Indian Journal of Agricultural Sciences **88** (6): 948–57, June 2018/Article

Genetic variability, heritability, and diversity analysis in short day tropical onion (*Allium cepa*)

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Received: 7 September 2017; Accepted: 2 April 2018

ABSTRACT

The main aim of the present investigation was to assess the degree of variability, heritability and genetic advance in onion (*Allium cepa* L.) using 13 quantitative and four biochemical traits. PCV was higher than GCV for all the traits but the difference was less in plant height, pyruvic acid, leaf length, number of leaves, pseudostem length, pseudostem width, leaf width and total phenols indicating higher contribution of genotypic effect towards phenotypic expression. Highest heritability was observed for plant height, number of leaves, leaf length, leaf width, pseudostem length, pseudostem diameter, total phenols and pyruvic acid. High heritability along with high genetic advance as percent of mean was recorded in number of leaves, leaf length, leaf width, pseudostem length, pseudostem diameter, total phenols and pyruvic acid indicating the presence of additive gene action for the expression of these traits. Based on Euclidean distance and Ward's minimum variance, all accessions were clustered into four groups. Cluster I comprised of accessions with highest yield, yield related traits and high pungency. Cluster II was the largest cluster and composed of accessions having highest TSS and dry matter content. Cluster III was the smallest cluster comprising of accessions having highest polar diameter and total phenols. Cluster IV comprised of accessions having low yielding potential. Five principal components (PC1 to PC5), having latent roots greater than one, accounted for 78.5% total variation. Cluster analysis and Principal component analysis (PCA) were in agreement for assigning genotypes into four clusters. In the first principal component, plant height, leaf length and pseudostem diameter were the most contributing traits, whereas dry matter, total soluble solids (TSS) and pyruvic acid were the principal traits of the second principal component. Based on squared cosine value (Cos2) for variables, average bulb weight, gross yield and marketable yield in positive direction and plant height, leaf length and pseudostem width in negative direction, were the major contributing traits. Squared cosine value (Cos2) for individual factor determined that Superex and Black Gold were the most prominent genotypes contributing towards PCA. This study would provide a better opportunity to select potential genotypes for yield related traits and help breeders in precise selection of promising diverse parents for purposeful heterosis breeding.

Key words : Euclidean distance, GCV, Heritability, Onion, PCA, PCV, Ward's method

India is the second largest onion (*Allium cepa* L.) producing country in the world with an output of 19.40 million tonnes from an area of 1.2 million ha (FAOSTAT 2017). More than 50% of the vegetable export from India comprises of onion and its forex earning value was US $464 million as compared to all other vegetables amounting to US$420 million on combined basis including garlic and shallots (APEDA 2017). On worldwide basis, India occupies 19% of the gross cultivated area and produces 17% of the total production. But on productivity basis, India stands at 88th position (16.1 t/ha) compared to the highest productivity countries, viz. Republic of Korea (66.5 t/ha), Austria (64.1 t/ha), USA (55.9 t/ha) etc (FAOSTAT 2017). Low productivity is due to cultivation of open pollinated varieties (OPVs) instead of high-yielding hybrids. Besides OPVs, tropical climate is also conducive towards spread of insect pests and diseases which reduce the yield per unit area.

Hybrids have been reported to be superior than OPVs in terms of yield and other horticultural traits (Singh and Bhonde 2011, Nunes *et al*. 2014). For initiation of an effective breeding programme for hybrid development, knowledge of genetic diversity is of prime importance. Genetic variation forms the base of plant breeding and provides an array of genotypes that can be selected to develop new varieties or breeding material. Research studies on Indian onion diversity have been reported (Mohanty 2004, Khosa and Dhatt 2013, Chattopadhyay *et al*. 2013, Singh *et al*. 2013, Arya *et al*. 2017, Santra *et al*. 2017) but most of the studies are focused on local commercial varieties or germplasm. Besides this, the number of genotypes used for diversity

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analysis are very less (10-12) (Santra *et al*. 2017, Mohanty 2004). Use of less number of genotypes are not ideal for diversity assessment which leads to the unavailability of diverse potential genotypes for hybridization and causes research gap in onion improvement. Genetic diversity assessment within the crops is of fundamental importance for sustainable crop production as the improvement of a crop and expansion of its genetic base depends upon the variability existing for the breeder (Rivera *et al*. 2016). Furthermore, analysis of genetic divergence figures out the magnitude of diversity present among selected germplasms and helps breeders in precise selection of promising diverse parents for purposeful heterosis breeding. In addition, when there is need to develop a cultivar or hybrid for particular set of climatic conditions, it is highly essential to know about local populations exactly. Coefficient of variation only suggests the degree of variation, it does not anticipate the heritable proportion of variability. Therefore, the assessment of heritability along with genetic advance provides greater opportunity for effective selection by overcoming the influence of environment from the total variation and thereby permitting precise selection of a potential genotype. Cluster analysis helps in precise clustering of genotypes which will aid in selecting genotypes for future breeding objectives. Moreover, the principal component analysis (PCA), a multivariate analysis technique, demonstrates the traits critical in variation of genotypes and also enables ease in understanding of effects and associations among various traits and proper explanation of them.

Breeding of short day onion varieties with high yield potential, good storage quality and resistance to various biotic and abiotic stress is of prime importance under Indian conditions. Hence, the main aim of our study was to know the effect of genetic architecture and environment on morphological and biochemical traits, estimate the extent of genetic diversity of onion accessions and highlight the traits associated with characterising genotypes which would be useful for diversified onion breeding program. Besides, identification of diverse parents with desirable traits would form the basis for heterosis breeding programme in onion. In our studies, we have used for the first time, hybrids and exotic lines from USA and Japan, which are sold in the local market and are grown by the local farmers.

MATERIALS AND METHODS

Fifty-eight onion accessions comprising 35 open pollinated varieties (OPV), 13 hybrids, four landraces (LR), and six breeding lines (BL) were used (Table 1). Research trial was carried out in the experimental field of Division of Vegetable Science, IARI, New Delhi (28° 38' 41.2800" N, 77° 13' 0.1956" E, Elevation of 222 m above mean sea level). The experiment was laid out in randomized block design with three replications. In each replication, total 60 plants per genotype were transplanted with a spacing of 10 cm (plant to plant) and 15 cm (row to row). Recommended package of practices consisted of applying nitrogen, phosphorus, potash (NPK) @ 110:40:60 kg/ha. Half dose of the N and full dose of P and K were applied at the time of transplanting while remaining dose of N was applied 30 days and 45 days after transplanting.

Thirteen morphological traits, viz. plant height (PH, cm), number of leaves per pseudo-stem (NOL), leaf length (LL, cm), leaf width (LW, cm), pseudostem length (PsL, cm), Pseudostem width (PsW, cm), polar diameter (P, cm), equatorial diameter (E, cm), neck thickness (N, cm), average bulb weight (ABW, g), foliage weight (FW, kg), gross yield (GW, t/ha), marketable yield (MY, t/ha) and four biochemical traits, viz. TSS, dry matter (DM), pyruvic acid (PA) and total phenols (TP) were estimated. Total soluble solids (TSS) were determined by using a hand refractometer model-PAL-3 and expressed in °B. Dry matter of the bulbs was assessed according to Nieuwhof *et al.* (1973) with a couple of modifications and expressed in percentage (%). Pyruvic acid (PA) was estimated according to Anthon and Barrett (2003) and expressed as µmol/ml whereas total phenolic content (TPC) of the onion leaves was determined by Folin Ciocalteu reagent (FCR) method of Singleton and Rossi (1965) with minor modifications and expressed as mg/g FW.

The analysis of variance and comparison of means, genetic parameters including the genotypic and phenotypic variance, genotypic and phenotypic coefficient of variance, heritability (broad sense), expected genetic advance (GA) and genetic advance as percent of mean (GAM) were performed by SAS software version 9.3 (SAS Institute, Cary, NC, USA). For cluster analysis, genetic dissimilarity was calculated using Euclidean distance and cluster analysis using Ward.D2 criterion (Murtagh and Legendre 2014). Principal component analysis, calculation of cos2 values and PCA graphics was done using R software (ver. 3.1.2), factoextra (ver. 1.0.2) and ggplot 2 (R 2014).

RESULTS AND DISCUSSION

Determination of genetic variations

Experimental results revealed a wide range of variation among 58 onion accessions for both morphological and biochemical traits. The genotypic variance ($\sigma 2G$) of all the traits was lower than the phenotypic variance ($\sigma 2P$). Genotypic variance ranged from 0.01 (LW and N) to 92.67 (ABW), whereas phenotypic variance ranged from 0.02 (LW) to 119.99 (ABW). GCV values ranged from 5.78% for equatorial diameter to 39.2% for foliage weight. Similarly, the PCV values ranged from 8.30% for equatorial diameter to 49.55% for foliage weight (Table 2). PCV values were higher than the GCV values for all the traits which indicates the environmental role in trait expression. Higher PCV values than the GCV values have been reported by Khosa and Dhatt (2013), Singh *et al*. (2013), Arya *et al*. (2017), Dwivedi *et al*. (2017) and Santra *et al*. (2017). Deshmukh *et al*. (1986) suggested that PCV and GCV values greater than 20% are regarded as high, values between 10% to 20% as medium, whereas values less than 10% are considered to be low. Accordingly, highest GCV was recorded for foliage

Table 1 Details of the 58 short day onion accessions along with their status and colour used in diversity assessment

Accession	Code	Status[1]	Origin	Colour[2]	Accession	Code	Status[1]	Origin	Colour[2]
F1 Hybrid 1	F1-1	H	India	DR	106BS3	106BS3	BL	India	W
F1 Hybrid 2	F1-2	H	India	MR	Superex	Sprx	H	Japan	B
XP Red	XPRd	H	India	DR	Pioneer	Pnr	H	India	DR
Arka Kalyan	AKlyN	OPV	India	LR	BSS258	BSS258	H	India	MR
Prema 178	Pr178	OPV	India	LR	N241	N241	OPV	India	LR
Red Creole 1	RCr1	OPV	USA	MR	PRO6	PRO6	OPV	India	DR
Black Crown	Bcrown	OPV	India	DR	Early Grano	Egrno	OPV	India	Y
Indam 4	Indam4	H	India	LR	Bhima Shubhra	BShbr	OPV	India	W
KSP1191	KSP1191	H	India	LR	Sel. 126	S126	OPV	India	B
Phursungi Local	PLcl	L	India	LR	Yellow Grano	YGrno	OPV	USA	B
Hisar 3	Hsr3	OPV	India	LR	Pusa Riddhi	Prdhi	OPV	India	DR
KRR	KRR	OPV	India	LR	Juni	Juni	H	India	DR
Bhima Kiran	BKrn	OPV	India	MR	AKON555	AK555	L	India	DR
BSS262 Ujjwal	BSS262	H	India	W	KSP1121	KSP1121	H	India	MR
NP-4	NP4	H	USA	LR	GWO-1	GWO1	OPV	India	W
Punjab Naroha	Pnrha	OPV	India	MR	JNDWO85	JNDWO85	OPV	India	W
Hisar 2	Hsr2	OPV	India	DR	Arka Kirtiman	Akrtmn	OPV	India	LR
Bhima Shweta	Bshwta	OPV	India	W	Pusa Madhavi	Pmdhvi	OPV	India	MR
PWR	PWR	OPV	India	W	L28	L28	OPV	India	DR
PWF	PWF	OPV	India	W	ALR	ALR	OPV	India	MR
Udaipur Local	Ulcl	OPV	India	W	ADR	ADR	OPV	India	LR
Red Creole 2	RCr2	OPV	USA	DR	L782	L782	BL	India	LR
Red Creole 3	RCr3	OPV	USA	LR	Black Gold	BGld	OPV	India	DR
Pusa Red	PRd	OPV	India	MR	106BS2	106BS2	BL	India	W
AFW	AFW	OPV	India	W	106BS10	106BS10	BL	India	W
Sukhsagar 1	SSr1	L	India	DR	Krishna	Krishna	OPV	India	DR
Sel325	S325	BL	India	LR	VL Pyaz	VLPz	OPV	India	MR
Bhima Shakti	Bskti	OPV	India	LR	383BS10	383BS10	BL	India	DR
Lucifer	Lcfr	H	India	LR	Sukhsagar2	SSr2	L	India	MR

[1]Status : L-Landrace, BL-Breeding line, H-Hybrid, OPV- Open pollinated varieties. [2]Colour: DR-Dark Red, MR-Medium Red, LR-Light Red, W-White, B-Brown, Y-Yellow.

weight (39.2%), marketable yield (37.16%) and gross yield (30.08%), whereas medium GCV was recorded for pyruvic acid, pseudostem width, total phenols, dry matter, average bulb weight, pseudostem length, neck thickness, leaf width, number of leaves and leaf length and lowest GCV was observed for plant height, TSS, polar and equatorial diameter. Similarly, the highest PCV was also recorded for foliage weight (49.55%), marketable yield (43.24%), gross yield (34.57), neck thickness (23.86%) and average bulb weight (21.79%). Medium PCV was recorded in rest of the traits except neck thickness where PCV was low. High PCV for marketable yield and total yield (Solanki *et al*. 2015, Degewione *et al*. 2011), medium PCV for average bulb weight, leaf length and number of leaves (Khosa and Dhatt 2013), neck thickness (Solanki *et al*. 2015, Santra *et al*. 2017) average bulb weight, pyruvic acid, leaf length (Santra *et al*. 2017, Degewione *et al*. 2011), whereas low PCV for plant height, equatorial diameter (Solanki *et al*. 2015), polar diameter and TSS (Degewione *et al*. 2011, Santra *et al*. 2017, Chattopadhyay *et al*. 2013) have been reported and are in agreement with our results. Similarly, in agreement with our results, highest GCV was recorded in marketable and total yield (Solanki *et al*. 2015, Degewione *et al*. 2011). Medium GCV for average bulb weight, leaf length, number of leaves, neck thickness, pyruvic acid, pseudostem width, total phenols has also been reported by others (Khosa and Dhatt 2013, Solanki *et al*. 2015, Santra *et al*. 2017, Degewione *et al*. 2011, Chattopadhyay *et al*. 2013). Difference between PCV and GCV was less (<1) in some traits, viz. plant height, pyruvic acid, leaf length, number of leaves, pseudostem length, pseudostem width, leaf width and total phenols which indicates higher contribution of genotypic effect towards phenotypic expression of such traits. In traits like foliage weight, neck thickness, average

Table 2 Assessment of genetic variability of 13 morphological and four biochemical traits of onion

Traits	Mean	MSG[1]	MSE[2]	genotypic variance (σ^2G)	phenotypic variance (σ^2P)	GCV[3] (%)	PCV[4] (%)	Heritability h^2_B (%)	Genetic advance GA (%)	GAM[5]
PH	52.31	80.99	1.15	26.61	27.78	9.86	10.07	95.83	10.40	19.88
NOL	8.43	2.96	0.10	0.95	1.05	11.57	12.18	90.31	1.91	22.66
LL	38.63	53.53	1.78	17.25	19.03	10.75	11.29	90.70	8.15	21.10
LW	0.91	0.04	0.00	0.01	0.02	13.16	14.03	88.04	0.23	25.27
PsL	11.65	8.90	0.29	2.87	3.16	14.54	15.25	90.89	3.33	28.58
PsW	1.27	0.15	0.00	0.05	0.05	17.22	17.96	92.00	0.43	33.86
P	3.79	0.33	0.07	0.08	0.16	7.34	10.58	48.1	0.40	10.55
E	4.97	0.33	0.09	0.08	0.17	5.78	8.30	48.66	0.41	8.25
N	0.78	0.06	0.02	0.01	0.03	14.30	23.86	35.92	0.13	16.67
ABW	50.26	305.34	27.31	92.67	119.99	15.15	21.79	77.24	17.42	34.66
FW	0.55	0.16	0.03	0.05	0.07	39.20	49.55	62.58	0.35	63.64
GY	25.34	192.90	18.62	58.09	76.71	30.08	34.57	75.73	13.66	53.91
MY	20.74	199.09	21.02	59.35	80.38	37.16	43.24	73.85	13.63	65.72
TSS	11.52	5.43	1.60	1.28	2.87	9.81	14.71	44.45	1.55	13.45
DM	11.44	10.60	0.90	3.23	4.14	15.70	17.54	78.22	3.28	28.67
PA	3.84	1.55	0.01	0.51	0.53	18.62	18.90	97.02	1.45	37.76
TP	25.46	52.12	1.89	16.74	18.63	16.07	16.95	89.83	7.99	31.38

PH : Plant height (cm) ; NOL-Number of leaves; LL-Leaf length (cm); LW-Leaf width (cm); PsL-Pseudostem length (cm); PsW-Pseudostem width (cm); P-Polar diameter (cm); E-Equatorial diameter (cm); N-Neck thickness; ABW-Average bulb weight; FW-Foliage weight (Kg); GY-Gross yield (t/ha); MY- Marketable yield (t/ha); TSS-Total soluble solids (°B); DM-Dry matter (%); PA-Pyruvic acid (µmol/ml); TP-Total phenols (mg/g Fresh weight). [1]MSG- Mean square of genotypes; [2]MSE- Mean square of error; [3]GCV- Genotypic coefficient of variation; [4]PCV- Phenotypic coefficient of variation; [5]GAM- Genetic advance as percent of mean.

bulb weight, marketable yield, TSS, gross yield, the gap was high indicating that environmental factors are playing an important role in addition to the genotype for expression of these traits.

Genotypic coefficient of variance provides information about the genetic variability in the quantitative traits but it does not give any estimation about what amount of variation was heritable from the genotypic coefficient of variation. Genetic coefficient of variance together with heritability estimates would give the best picture of the amount of advance to be expected from selection (Burton and Devane 1953). Heritability values are helpful in predicting the expected progress to be achieved through selection. Estimation of heritability in broad sense ranged from 97.02% for pyruvic acid to 35.92% for neck thickness. Singh (2001) suggested that heritability values greater than 80% were very high, values from 60-79% were moderately high, 40-59% were medium and less than 40% low. Accordingly, highest heritability was observed for plant height, leaf length, leaf width, number of leaves, pseudostem length, pseudostem diameter, total phenols and pyruvic acid, whereas moderately high heritability was observed in foliage weight, average bulb weight, marketable yield, gross yield and dry matter; medium in polar diameter, equatorial diameter, TSS and lowest in neck thickness. Fehr (1987) suggested that heritability of a trait is determined by the population studied, the environment and the method used. In agreement with our findings, very high heritability was recorded for plant height, number of leaves, total phenols and pyruvic acid (Chattopadhyay *et al*. 2013), pungency (Degewione *et al*. 2011) and plant height (Khosa and Dhatt 2013, Santra *et al*. 2017). But the amount of genetic improvement which would result from selecting individual genotype is not provided by heritability alone. Knowledge of heritability along with genetic advance is more useful. Genetic advance (GA) under selection refers to the improvement of characters in genotypic value for the new population compared with the base population under one cycle of selection at a given selection intensity (Singh 2001, Hamdi *et al.* 2003). Genetic advance ranged from 0.13-17.42 and was highest in average bulb weight (17.42 g) which means that whenever we select the best 5% high-yielding genotypes, average bulb weight of the progeny can be improved as much as 17.42 g, i.e. mean genotypic value of the new population for average bulb weight will be improved from 50.26 g to 67.68 g. Similarly, gross yield can be improved from 25.34 t/ha to 39.0 t/ha and marketable yield from 20.74 t/ha to 34.37 t/ha. Aditika *et al*. (2017) reported a high range of genetic advance ranging from 8.15 to 27.05%. Similar to our findings, low genetic advance for neck thickness, bulb diameter, plant height, and number of leavers/plant while, high genetic advance for bulb weight, yield and number of marketable bulb was reported by Trivedi *et al.* (2006), Bharti *et al.* (2011) and Aditika *et al*. (2017). Genetic advance as percent of the mean (GAM), in the present study, ranged from 8.25% to 65.72% for marketable yield (MY) and equatorial diameter, respectively. Johnson *et al.* (1955) categorised genetic advance as percent of mean as low (<10%), moderate (10-20%) and high (>20%). Based on this classification, marketable yield, foliage yield, gross yield, pyruvic acid, average bulb weight, pseudostem length, pseudostem width, total phenols, dry matter, leaf length, leaf width and number of leaves had highest genetic advance as percent of mean followed by medium GAM in plant height, neck thickness, TSS and polar diameter whereas low GAM was recorded for equatorial diameter. High GAM for bulb yield, total yield and marketable yield (Solanki *et al*. 2015), pyruvic acid and total phenol (Santra *et al*. 2017), average bulb weight and yield (Aditika *et al*. 2017) followed by medium GAM in plant height, neck thickness and TSS (Aditika *et al*. 2017) have been reported. High heritability along with high genetic advance as percent mean is more helpful in predicting gain under selection than heritability alone. Accordingly, high heritability along with high GAM was observed in number of leaves, leaf length, leaf width, pseudostem length, pseudostem diameter, total phenols and pyruvic acid indicating the presence of additive gene action for the expression of these traits and selection in next population based on these traits would be ideal. Solanki *et al*. (2015) reported high heritability coupled with high genetic advance for bulb yield and total yield, whereas Chattopadhyay *et al*. (2013) reported that all the traits except polar diameter had high heritability and high genetic advance as percent of mean. Traits with high values of heritability coupled with moderate genetic advance as percent of mean, viz. plant height suggest that selection for improvement of these characters may be rewarding. It also indicates greater role of non-additive gene action in their inheritance.

Cluster analysis

The Euclidean distance was calculated and based on ward's minimum variance method (Ward.D2), all the 58 accessions were clustered into four distinct clusters (Fig 1). Cluster I comprised fifteen accessions of Indian origin in which 80% were open pollinated varieties, 13.3% breeding lines and 6.7% were landraces. This cluster was characterised with highest plant height, number of leaves, leaf length, leaf width, pseudostem length, pseudostem diameter, highest average bulb weight, foliage weight, gross yield, marketable yield and pyruvic acid. Most of the widely adapted commercial varieties, viz. PWF, Punjab Naroha, Pusa Riddhi, Pusa Madhavi and Pusa Red were grouped under this cluster. Bulbs with high pungency levels are related to good storage ability (Coolong *et al*. 2008, Larsen *et al*. 2009). Hence, this group may be used for selection of genotypes having bulbs with higher yield and higher pungency coupled with good storage ability. Cluster II was

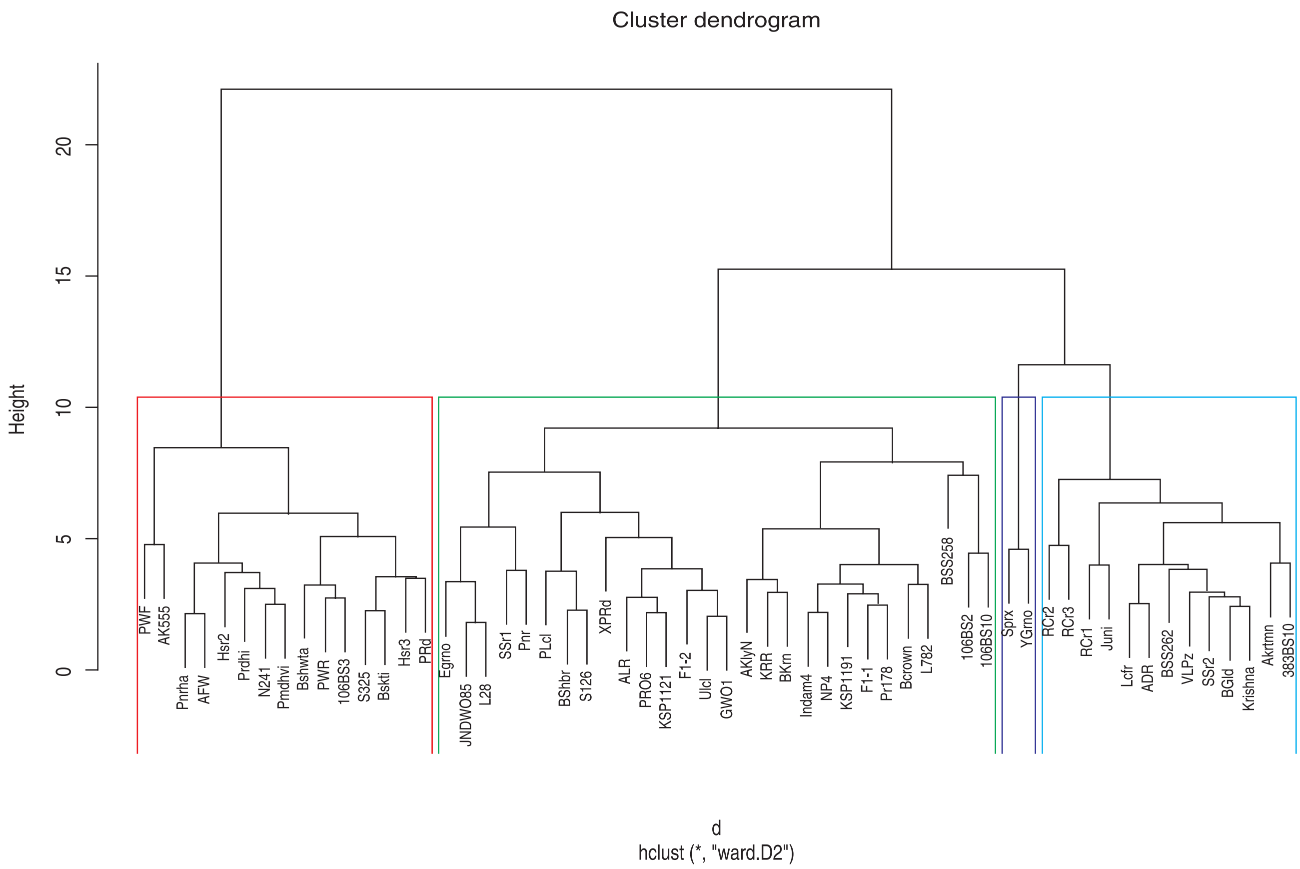

Fig 1 Cluster analysis of 58 short day onion accessions by Euclidean distance using Ward's minimum variance method.

the largest group having 28 accessions. Out of these 28 accessions, 16 were OPVs, eight hybrids, 3 breeding lines and one landraces. This cluster composed of accessions having highest TSS and highest dry matter content. Hybrids like XP Red, KSP1121, F1-2, Indam 4, NP4 KSP1191, F1-1 and BSS258 were included in this cluster. All these hybrids are from private companies and can be used as a source for introgression of genes for high TSS and high dry matter content. Significant and positive genetic and phenotypic correlations have been observed between soluble solids content (SSC) with dry matter (DM %) (Nieuwhof *et al.* 1973, Jaime *et al*. 2001, Vågen and Slimestad 2008) and also with pungency and onion-induced *in vitro* antiplatelet activity (OIAA) (Galmarini *et al*. 2001). Hence, this group is important for selecting accessions for breeding varieties with high TSS and dry matter content. In contrast, cluster III was the smallest one with two accessions, viz. Superex (Sprx) and Yellow Grano (YGrno). Out of these, Superex is a hybrid and Yellow Grano is an OPV. This cluster was smallest one and comprised accessions having lowest pseudostem length, pseudostem diameter, neck thickness, TSS, dry matter, pyruvic acid but highest polar diameter and total phenols. Significant negative correlation between total phenols and thrips damage has been reported in onion (Njau *et al*. 2017) and Persian Leek (Akhtari *et al*. 2014), Similarly, Kandakoor *et al*. (2014) and Chandrayudu *et al*. (2016) demonstrated a significant negative correlation between phenols and thrips damage in peanut. Hence, both the accessions can be used for breeding disease and insect resistant onion cultivars. Cluster IV comprised of 13 accessions encompassing seven OPVs, four hybrids, one landrace and one breeding line. This cluster consisted of accessions having lower polar diameter, equatorial diameter, average bulb weight, gross yield and marketable yield. Accessions of cluster IV were exotic lines, breeding lines, and landraces which are generally not grown on large scale in India and have narrow adaptability. This cluster comprised of private hybrids Juni, Lucifer, BSS262 and one public hybrid Arka Kirthiman. It has been reported that open-pollinated cultivars are a feasible option, wherever hybrid development is not established and locally developed onion cultivars outperform introduced hybrids (Kik *et al*. 1998, Cramer 2001). Similarly, Arka Kirthiman and Arka Lalima, hybrids released by IIHR, Bengaluru, did not gain farmer's attention and were not released at the national level because of their low yield (Khar and Saini 2016). Other exotic varieties, RCr1, RCr2, RCr3 also yielded low since they have not yet adapted to the short day tropical conditions of India. ADR in Cluster IV is a widely grown commercial variety but this variety is suitable for *rainy/kharif* season hence it yields less in winter season. Clustering was not observed on the basis of geographical area but on

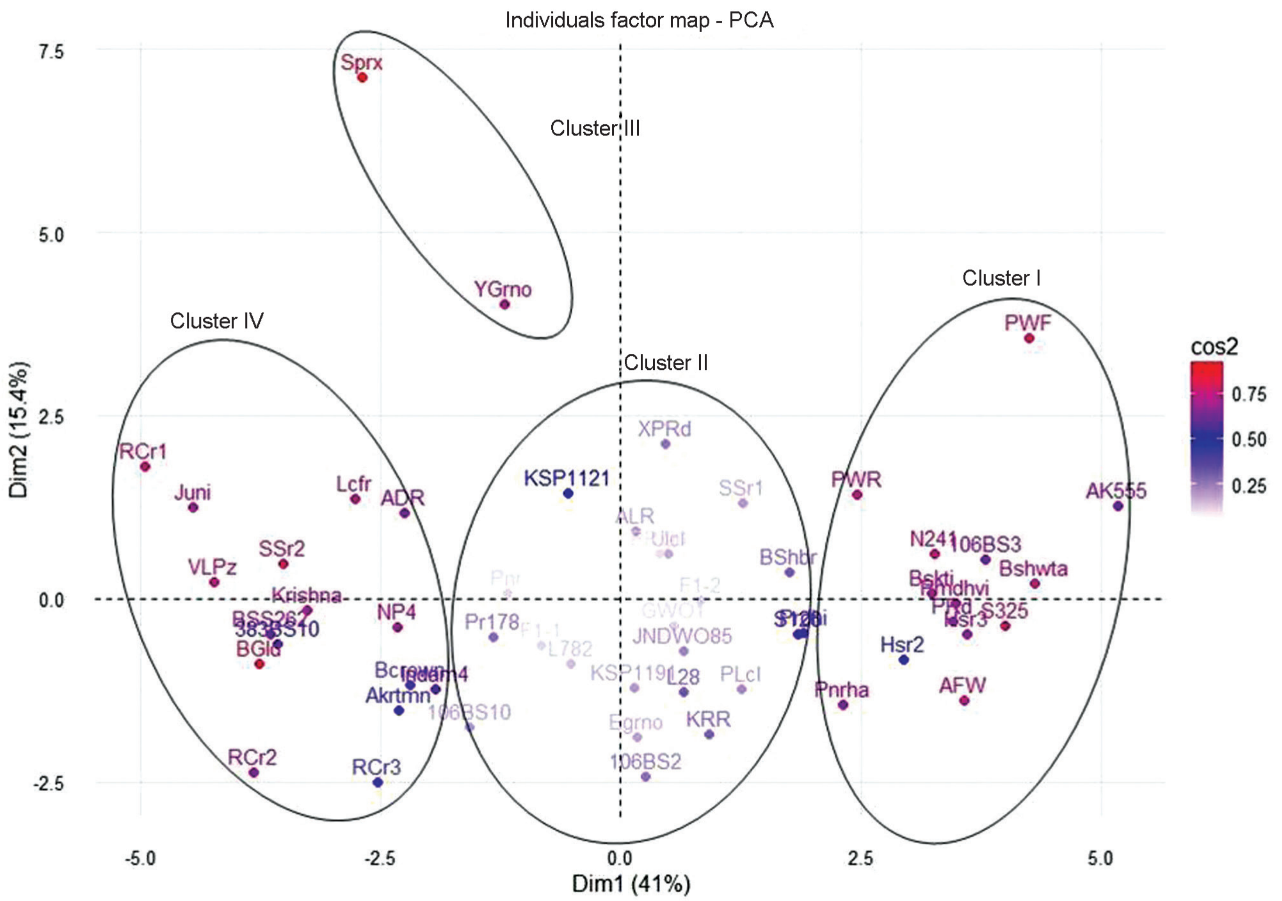

Fig 2 Principal component analysis of 58 short day onion accessions using morphological and biochemical traits.

Table 3 Eigenvectors and eigenvalues of the first four principal components of 17 traits of onion

Variable	PC1	PC2	PC3	PC4	PC5
Eigenvalue	6.97	2.63	1.32	1.24	1.18
Variation (%)	41.0	15.4	7.8	7.3	7.0
Cumulative (%)	41.00	56.4	64.2	71.5	78.5
PH	0.329	0.125	0.220	-0.114	-0.186
NOL	0.284	0.154	-0.002	0.044	-0.099
LL	0.328	0.073	0.220	-0.018	-0.147
LW	0.294	0.096	0.127	0.199	-0.191
PsL	0.258	0.182	0.121	-0.279	-0.331
PsW	0.331	0.154	0.125	-0.052	0.039
P	0.175	-0.256	0.231	-0.454	0.210
E	0.237	-0.264	-0.358	0.200	0.088
N	0.177	0.197	0.059	-0.179	0.606
TSS	0.072	0.397	-0.299	-0.284	0.204
ABW	0.313	-0.286	-0.103	0.007	0.094
FW	0.192	0.064	-0.112	0.051	0.403
GY	0.305	-0.270	-0.190	0.152	0.019
MY	0.281	-0.303	-0.205	0.174	-0.050
DW	0.099	0.420	-0.233	0.276	-0.187

Contd.

Table 3 (*Concluded*)

Variable	PC1	PC2	PC3	PC4	PC5
PA	0.029	0.307	0.184	0.538	0.311
TPC	-0.017	-0.190	0.627	0.291	0.141

PH : Plant height (cm) ; NOL-Number of leaves; LL-Leaf length (cm); LW-Leaf width (cm); PsL-Pseudostem length (cm); PsW-Pseudostem width (cm); P-Polar diameter (cm); E-Equatorial diameter (cm); N-Neck thickness; ABW-Average bulb weight; FW-Foliage weight (Kg); GY-Gross yield (t/ha); MY- Marketable yield (t/ha); TSS-Total soluble solids ($^{\circ}$B); DM-Dry matter (%); PA-Pyruvic acid (µmol/ml); TP-Total phenols (mg/g fresh weight).

morphological and biochemical traits. The results are in agreement with the findings of Mallor *et al.* (2011) who grouped 86 Spanish onion into four distinct clusters based on bulb size, pungency, dry matter and TSS. Khosa and Dhatt (2015) clustered 43 Indian onion accessions into seven clusters and Arya *et al.* (2017) classified 26 onion accessions into four clusters and they reported that clustering was not on the basis of geographical origin which is in confirmation with our findings.

Principal Component Analysis (PCA)

PCA reduces the dimensionality of the data by transforming initial variables into a new small set of variables without losing the important information in the original

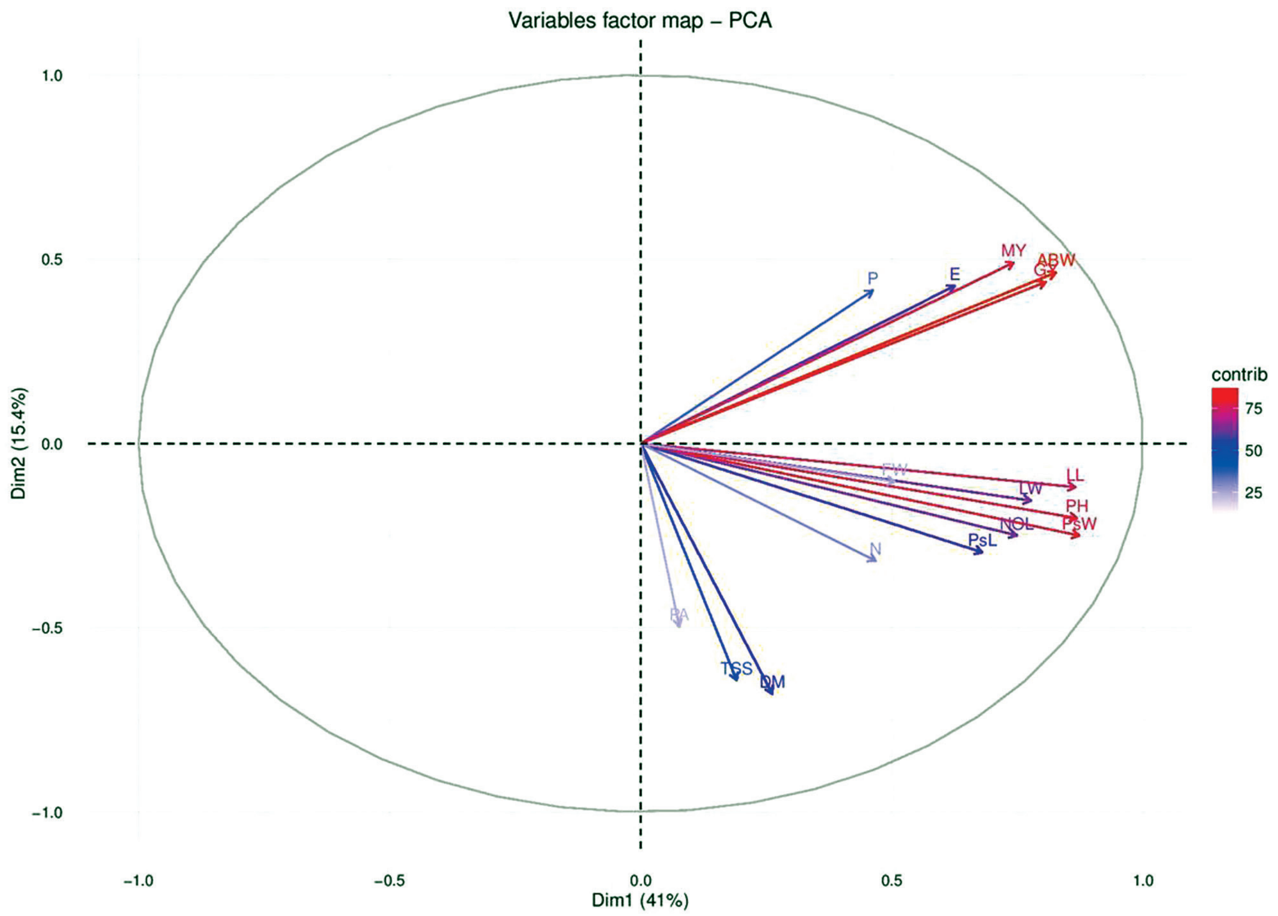

Fig 3 Contribution of variables towards PCA analysis based on cos2 value.

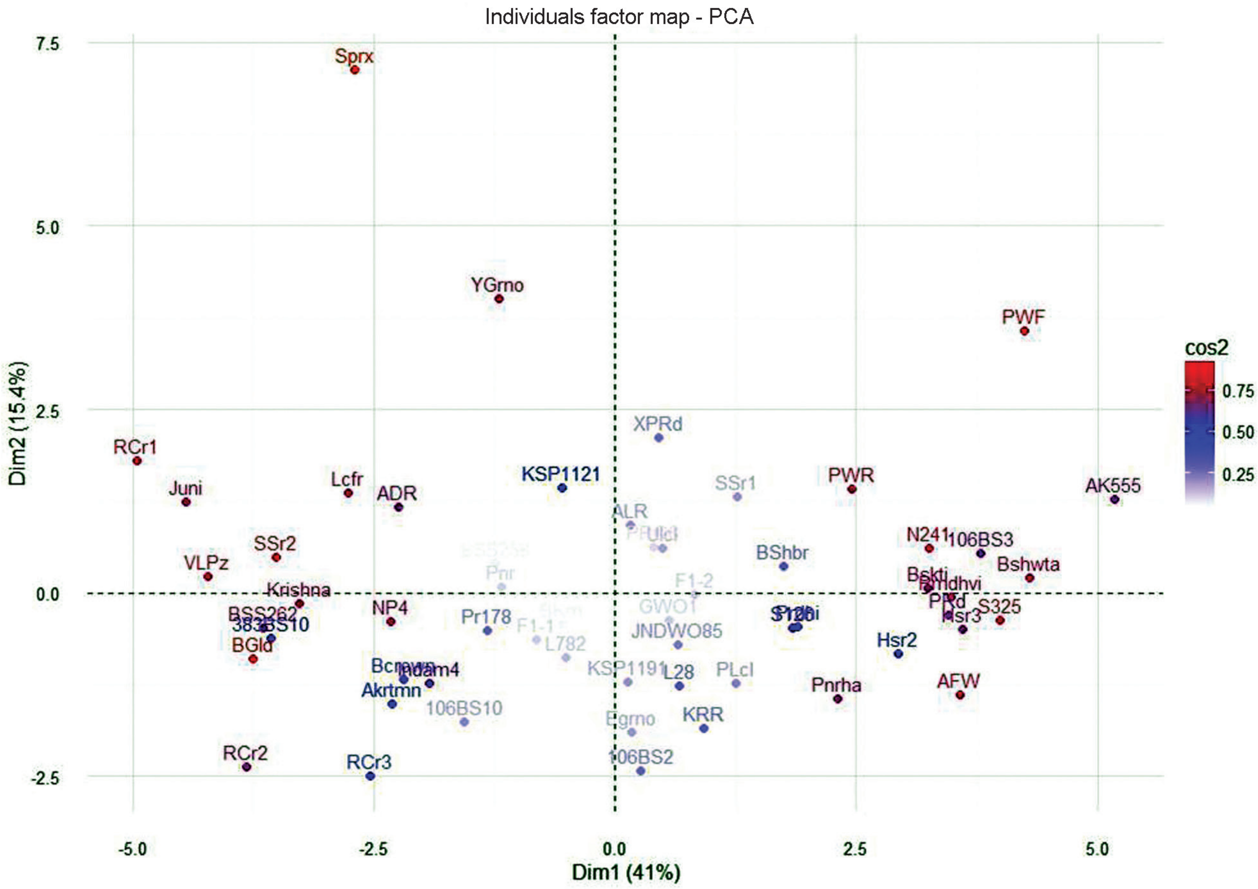

Fig 4 Contribution of onion accessions towards PCA analysis based on cos2 value.

variables. The results of PCA confirmed the findings of cluster analysis. In PCA, genotypes were clustered into four groups (Fig 2) with only a few differences between cluster II and IV. This demonstrates that the data obtained from this experiment is precise, accurate and reliable. Five principal components, PC1 to PC5, which were extracted from the original data and having latent roots greater than one, accounted for nearly 78.5% of the total variation. According to eigen vector analysis, the observed variation for first, second, third, fourth, and fifth principal component were about 41 %, 15.4%, 7.8%, 7.3%, and 7%, respectively (Table 3). In the first principal component, pseudostem width (0.331), plant height (0.329) and leaf length (0.328) were the most contributing traits, whereas dry matter (0.420), TSS (0.397) and pyruvic acid (0.307) were the principal traits of second principal component. According to squared cosine value (Cos2) for variables, traits, *viz*. average bulb weight, gross yield and marketable yield in positive direction and plant height, pseudostem width and leaf length in negative direction, were the major contributing traits, whereas neck thickness, foliage weight, and pyruvic acid were the least contributing traits (Fig 3). On the basis of squared cosine value (Cos2) for individual factor, Superex and Black Gold were the most prominent genotypes contributing towards PCA whereas BSS258, Bhima Kiran and PRO-6 were the least contributing individual factors (Fig 4). Arya *et al*. (2017) observed that three principal components contributed to 95.61% of the variation. They observed that high positive loading from average bulb weight, bulb yield and high negative loading from leaf length, double/deformed bulb in PC1 contributed more towards differentiating the clusters which is in agreement with our studies. Similarly, Singh *et al*. (2013) observed 3 principal components having 71.03% of total variation and in first principal component plant height, marketable yield, bulb polar diameter and bulb neck thickness were the major contributors which is in agreement with our findings. In contrast, Hanci and Gokce (2016) observed that nine PCs with eigen values >1 contributed 71.84% of the variability among 96 Turkish onion accessions. But in agreement with our findings, the characters contributing more positively with PC1 were bulb weight and diameter of the pseudostem. Genetic diversity is very important for the selection of the parents. It was observed that Superex and Yellow Grano, accessions originating from Japan and USA, could be hybridised with short day accessions of India or vice versa to create a broader genetic base for yield and other favourable characters.

The present study exhibited considerable level of genetic diversity among the fifty eight onion accessions. Based on our findings, high heritability was recorded for parameters, viz. plant height, number of leaves, pseudostem length, pseudostem width, leaf length, leaf width, total phenols and pyruvic acid. This suggests that these traits can be successfully transferred to offspring, if selection for these traits is performed in the hybridization programme. Besides this, traits like average bulb weight, gross yield, marketable yield showed high genetic advance which implies that these characters could be used to select onion genotypes for a notable improvement in cultivation in changing environments. Furthermore, crossing the genotypes from other clusters, e.g. Cluster III with Cluster I could result in heterotic expression and a large variability in the segregating generation.

ACKNOWLEDGEMENT

The authors are thankful to the Director, ICAR-IARI and Head, Division of Vegetable Science, ICAR-IARI for making the facilities available to support this work.

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