564056, IC 571927, IC 571919 and IC 564059, which may be effectively tapped in sound breeding and conservation program.

Key words
Onion, cluster analysis, germplasm, diversity

Introduction

Onion (*Allium cepa* L.) is one of the most ancient vegetables known to mankind and cultivated throughout the world for its cuisinal and medicinal value. In India, historical and cultural significance of this crop has been well documented in ancient scripture, Garuda Purana (Shastri, 1995). Depending on the variety, an onion can be spicy, tangy and pungent or mild and sweet. Both bulb and green onions are rich in minerals, protein and ascorbic acid (Sangeeta Kumari and Singh, 2012). Onion originated from central Asia, and Near East is the secondary center (McCollum, 1976). It is believed to have been domesticated from indigenous wild species in Vavilov's Central Asiatic Center, comprising Pakistan, Afghanistan, and the Central Asian republics of the former Soviet Union (Jones and Daviszzzz, 1944). It is a large genus containing five hundred or more species (Abubakar and Ado, 2014). However, molecular analysis data have favoured a new phylogenetic classification of genus *Allium* consisting of 15 monophyletic subgenera and provided evidences for inclusion of a central Himalayan and closely related genus *Milula* in genus *Allium* (Stearn 1960; Rabinowitch and Currah 2002; Friesen *et al*. 2006). About 35-40 species occur in temperate and Alpine regions of Himalaya (Hooker 1892; Stearn 1947; Kachroo *et al*. 1977; Polunin and Stainton 1984; Karthikeyan *et al*., 1989) in India. Onion is a diploid (2n = 2x = 16) plant with natural out crossing rates in the field ranging between 70 and 100% (Van Der Meer and Van Bennekom 1968, 1972) and is reported to show strong inbreeding depression (Jones and Davis 1944). Due to its close proximity to centre of origin and domestication as well as distribution of more species in India, diversity is expected among the onion germplasm from Indian subcontinent.

Germplasm forms the fundamental and valuable source of genetic variation for sound breeding programme. Collection of germplasm results in accessions which are challenged by both biotic (pests and diseases) and abiotic (environmental) forces to produce modern varieties/hybrids combining high yield, earliness, good storability and high quality bulbs including tolerance to several pests and diseases under scientific and minimum agronomic practices (Rouamba *et al*.,

1995). Assessing the genetic variability in a population and evaluation is pre-requisite for selecting the parents for sound crossing programme. Breeding aims change rapidly, hence evaluation needs to be adaptive. However, there is erosion of genetic diversity of local landraces due to intensive agriculture, uniform cultivars and other market driven factors. Exotic hybrids have made big inroads and farmers grow them for local as well as export market. It has often been seen that hybrid cultivation leads to displacement of local landraces and open pollinated varieties. Onion breeders in India are relying upon variability existing in local land races and varietal development through mass selection. Continuous breeding efforts have led to the release of 45 open pollinated varieties and two F_1 hybrids but the productivity has still not met the expectations. However, existing potential diversity of onion has not been realized as a result there are only two public bred hybrids in the Indian market. The productivity of onion is very low as most Indian farmers do their own seed production which leads to non-uniformity in bulbs (Anil *et al*., 2011). As onion production play a significant role in the economy as other annual crops, more attention should be accorded to the selection of high yielding cultivars for bulb production.

In view of the above, there is need to increase the onion production which can meet the fast expanding domestic and export markets. Exploitation of new onion genetic resources having gene for higher productivity and adaption to diverse agro climatic conditions would assume great significance. Onion being a cross-pollinated crop always provides scope for selection as variability is continuously created.

Material and Methods

Two onion-specific exploration surveys covering different agro-ecological regions of Andhra Pradesh and Orissa states of India were undertaken during 2007-08. Following random sampling strategy, 23 germplasm lines of onion were collected. The collected accessions were evaluated along with three controls namely Nasik Red (N-53), Light Red and White Marglobe in an augmented block design during *kharif*, 2009-10 at NBPGR Regional Station, Rajendranagar, Hyderabad. The farm is situated at an altitude of 546.2 m above mean sea level. Geographically, it lies at latitude of 17.19 ^{0} N and longitude of 79.23^0 E. The monthly mean maximum temperature during the crop growth period ranged from 27.8^{o}C to 30.3^{o}C with an average of 29.2^{o}C, while the monthly mean minimum temperature ranged from 13.2^{o}C to 22.6^{o}C with an average of 20.0^{o}C. Relative humidity in forenoon and afternoon fluctuated between 86.0 to 93.0 percent and 44.0-77.0 percent, respectively. Rainfall ranged from 18.2 to 278.9 mm with an average of 146.6 mm was received during the crop period. The monthly mean sunshine hours varied from 2.5 to 7.2 with an average of 4.91 hours per day. At all stages of the crop growth, weather was congenial for growth and development of onion crop during *kharif*, season. Each accession was raised in a single row plot of 3 m length per block. A row-to-row and plant-to-plant spacing of 30 x 15 cm was maintained, accommodating 20 plants per accession. Observations were recorded on five randomly selected plants for all the traits except bolting percentage and bulb yield per plant which were recorded on whole plot basis. The mean data on various biometric traits were subjected to analysis of variance of augmented block design as per the standard statistical procedure suggested by Federer (1956). Pearson's correlation coefficients were worked out among nine growth and yield attitudes using mean values to identify the yield components using Excel program in MS office. In addition, direct and indirect effect of various independent quantitative traits on dependent bulb yield was also worked out. Multivariate cluster analysis was done using SAS Enterprise guide. Characterization of 14 qualitative traits was carried out as per the minimal descriptors of onion (Srivastava *et al*, 2001).

Results and Discussion

The mean performance of the accessions for various agro-economic traits such as plant height, number of leaves per plant, leaf length (cm), leaf girth (cm), number of scales per bulb, TSS (Brix), bulb weight (g) and bulb yield per plant (g) has been presented in Table 1. The plant height ranged between 43 cm (IC571913) to 61 cm (IC571927) with mean plant height of 53.31 cm, which recorded significant difference ($P < 0.05$) and phenotypic coefficient variation of 9 %. Five accessions IC571927, IC571959, IC564056, IC564078 and IC 564070 recorded exceedingly higher plant height in comparison to controls. Significant difference ($P < 0.05$) was also recorded in number of leaves per plant, which ranged from 6.40 (IC564085) to 11.60 (IC571904) with phenotypic coefficient variation of 15.13. Six accessions IC571904, IC571935, IC564084, IC571919, IC571913, IC571959 and IC564076 recorded more leaves per plant than controls. The leaf length, which also recorded significant difference ($p<0.05$), ranged between 39.31cm (IC 564084) and 55.80 cm (IC 571927). The mean leaf length was 48.00 cm. Leaf girth recorded higher phenotypic coefficient of variation at 16.14 %. Only two accessions recorded bolting percentage *viz.* IC571904 (5%) and IC 571935(11 %). The number of scales per bulb ranged between 10.60 (IC654054) and 14.60 (IC 564076). The mean value for TSS of bulbs was 9.06 with phenotypic coefficient of variation of 15.24%. TSS also

recorded significant difference (P<0.05). There were ten accessions with high TSS values than controls namely IC571935, IC571921, IC571904, IC 571913, IC571922, IC571924, IC564069, IC564078 and IC564084. The mean bulb weight recorded highest phenotypic coefficient of variation of 28.84%. There was a significant variation and difference (P<0.05) in average bulb weight (bulb yield per plant). Among controls checks, Nasik Red recorded highest bulb weight (g) per plant (135.94) and accessions which recorded high bulb weight than the controls were IC571919, IC571927, IC 571959 and IC564056. Among the qualitative traits (data table not provided), accessions IC571919, IC571921, IC571927 and IC564056 exhibited very good vigour. No variation was observed in leaf color, leaf habit, leaf arrangement, plant habit at maturity and bulb location. Seventeen accessions possessed semi-circular leaf cross section remaining accessions had prostrate shape. Majority of the accessions had rounded stem shape and only two accessions IC 571904 and IC571927 possessed flat stem shape including checks. High variability was observed for bulb shape. The bulb skin color also varied from white to dark violet color. Accessions IC 571904, IC 571913, IC 571921, IC 571922, IC 571924, IC 571927 and IC 571935 had white colored skin. There were three bulb sizes namely large (IC571985, IC564063, IC564069, IC564070, IC564071, IC564054, IC564076, IC564078, IC564055, IC564058 and IC564059), medium (IC571904, IC571921, IC571922, IC571924, IC 571927 and IC571935) and rest recorded small bulb size. Two accessions IC571904 and IC571935 recorded bulb hearting as double bulbs were noticed. Pinkish white color flesh was recorded in IC564071. Twelve accessions IC571919, IC571959, IC 564063, IC564069, IC564070, IC564054, IC564076, IC564078, IC564055, IC564084, IC 564085 and IC 564058 had reddish color flesh and remaining accessions had white color flesh.

The onion germplasm accessions exhibited good genetic variability for both qualitative and quantitative traits. The results revealed that the germplasm under study had highest genetic diversity for bulb weight among quantitative traits and bulb shape among qualitative traits. However, other traits leaf length, plant height, leaf girth, TSS, number of leaves per plant and number of scales per bulb have exhibited moderate to low degree of diversity in comparison to yield (bulb weight per plant). Such a large variation for bulb weight per plant from small set of 23 diverse accessions may be attributed to distinct and diverse genetic base of the germplasm under study (Kamala *et al*, 2011). Among the qualitative traits, bulb shape exhibited high variability as 12 different bulb shapes (thick flat, flat globe, globe, high globe, spindle, cylindrical, high top, rhombic, broad ovate, broad elliptic, ovate, and elliptic) were recorded. Such variation within particular trait helps to identify the germplasm into their respective taxon and accession group. Only one accession- IC571927 had thick flat bulb shape and found to be high yielding (bulb weight) and recorded high plant height. Plant height was reported to have high heritability and high genetic advance by Melke and Ravishankar (2006). The plant height also had positive indirect effect on yield and was favourable through bulb length, bulb neck thickness, TSS and dry matter content. Accessions with cylindrical bulb shape had highest TSS and bolting percentage. Hosamani *et al*. (2010) reported that TSS at genotypic as well as at phenotypic level negatively associated with yield, which suggested that there is further need to study cylindrical bulb types for other bio-chemical parameters to ascertain its association with yield. According to Wall and Corgan, (1999) soluble solids are known to comprise the bulk of onion dry mass and that dehydrator cultivars are developed from breeding populations that have high dry mass content. This may help the breeder to avoid selection of cylindrical bulp shape types in breeding programme which saves time and cost. The high top bulb accession recorded highest number of leaves per plant. Such qualitative trait may be considered as desirable in crossing programme as number of leaves per plant found to have high heritability (Pramod and Gangaprasad, 2007). The elliptic shape recorded favourable values for yield (bulb weight per plant) and yield contributing traits plant height, number of scales per bulb and low TSS, as the plant height and TSS were reported as highly heritable traits (Pramod and Gangaprasad, 2007) and selection of such traits would be fairly simple. The influence of environmental modifications on heritable traits would be least and phenotypic selection based on bulb shape (elliptic) would be more reliable and time saving in breeding programme to enhance the productivity of onion (Hosamani *et al*., 2010). Total soluble solids are an important factor which determines the sweetness of the accession. There were four pungent accessions identified *viz.* IC571959, IC564056, IC564085 and IC 571919 due to their low values for TSS which are preferred at national level for domestic consumption (Singh, 1997). The accessions IC571935 and IC571921 with high TSS are considered to be least pungent which are preferred by dehydration industry for export purpose (Lawande, 2001). These accessions may be promoted for long term storage as they considered to have enhanced keeping quality (El-Aweel *et al*., 2000 and Moanapa *et al*., 2005). The development of high yielding onion cultivars with high soluble solid content could provide good incentive to increase production for processing and storage such

as dehydration so as to minimize onion loss due to poor storage by farmers and marketers (Ibrahim *et al*., 2013)

Correlation coefficient analysis of eight quantitative traits (Table 2) revealed strong association among growth and yield parameters of onion. Leaf length had positive significant correlation against number of scales per bulb (r=0.54), while it recorded negative significant correlation with leaf length (r= -0.88), bolting percentage (r= -0.63) and TSS (r= -0.40). Leaf girth had positively significant correlation for bolting percentage (r= 0.47) and negatively significant correlation with number of scales per bulb (r= -0.45). The bolting percentage had significant correlation with TSS (r=0.44), while it had significantly negative correlation with number of scales per bulb (r= -0.65) and bulb weight (r= -0.45). Among all the traits under study, the number scales per bulb had high significant correlation with bulb weight per plant (r=0.71), while it was negatively correlated against TSS (r= -0.44). Of the seven independent quantitative traits studied for their direct effects on bulb weight per plant, the traits TSS (9.54) and number of scales per bulb (9.49) had positively high direct effect on bulb weight per plant followed by leaf length (1.04) and leaf girth (0.89). However, the traits plant height (-2.83), number of leaves per plant (-1.12) and bolting percentage (-0.17) had high negative direct effect on bulb weight per plant. From the result of the correlation coefficient analysis, it is evident that the character bolting percentage had strong negative correlation with bulb weight and number of scales per bulb had positive association with bulb weight suggesting that bulb weight could be improved by making selection on the basis of the afore said character, which is considered as major yield attribute in onion. The contribution of components of yield is through component compensation mechanism (Adams, 1967). The path coefficient study indicated that leaf length, leaf girth, number of scales per bulb and TSS (Hosamani *et al.*, 2010) had positively high direct effect on bulb weight. However, Hyder *et al*. (2007) and Singh *et al* (2010) reported that plant height, bulb length, bulb diameter, days to harvest were the important traits contributing to bulb yield in onion. Significant genotypic correlation with bolting percentage and bulb yield implies that increase in bolters affect total yield (Ibrahim *et al*., 2013). There was indirect effect on bulb yield of each trait. High negative direct effect was exerted by plant height and number of leaves on bulb yield but was favourably influenced through leaf length, leaf girth, number of scales per bulb and TSS. Whereas, bolting percentage had low negative direct effect among all the traits studied.

The principal component analysis revealed a difference among the accessions studied. The first four principal components explained 99.76% of the total variation among the 23 accessions and three local checks. The first principal component accounted for 97.04% of variation, which had maximum influence on bulb weight followed by plant height. The second component traits were leaf length and plant height which accounted for 1.97% of the variance. However, leaf length and leaf girth with largest coefficient values found to be important traits in third and forth principal components, respectively. Latter two components contributed for 0.39 and 0.36% of variance, respectively. The biplot (Fig.1) analysis found that accession IC571904 and IC571935 have scored highest value for number of leaves (11.60) and TSS (12.00). Both of these accessions found to be diverse from remaining accessions. The biplot (Fig. 1) analysis revealed that accession-wise trait richness and variation was recorded by IC571935 for TSS, IC571904 and IC 564076 for number of leaves (NL) followed by IC564078, IC571919, White Marglobe, IC571927 and IC571959 scored higher value for leaf girth (LG), number of scales per bulb (NS), bulb weight (BW), plant height (PH) and leaf length (LL). On contrary, the accessions IC564085 and Light Red found to be highly diverse and lowest value for all the traits. Hence, these genotypes can be used as contrast parents for genetic study for any of these traits along with another parent of high value for that particular trait. The principal component analysis revealed bulb weight had maximum influence in PCA I which may be due to high phenotypic coefficient of variation and other Eigen vectors have scored positive values except TSS which has negative values. (Singh *et al*., 2010).The plant height is the only trait which influenced in the first two principal components. The PCA II had plant height, leaf length, leaf girth and number of scales per bulb with positive scores and traits such as number of leaves per plant, TSS and bulb weight with negative scores. The PCA III had negative scores for most of the traits like plant height, number of leaves per plant, leaf girth and TSS and remaining trait with positive scores (leaf length, number of scales per bulb and bulb weight). The PCA IV had dominated by positive Eigen vectors except plant height which scored negative values. Rehman *et al*. (2002) reported variation in average performance for plant height, number of leaves per plant and bulb yield per plant in onion lines. Purseglove (1972) and Smith (2003) reported that due to out crossing behavior of onion, they tend to be heterozygous at many loci, exhibiting variations in the shape and colour of their bulbs, in their response to photoperiod, temperature, storage quality, pungency, stage of maturity, length of storage and in other characteristics. Thus, such a

striking variability among the onion germplasm may be attributed to genus *Allium* as diverse one (Abubakar and Ado, 2014). The biplot analysis revealed that accessions IC571904 and IC571935 found to be different and separate from remaining accessions with the traits TSS and number of leaves having contributed to their diversity and separation.

The dendrogram (Fig 2) enabled a relatively good comparison of different onion germplasm and resulted in formation four distinct clusters. The cluster I included two accessions IC571904 and IC571935 and cluster II also had two accessions *viz.*, IC571913 and IC564084.Cluster III was represented by sixteen accessions *viz.*, IC 571921, IC 571922, IC 564076, IC 571924, IC 564063, IC 564059, IC 564069, IC 571985, Light Red, IC 564070, IC 564071, IC 564055, Nasik Red, White marglobe, IC 564058 and IC 564054.The cluster IV consisted of five accessions -IC 571919, IC 564056, IC 571959, IC 571927 and IC 564078. The mean bulb weights for cluster I, cluster II, cluster III and cluster IV were 88.09, 53.12, 106.78 and 152.29 g, respectively. The Hierarchical Cluster analysis deals number of different algorithms and methods for grouping samples of similar kind in to respective categories. It is an exploratory data analysis tool which aims at sorting different samples in to groups in a way that degree of association between two samples is maximal if they belong to the same group and minimal otherwise (Rusjan *et al*., 2008). The cluster analysis studies explain grouping of accessions into different clusters. The distribution of accessions in to different clusters was not based on similar geographical collection, which is similar to the findings of Kamala *et al*. (2011), thus ruling out geographical origin as a factor for and genetic divergence (Mallikarjun, *et al*., 2010). The cluster-I consisted of only two accessions IC571904 and IC571935, former with highest number of leaves per plant and the latter with highest bolting percentage and TSS. Such accessions tend to produce more economic dry matter per unit area (Ananthan and Balakrishnamoorthy, 2007).The accessions in cluster II *viz.* IC571913 and IC564084 were collected from Karimnagar district in Telangana region (Andhra Pradesh) representing dry inland climate with hot summer and cool winter and temperate climate (Koraput in Orissa) respectively. The cluster III has fourteen accessions and three controls which were the popular varieties in different states under varying agro-ecological conditions. The accessions from Cluster III and IV represents highly diverse climatic conditions varying from dry hot to sub humid as well as coastal to temperate climates. This suggests that the accessions from Cluster III and IV are suitable for utilization in breeding to evolve hybrids or varieties adapted to diverse climate. Cluster IV included IC571919, IC564056, IC571959 and IC 571927 and IC564078 with lowest number of leaves per plant, leaf girth and number of scales per bulb respectively. The highest cluster mean was recorded by cluster IV followed by cluster III, cluster I and cluster II. Crossing programme involving genetically diverse lines has been effective for the development of novel hybrids with high heterosis in the desired direction (Mallikarjun *et al*., 2010). As cluster IV has highest value for bulb weight (g), an important yield attributing trait as well represents highly diverse eco-geographical conditions, therefore hybridization of cluster IV with cluster-III would be beneficial with the advantage that cluster III has leading check varieties performing excellent in onion growing states of India under diverse season as well as climatic conditions.

There is need to identify trait specific diversity rich pockets and regions having gaps for bulb shape and bulb weight to undertake thorough exploration to collect highly divergent lines for yield and yield contributing traits as well as lines expressing resistance to biotic and abiotic stresses. The qualitative and quantitative data presented in the present study would be useful for plant breeders and gene bank curators, as the traits exhibited significant variability. Even though only twenty three lines were studied these may be effectively utilized in onion improvement and conservation efforts.

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Table 1. Mean performance of onion germplasm for yield and yield components

Accession No.	Plant height (cm)	No. of leaves per plant	Leaf length (cm)	Leaf girth (mm)	Bolting percentage	No. of scales per bulb	TSS (^{o}Brix)	Bulb weight (g)
IC 571904	54.20	11.60	48.04	16.18	5.00	11.50	10.84	91.24
IC 571913	43.60	9.20	40.04	10.89	0.00	12.33	9.54	44.64
IC 571919	55.80	9.60	50.04	15.96	0.00	12.60	7.32	149.53
IC 571921	50.00	8.20	47.78	9.82	0.00	12.40	11.20	90.69
IC 571922	49.00	7.80	44.38	10.66	0.00	12.80	9.84	107.72
IC 571924	51.60	7.40	46.98	14.68	0.00	11.60	10.20	99.27
IC 571927	61.00	7.20	55.58	17.36	0.00	14.40	8.64	152.32
IC 571935	48.20	10.20	43.58	13.68	11.00	13.00	12.20	84.95
IC 571959	60.60	9.20	54.38	14.38	0.00	14.40	6.92	179.13
IC 571985	55.20	7.20	41.31	11.00	0.00	12.00	9.68	79.32
IC 564063	49.40	7.80	45.91	12.62	0.00	13.20	7.92	117.99
IC 564069	53.40	8.40	42.71	12.88	0.00	12.40	9.76	120.97
IC 564070	59.00	7.40	53.68	12.45	0.00	11.80	8.36	87.55
IC 564071	55.10	7.80	52.88	13.07	0.00	13.00	7.88	111.69
IC 564054	52.60	6.80	53.08	11.33	0.00	10.60	8.76	96.63
IC 564076	50.60	8.60	47.71	12.34	0.00	14.60	9.76	106.46
IC 564078	59.20	7.60	53.91	17.01	0.00	13.60	10.48	109.52
IC 564055	55.20	8.20	53.31	14.63	0.00	13.20	8.56	109.81
IC 564084	43.40	10.00	39.31	10.96	0.00	11.00	10.76	61.60
IC 564085	49.00	6.40	42.91	11.16	0.00	11.20	7.36	71.72
IC 564056	60.60	8.40	49.51	12.35	0.00	12.50	7.50	170.97
IC 564058	54.20	6.60	49.51	10.85	0.00	12.60	8.06	104.86
IC 564059	52.40	7.80	46.31	13.24	0.00	12.00	7.96	127.97
Nasik Red (N-53)	56.21	8.31	51.80	13.36	0.14	12.46	7.43	135.94
Light Red	49.87	6.43	45.67	10.39	0.00	11.37	9.12	93.74
White Marglobe	56.61	8.49	50.46	13.11	0.00	12.36	9.47	117.98
Minmum	43.40	6.40	34.80	9.82	0.00	10.60	6.92	44.64
Maximum	61.00	11.60	55.80	17.36	11.00	14.60	12.20	179.13
Mean	53.31	8.18	48.00	12.94	0.62	12.50	9.06	108.62
CD (0.05)	9.50	2.73	6.00	3.20	-	3.10	3.38	87.27
CV (%)Error	6.72	13.55	4.67	9.99	-	9.86	14.96	28.90
CV(%)Phenotypic	9.00	15.13	9.22	16.14	-	8.18	15.24	28.84

Table 2. Association among growth and yield attributes of onion

Variable	Plant height (cm)	No. of leaves per plant	Leaf length (cm)	Leaf girth (mm)	Bolting percentage	No. of scales per bulb	TSS (^{o}Brix)	Bulb weight (g)
Plant height (cm)	1.000	-0.188	0.201	-0.308	-0.145	0.323	-0.099	0.006
No. of leaves per plant		1.000	0.219	-0.219	-0.209	0.000	-0.108	-0.019
Leaf length (cm)			1.000	-0.886*	-0.638*	0.548*	-0.405*	0.372
Leaf girth (mm)				1.000	0.472*	-0.457*	0.176	-0.312
Bolting percentage					1.000	-0.658*	0.444*	-0.451*
No. of scales per bulb						1.000	-0.448*	0.712*
TSS (^{o}Brix)							1.000	0.000
Bulb weight (g)								1.000

*Significant at 5% level

Table 3. Direct effects of various quantitative traits on bulb weight of onion

S. No.	Character	Regression coefficient	Correlation with yield
1	Plant height (cm)	-2.837 ^{N}	0.006
2	No. of leaves per plant	-1.127^{N}	-0.019
3	Leaf length (cm)	1.047^{H}	0.372
4	Leaf girth (mm)	0.893 ^{H}	-0.312
5	Bolting percentage	-0.179^{N}	-0.451*
6	No. of scales per bulb	9.490 ^{H}	0.712*
7	TSS (^{o}Brix)	9.543 ^{H}	0.000

* Significant at 5% level; N= Negligible (0.00 to 0.09); L=Low (0.10 to 0.19);
M= Moderate (0.20 to 0.29); H= High (≥0

Table 4. Principal component analysis (PCA) performed on eight traits for onion germplasm lines

Agro-economic trait	Eigen vectors			
	PC1	PC2	PC3	PC4
Plant height (cm)	0.11454	0.60163	-0.72298	-0.29060
No. of leaves per plant	0.00002	-0.06478	-0.11164	0.46137
Leaf length (cm)	0.09357	0.76130	0.62117	0.10007
Leaf girth (mm)	0.03256	0.17825	-0.24373	0.74220
No. of scales per bulb	0.01724	0.01536	0.03367	0.15808
TSS (^{o}Brix)	-0.02448	-0.01572	-0.13264	0.34175
Bulb weight (g)	0.98801	-0.14838	0.02915	0.00545

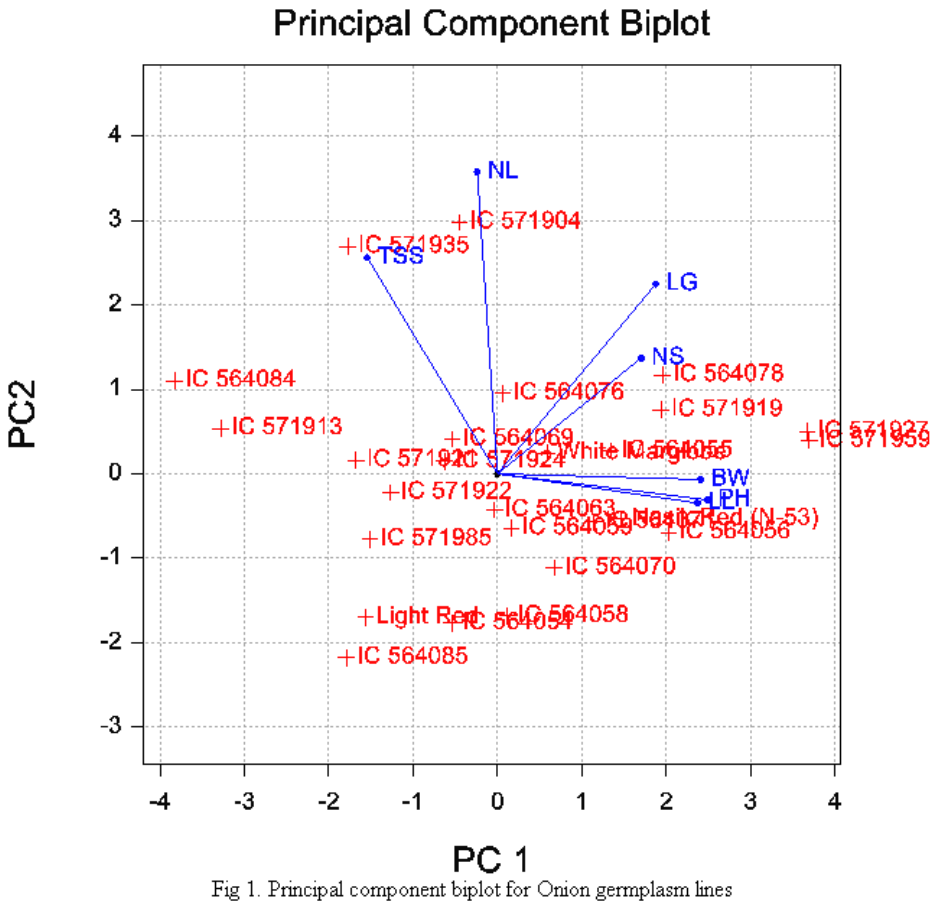

Fig 1. Principal component biplot for Onion germplasm lines

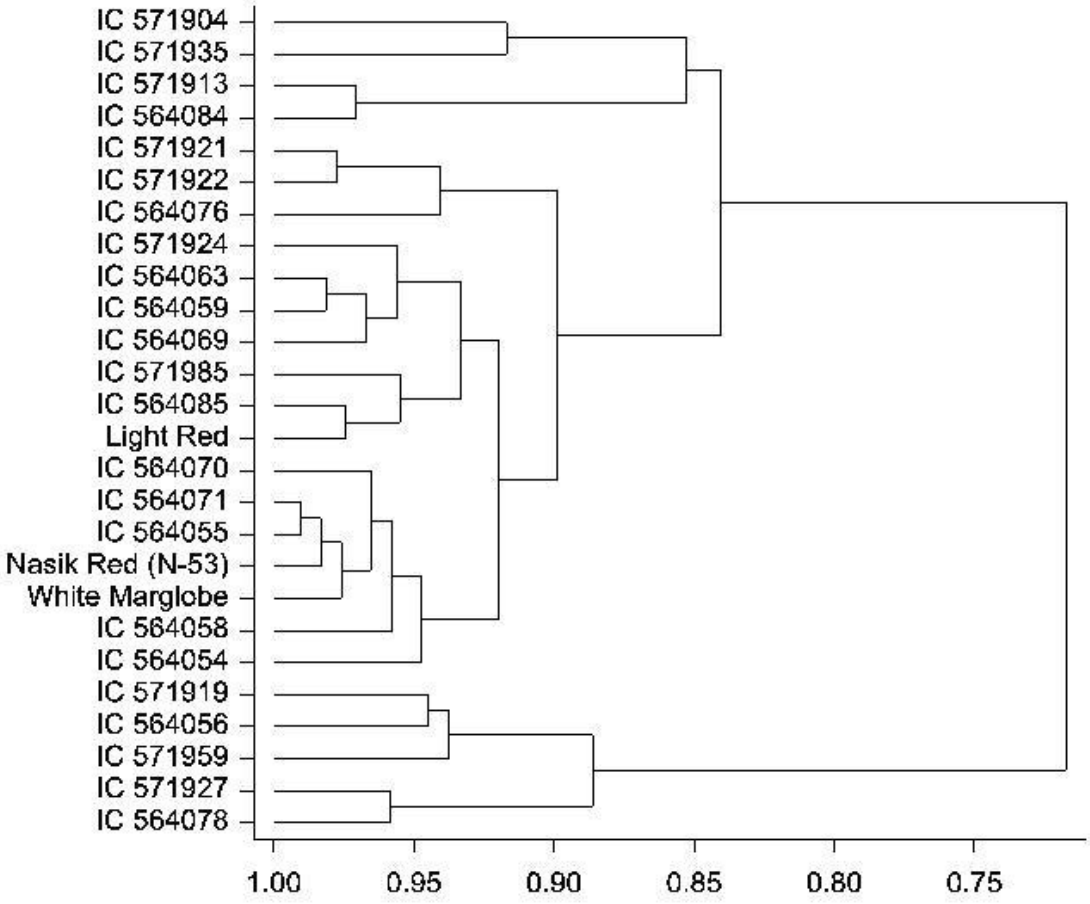

Fig 2. Multivariate cluster analysis of the Onion germplasm lines