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Evaluation of genetic diversity and development of core collection of onion

Amar Jeet Gupta*, Ashwini P. Benke, V. Mahajan and Major Singh

ICAR-Directorate of Onion and Garlic Research, Rajgurunagar 410 505, Pune, Maharashtra, India.

ABSTRACT

Onion (Allium cepa L.) is a bulbous crop grown in three different seasons: kharif, late kharif and rabi in India. ICAR-Directorate of Onion and Garlic Research, the National Active Germplasm Site (NAGS), holds a vast collection of onion accessions from different parts of the country. Onion being a highly cross-pollinated crop, its collection depicts tremendous variation at phenotypic, biochemical and molecular levels. Therefore, handling more accessions becomes difficult for evaluation. Hence the formulation of the core group becomes a pre-requisite. PowerCore software has been used to constitute a season-wise core group using mean data of 24 important traits. In total, 131, 150 and 237 onion accessions were used to formulate the core group, where 27, 35 and 38 accessions were constituted in the core for Kharif, late kharif and rabi seasons, respectively. The formulated core was validated using mean difference percentage (MD%), variance difference percentage (VD%), and coincidence rate percentage (CR%), where MD% for all three sets ranged between 7 to 11%, VD% between 25 to 46% and CR% between 94 to 96%. A scattered Principal Component Analysis (PCA) diagram for the core and entire collection showed the core group, representing the entire collection. Further correlation strength among traits for the entire and core group was similar. This characterization and formulated group accessions will be helpful for further critical analysis and identifying trait-specific accessions.

Keywords: Core collection, Onion accessions, PowerCore, Dendrogram and PCA

INTRODUCTION

Onion (*Allium cepa* L.) is an impatant bulbous vegetable crop cultivated in almost all parts of the country. In India, onion occupies an area of 1.32 million hectares with the production of 20.93 million tonnes (NHB, 1). Though India ranks first in the area and second in production in the world, its productivity is low (15.86 t/ha) compared to world productivity (20.40 t/ha) (NHB, 1). Successful onion production depends on the selection of varieties that are adapted to different conditions imposed by the specific environment. Conservation of genetic diversity is an essential pre-requisite for developing new cultivars with desirable horticultural traits under changing agro-climatic conditions. Although a large number of germplasm collections have been established world-wide, many of them face major difficulties due to large holdings and lack of adequate information about population structure and genetic diversity. Core collection with a minimum number of accessions and maximum genetic diversity will facilitate easy access to genetic material as well as the use of hidden genetic variation in onion.

A proper understanding of genetic diversity among the constituents of germplasm collection and their proper documentation is essential for developing a representative set. Several national and international groups have developed/ or are developing core collections of various crops. According to FAO (2), germplasm of crops and its wild relatives is conserved in more than 575 gene-banks worldwide, with a total of about 4.9 million accessions maintained under medium and long-term conditions globally. Keeping in view the importance of onion in agricultural diversification, the ICAR-Directorate of Onion and Garlic Research, Rajgurunagar, Pune (ICAR-DOGR) has been identified as National Active Germplasm Site (NAGS) for onion and garlic germplasm collection and conserved 1229 onion germplasm accessions from all over the country collected in collaboration with NBPGR and being utilized in onion research and development programmes. The effective utilization of these accessions depends upon the identification of diverse trait-specific accessions. Therefore, these accessions need to be evaluated for important horticultural traits exhibiting genotype-environment interactions across multi-locations. However, evaluating the entire collection of such big size is cumbersome, time-consuming as well as resource demanding. In order to utilize and manage the germplasm collection more effectively and easily, Frankel (3) proposed the concept of core collection which is a representative sample of the entire collections with minimum repetitiveness and

*Corresponding authorl: guptaaj75@yahoo.co.in

rich genetic diversity of a crop. Brown (4) observed that reduction of about 10% of the entire collection in the core which can be evaluated extensively at a relatively low cost across multi-locations. Further, the information derived could be used as a guide towards more efficient utilization of the entire collection (Frankel, 5; Ortiz *et al*. 6; Upadhyaya *et al*. 7).

The inter-relationship between yield and yield contributing characters can be estimated by correlation analysis which provides information on nature, extent and direction of selection. Principal Component Analysis (PCA) enables ease in understanding of effects and associations among various traits (Dangi *et al.* 8). Very less work has been done in onion with reference to core collection. Hence the present investigation was carried out to constitute a core collection of short day red onion for different seasons representing the diversity of the entire collection for use by breeders in crop improvement.

MATERIALS AND METHODS

A total of 518 red onion accessions were evaluated in different seasons (*kharif, late kharif,* and *rabi*) in randomized block design with three replications for three years (2014-15 to 2016-17) at ICAR-DOGR. The experimental site, Rajgurunagar is located at 18°51'N and 73°53'E at an altitude of 604 m. The average annual rainfall is 683 mm, which normally occurs from June to September. Time of seed sowing was May-June, Aug-Sept and Oct-Nov for *kharif, late kharif* and *rabi*, respectively and transplanting was done after 40-45 days from seed sowing at the spacing of 15 cm row to row and 10 cm plant to plant. All cultural practices and data recordings were similar for all the three years of characterization during this period. Number of accessions along with origin are mentioned in Table 1 & 2.

The observations were recorded on 24 important growth, yield and quality parameters of onion *viz.*; plant height (cm), number of leaves per plant, collar thickness (cm), A grade bulbs (%), B grade bulbs (%), C grade bulbs (%), double bulbs (%), undersized bulbs (%), bolter bulbs (%), rot bulbs (%), marketable bulbs (%), marketable yield (q/ha), total yield (q/ha), days to harvesting, polar diameter (cm), equatorial diameter (cm), neck thickness (cm), average bulb weight (g), TSS (%), centerness, E:P ratio, plant establishment (%), total storage loss (%) and colour of bulb in five randomly selected plants of each accession from each replication.

Data from all the three trial sets were statistically analyzed by using SAS 9.3 (Proc GLM). The principal

Table 1. Season-wise core sets of red onion.

Season	Entire count	Core count	Percent selection in the core group	No. of traits evaluated	MD%	VD%	CR%	VR%
Kharif	131	27	20.61	23	10.98	38.64	94.83	127.46
Late *Kharif*	150	35	23.33	24	7.59	24.02	94.36	111.28
Rabi	237	38	16.03	24	8.57	45.94	95.94	135.46

Table 2. Frequency distribution of red onion entire and respective core collection accessions in different states of India.

Region/state/country	*Kharif*		*Late Kharif*		*Rabi*	
	Entire	Core	Entire	Core	Entire	Core
Maharashtra	98	21	115	24	170	21
Gujarat	01	01	09	02	10	02
Andhra Pradesh	01	-	01	01	06	02
Tamil Nadu	03	-	01	-	01	-
Karnataka	26	04	14	05	21	07
Chhattisgarh	01	-	03	01	02	01
Rajasthan	-	-	01	-	01	
Delhi	01	01	03	01	10	02
Odisha	-	-	03	01	03	-
Bihar	-	-	-	-	01	-
West Bengal	-	-	-	-	12	03
Total	131	27	150	35	237	38

component analysis and clustering of all traits in the entire accessions of three seasons were analyzed by JMP Pro. Representative accessions were selected based on the advanced M strategy using a modified heuristic algorithm implemented in PowerCore software categorical variables, such as genotype and qualitative phenotype were applied in several classes (3-12 classes) based on distinct characters. Continuous variables *i.e.*, quantitative phenotypes, 7-12 classes) were automatically classified into different categories in the software based on Sturges' rule. The entire germplasm collection of onion was stratified into three groups based on seasons: *kharif* (131 accessions), *late kharif* (150 accessions) and *rabi* (237 accessions). The data on quantitative traits in all seasons were standardized using the range of each variable to eliminate scale differences (Milligan and Cooper 13). PCA axis with eigen values ≥0.8 were selected to define variation among accessions for different traits.

The data on geographic origin, qualitative and quantitative traits were used to validate the core collection composition. The expected frequencies of the accessions in different classes of a trait in the core collection were based on the proportion of core to the entire collection. The mean of entire and the constituted core collection were compared using the Newman-Keuls procedure, (Newman 14; Keuls 12) for all quantitative traits. The percentage of the significant difference between the core and entire collections was calculated for the mean difference percentage (MD%) and the variance difference percentage (VD%) of traits. The coincidence rate (CR%) and the variable rate (VR%) were calculated to compare the entire and core collection following the method used by Hu *et al.* (9).

RESULTS AND DISCUSSION

Data were analyzed for 24 important traits in 131 (*kharif*), 150 (*late kharif*) and 237 (*rabi*) accessions. In results, analysis of variance of all recorded traits was found significant among genotypes in all three conducted trials during *kharif, late kharif* and *rabi*. However, genotypes into year interaction showed non-significance, hence average data of recorded traits was considered for further analysis such as cluster analysis, corset formulation, correlation studies and principal component analysis.

Mean data of total 131, 150 and 237 red onion accessions evaluated during *kharif, late kharif* and *rabi* seasons, respectively was used to formulate the core group. The heuristic approach of PowerCore successfully sorted 27, 35 and 38 accessions in a core set of red onion for *kharif, late kharif* and *rabi* season, respectively (Table 1). Hence, total 100 accessions out of 518 *i.e.* 19.30% of the entire collection were selected in the core group. This season-wise core set representing the total diversity of the entire collection can be used very efficiently for the identification of new sources of diversity for important traits following extensive multi-location evaluation. Generally 10% population is representing entire variation of base population. In foxtail millets, Gowda *et al.* (6) found 4% accessions as a core group. But there is no such limitation where the variation need representation of all alleles from a base population. It will differ as per crop biology and fertilization pattern. Onion being highly cross-pollinated crop has wide variability in disperse population.

MD% of all three sets ranged between 7 to 11%, which showed that there was no major difference in the mean value of the core set and the entire set (Table 1). The 10% value for the MD% indicated that the core collection effectively represented the whole collection as reported by Hu *et al*. (9). VD% indicated that the variance of the core set was different from the entire collection, the range of all three core sets were 25% to 46%. The 20% value for the VD% measured in the core collection suggested the adequate representation of the core collection (Kang *et al.* 11). The coefficients of variations or variable rate for most of the traits were higher in the core collection than in the entire collection, resulting in 127.46%, 111.28% and 135.46% VR for *kharif, late kharif,* and *rabi*, respectively for quantitative traits, which was higher than entire collection. The CR 94.83%, 94.36% and 95.94% were captured for all quantitative traits in the core collection for *kharif, late kharif* and *rabi,* respectively which was nearly 100% indicating that core has captured all the variability of the entire collection (Kang *et al.* 11).

The entire collection of red onion was represented by 11 states of the country. The maximum number of accessions of all three sets in core collections were reflected from Maharashtra followed by Karnataka, Gujarat, Delhi and Andhra Pradesh. There was no reflection from Bihar in all the three sets (Table 2). The 131 accessions (*kharif*) clustered into three primary groups (23, 84 and 24 accessions). The closest distance was found in the accessions (1416 and 1445) and distantly related accessions were 48 and 85. The *late kharif* 150 accessions were clustered into two primary groups, the number of accessions in each group was 117 and 33. The accession 131 and 205 were closely related and the accession 12 and 554 had the highest distance between them. The third set of 237 *rabi* accessions were clustered in two groups (62 and 175). Accession 531 and 638 were closest in all clusters and distantly related accessions were 12 and 26. The highest entries were collected from Maharashtra (383) followed by Karnataka (61), Gujarat (20), Delhi (14), West Bengal (12), Andhra Pradesh (8) and lowest entries from Bihar (1) (Table 2). Within the grouping of core set accessions, there is no relationship between the origin of accessions with grouping patterns as well as season adaptability as some accessions from same states were grouped together and some in a different group. However, accessions from same states are performing better over different season.

The racial pattern of the entire collection reflected the prevalence set of *rabi* (45.75% accessions) followed by *late kharif* (28.95% accessions) and *kharif* (25.28% accessions) whereas in core collection, set of *late kharif* (23.33%) was highest followed by *kharif* (20.61%) and *rabi* (16.33%).

The range, mean, variance of entire and core accessions was analyzed for 12 important quantitative characters. A comparison of the range for five quantitative traits for *kharif, late kharif* and *rabi*, red onion across entire and core collections showed that 100% of the range was available in the entire collections which were included in the core collection. The characters included for *kharif* were bolter bulbs, marketable yield, total yield, neck thickness and TSS (Table 3), for *late kharif* were plant height, marketable yield, total yield, polar diameter and TSS (Table 4) and for *rabi* were number of leaves, double bulbs, days to harvesting, equatorial diameter and neck thickness (Table 5) in the core collection.

The remaining traits in *kharif* were plant height, number of leaves, doubles, days to harvesting, polar diameter, equatorial diameter and average bulb weight (Table 3); in *late kharif*, were number of leaves, doubles, bolters, days to harvesting, equatorial diameter, neck thickness and average bulb weight (Table 4) and for *rabi* were plant height, bolters, marketable yield, total yield, polar diameter, average bulb weight and TSS (Table 5). The range included in the core collection varied from 90 to 99%. Differences between the means of the entire and core collections were non-significant for all the recorded traits. The variance of the entire and core collection was homogeneous for all traits. It also suggests that the sampling technique to constitute core collection was appropriate and the core collection has captured adequate diversity from the entire collection. Ortiz *et al*. (1998) suggested that adequate and proper sampling essential in developing a representative core collection, should consider the conservation of phenotypic associations arising out of co-adapted gene complexes. Hence, the technique of heuristic approach of core set formulation in the present study using PowerCore is validated and proven by these strategies.

The Fig. 1 showed the scatter diagram of the entire collection and core collection were based on the principal component analysis using 24 important traits. This indicates that the selected core accessions effectively reflected the variation in the entire collection because the core accessions were selected universally from the range of the entire accessions.

In the entire and core set, the first two principal components accounted 45.35% and 49.31% for *kharif*, 34.26% and 42.16% for *late kharif* and for *rabi* 38.85% and 40.09% of the cumulative variation in the population. The character contributing to the

Table 3. Range, mean and variance in entire and constituted core collections of *kharif* red onion.

Traits	Range		Mean		Variance	
	Entire	Core	Entire	Core	Entire	Core
Plant height (cm)	35.06-61.08	35.06-59.98	51.74	49.73	23.37	47.42
No. of leaves	5.60-10.50	5.60-10.07	8.80	8.53	0.54	1.45
Double bulbs (%)	0.00-64.11	0.00-64.11	6.61	9.31	79.22	205.81
Bolter bulbs (%)	0.00-4.39	0.00-4.39	0.09	0.22	0.18	0.74
Days to harvesting	84.00-126.00	88.44-124.00	100.70	104.59	115.30	130.06
Polar diameter (cm)	2.92-4.94	2.92- 4.77	4.00	3.83	0.12	0.19
Equatorial diameter (cm)	3.62-5.46	3.62 - 5.25	4.69	4.50	0.12	0.15
Neck diameter (cm)	0.14-0.84	0.14-0.84	0.45	0.47	0.018	0.022
Average bulb weight (g)	21.60-75.28	21.60-71.99	52.46	50.82	101.48	119.94
TSS (%)	9.03-14.56	9.10-14.56	11.02	11.25	0.86	1.48
Marketable yield (q/ha)	9.63-326.00	9.63-326.00	137.62	130.99	2927.51	5365.99
Total yield (q/ha)	39.10-382.50	39.10-382.50	191.15	183.57	2789.91	5607.98

Table 4. Range, mean and variance in entire and constituted core collections of *late kharif* red onion.

Traits	Range		Mean		Variance	
	Entire	Core	Entire	Core	Entire	Core
Plant height (cm)	44.25-66.99	46.83-66.99	56.77	57.34	19.73	26.80
No. of leaves	7.40-12.85	7.40-12.70	10.05	10.14	1.15	1.29
Double bulbs (%)	0.00-42.00	0.00-39.88	13.43	14.26	110.56	129.50
Bolter bulbs (%)	0.00-42.32	0.00-37.34	9.81	12.26	89.74	119.95
Days to harvesting	106.00-140.00	109.00-139.00	122.75	121.43	37.79	54.29
Polar diameter (cm)	3.60-5.36	3.65-5.36	4.35	4.37	0.081	0.10
Equatorial diameter (cm)	4.04-5.85	4.04-5.72	5.00	4.96	0.11	0.14
Neck diameter (cm)	0.27-1.56	0.36-1.56	0.68	0.75	0.048	0.076
Average bulb weight (g)	43.60-95.11	43.60-88.69	69.08	69.76	80.29	98.39
TSS (%)	10.36-14.85	10.36-14.56	12.32	12.17	0.91	0.99
Marketable yield (q/ha)	36.33-542.56	36.33-542.56	303.35	291.54	9128.69	13716.16
Total yield (q/ha)	203.50-690.00	203.50-690.00	433.92	447.98	7507.45	11972.81

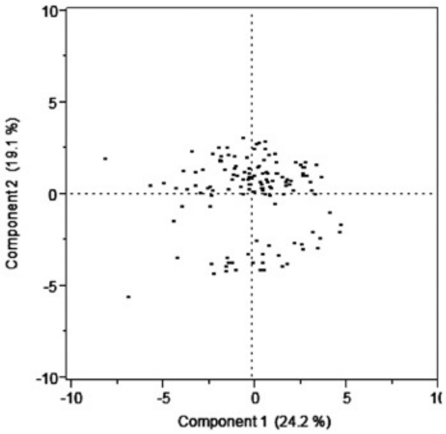
Table 5. Range, mean and variance in entire and constituted core collections of *rabi* red onion.

Traits	Range		Mean		Variance	
	Entire	Core	Entire	Core	Entire	Core
Plant height (cm)	35.68-57.87	37.63-55.63	49.25	47.60	18.59	25.67
No. of leaves	6.70-11.02	6.70-11.02	9.26	9.07	0.47	0.74
Double bulbs (%)	0.00-56.29	0.00-56.29	4.28	6.66	42.86	113.23
Bolter bulbs (%)	0.00-17.91	0.00-16.48	1.23	2.79	7.12	23.03
Days to harvesting	74.00-136.00	74.00-136.00	113.13	111.86	47.02	121.53
Polar diameter (cm)	3.04-4.88	3.13-4.78	4.03	3.86	0.10	0.17
Equatorial diameter (cm)	3.93-5.87	3.96-5.87	4.82	4.86	0.10	0.19
Neck diameter (cm)	0.21-0.82	0.21-0.82	0.50	0.46	0.02	0.02
Average bulb weight (g)	33.96-83.52	36.40-83.52	56.34	56.63	87.65	122.89
TSS (%)	9.54-14.64	9.79-14.64	11.32	11.53	0.47	0.76
Marketable yield (q/ha)	68.22-433.33	68.22-416.44	255.14	237.45	4879.58	8112.18
Total yield (q/ha)	142.70-483.11	154.00-483.11	292.11	286.42	4006.98	6019.45

Prin1 were A grade bulb, percent marketable bulbs, polar and equatorial diameter, average bulb weight, marketable yield and total yield in the entire and core accessions of all seasons. However, Prin2 has strong relation with the collar thickness, percent of undersized bulbs, rot percent, days to harvesting, percent double, B grade bulb, C grade bulb, equatorial diameter, total yield, number of leaves and neck diameter (Fig. 1).

The first principal component had the maximum number of characters towards genetic diversity and these traits could be effectively used for further breeding to generate more variability. Arya *et al.* (2017) reported that three principal components contributed to 95.61% of the variation in onion. It was also 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 are in agreement with the present studies. Hanci and Gokce (2016) observed nine PCs with eigen values >1 contributed 71.84% of the variability among 96 Turkish onion accessions. Dangi *et al.* (2018) reported that high heritability was noticed for plant height, number of leaves, pseudostem length, pseudostem width, leaf length, leaf width, total phenols, pyruvic acid and suggests that these traits can be successfully transferred to

Entire **Core**



Kharif Fig. (1a)

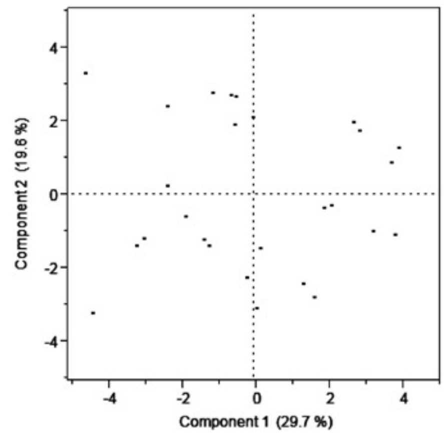
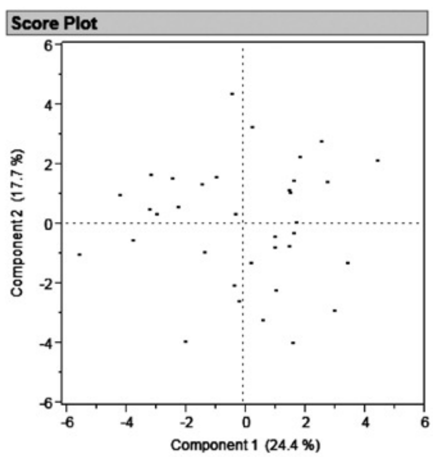


Fig. (1b)



Late *Kharif* Fig. (1c)

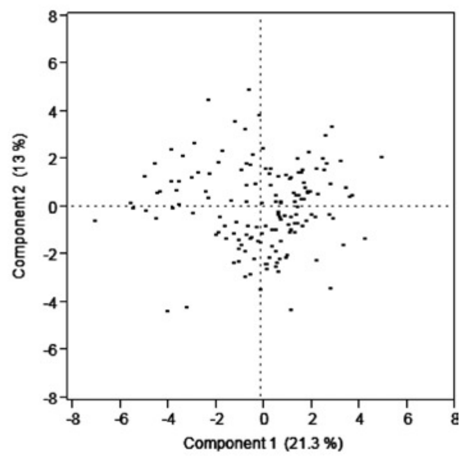
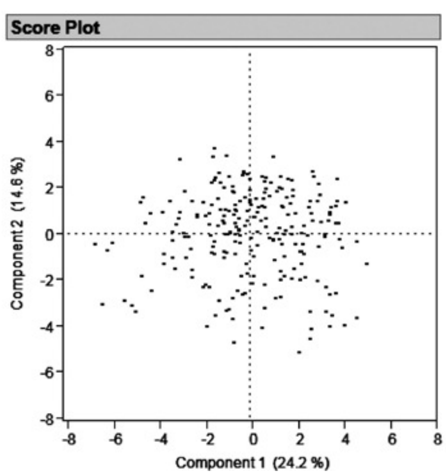


Fig. (1d)



Rabi Fig. (1e)

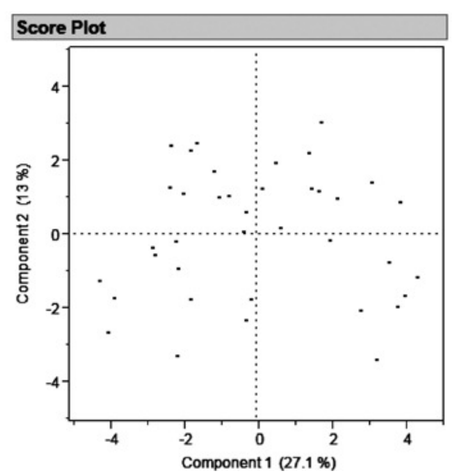


Fig. (1f)

Fig. 1: Scatter diagram for principal component analysis of red onion for the entire collection and the core collection. Prin1 (X-axis) and Prin2 (Y-axis) indicate the first and second principal components, respectively. Fig. (1a) Entire collection *Kharif* (131 accessions), Fig. (1b) Core collection *Kharif* (27 accessions), Fig. (1c) Entire collection *Late Kharif* (150 accessions), Fig. (1d) Core collection *Late Kharif* (35 accessions), Fig. (1e) Entire collection *rabi* (237 accessions), Fig. (1f) Core collection *rabi* (38 accessions).

offspring if selection for these traits is performed in the hybridization programme. A wide range of variability in onion accessions was reported by Kamala *et al.* (10) and Gupta *et al.* (7).

Phenotypic correlations were conducted between 12 quantitative traits in the entire and core collections separately. The pattern of correlation was similar in the entire and core collections, demonstrating that associations observed in the entire collection were well preserved in the core collection. Only those traits with correlation coefficients greater than ±0.458 are considered as biologically meaningful (Skinner *et al*. 18) as more than 50% of the variation in one trait is predicted by the other (Snedecor and Cochran, 19).

In present study, entire three sets have such meaningful significant positive relationships of total yield with plant height, number of leaves and equatorial diameter for core accessions. Other characters are positively correlated with total yield except double bulbs (%) in entire and core accessions in *kharif* red onion (Table 6). In *late kharif* red onion, a positive relationship between total yield with all traits was observed except number of leaves, doubles and bolter bulbs (%) in the entire and core accessions (Table 7). The polar diameter, equatorial diameter, and average bulb weight and other characters were positively correlated with total yield in entire and core accessions except double bulbs (%) and days to harvesting in *rabi* red onion (Table 8). Similar results were also found by Raghuwanshi *et al.* (17) in onion for correlation studies. Kamala *et al.* (10) observed strong positive association between bulb weight and equatorial and polar diameter.

Vast genetic diversity is being maintained in red onion germplasm at ICAR-DOGR. These germplasm accessions were characterized and formulated core collection. The core validation suggests that core groups are representative sub set of respective base collections. The identified core group is useful

Table 6. Phenotypic correlation coefficient of entire and core accessions of *kharif* red onion.

Traits	Collection	PH (cm)	NOL	Doubles (%)	Bolters (%)	DTH	P (cm)	E (cm)	N (cm)	ABW (g)	TSS (%)	MY (q/ha)	TY (q/ ha)
PH (cm)	Entire	1.000											
	Core	1.000											
NOL	Entire	0.729**	1.000										
	Core	0.856**	1.000										
Doubles (%)	Entire	-0.118	-0.097	1.000									
	Core	-0.160	-0.160	1.000									
Bolters (%)	Entire	0.125	0.051	0.082	1.000								
	Core	0.236	0.094	0.111	1.000								
DTH	Entire	-0.204	0.119	-0.317	-0.115	1.000							
	Core	-0.133	0.110	-0.399	-0.207	1.000							
P (cm)	Entire	0.307	0.234	0.080	0.126	-0.291	1.000						
	Core	0.695	0.603*	0.113	0.296	-0.220	1.000						
E (cm)	Entire	0.230	0.141	-0.012	0.064	-0.236	0.758**	1.000					
	Core	0.656	0.578*	0.034	0.177	-0.108	0.786**	1.000					
N (cm)	Entire	0.393	0.315	-0.044	0.056	-0.083	-0.092	-0.092	1.000				
	Core	0.398	0.379	-0.193	0.075	0.045	0.182	0.068	1.000				
ABW (g)	Entire	0.309	0.073	0.093	0.056	-0.464	0.510*	0.379	-0.124	1.000			
	Core	0.452	0.185	0.098	0.018	-0.304	0.455	0.383	-0.145	1.000			
TSS (%)	Entire	-0.188	-0.151	0.168	-0.052	0.260	0.054	0.139	-0.233	-0.028	1.000		
	Core	-0.026	0.020	0.305	-0.038	0.307	-0.193	0.085	-0.197	-0.088	1.000		
MY (q/ ha)	Entire	0.411	0.316	-0.443	-0.020	0.163	0.211	0.225	0.085	0.095	0.011	1.000	
	Core	0.644	0.523*	-0.471	-0.045	0.151	0.405	0.483	0.196	0.180	0.032	1.000	
TY (q/ ha)	Entire	0.457	0.374	-0.256	0.015	0.060	0.301	0.328	0.029	0.203	0.049	0.910**	1.000
	Core	0.698**	0.563*	-0.338	0.043	0.027	0.418	0.546*	0.114	0.291	0.033	0.930**	1.000

*, **: Significance at 5% and 1%, respectively.
PH: Plant height (cm), NOL: No. of leaves, DTH: Days to harvesting, P: Polar diameter (cm), E: Equatorial diameter (cm), N: Neck diameter (cm), ABW: Average bulb weight (g), MY: Marketable yield (q/ha) and TY: Total yield (q/ha)

Table 7. Phenotypic correlation coefficient of entire and core accessions of *late kharif* red onion.

Traits	Collection	PH (cm)	NOL	Doubles (%)	Bolters (%)	DTH	P (cm)	E (cm)	N (cm)	ABW (g)	TSS (%)	MY (q/ ha)	TY (q/ ha)
PH (cm)	Entire	1.000											
	Core	1.000											
NOL	Entire	0.284	1.000										
	Core	0.332	1.000										
Doubles (%)	Entire	-0.278	0.071	1.000									
	Core	-0.409	-0.088	1.000									
Bolters (%)	Entire	-0.075	0.021	0.375	1.000								
	Core	-0.305	-0.018	0.663**	1.000								
DTH	Entire	0.263	-0.037	0.089	0.123	1.000							
	Core	0.297	-0.151	0.220	0.239	1.000							
P (cm)	Entire	0.181	0.067	-0.100	0.149	0.210	1.000						
	Core	0.295	0.114	0.142	0.167	0.347	1.000						
E (cm)	Entire	-0.036	-0.078	0.043	0.101	0.177	0.601*	1.000					
	Core	-0.158	-0.288	0.143	0.092	0.107	0.575*	1.000					
N (cm)	Entire	0.072	0.222	0.017	-0.219	-0.123	0.158	-0.114	1.000				
	Core	0.260	0.556*	-0.034	-0.136	-0.004	0.043	-0.301	1.000				
ABW (g)	Entire	0.243	0.020	-0.119	0.116	0.427	0.451	0.395	-0.124	1.000			
	Core	0.254	0.135	0.022	0.064	0.475*	0.536*	0.440	-0.035	1.000			
TSS (%)	Entire	0.002	-0.128	0.106	-0.143	0.123	0.091	0.228	0.219	-0.061	1.000		
	Core	0.036	-0.157	0.006	-0.081	0.113	-0.073	0.238	0.140	0.007	1.000		
MY (q/ ha)	Entire	0.367	0.058	-0.625*	-0.612*	0.068	0.259	0.226	0.213	0.278	0.066	1.000	
	Core	0.504	0.145	-0.649*	-0.724**	0.063	0.235	0.262	0.209	0.429	0.119	1.000	
TY (q/ ha)	Entire	0.230	-0.043	-0.250	-0.288	0.106	0.226	0.370	0.183	0.263	0.117	0.744**	1.000
	Core	0.275	-0.018	-0.326	-0.379	0.184	0.404	0.542*	0.141	0.492	0.161	0.775**	1.000

*, **: Significance at 5% and 1%, respectively

PH: Plant height (cm), NOL: No. of leaves, DTH: Days to harvesting, P: Polar diameter (cm), E: Equatorial diameter (cm), N: Neck diameter (cm), ABW: Average bulb weight (g), MY: Marketable yield (q/ha) and TY: Total yield (q/ha)

Table 8. Phenotypic correlation coefficient of entire and core accessions of *rabi* red onion.

Traits	Collection	PH (cm)	NOL	Doubles (%)	Bolters (%)	DTH	P (cm)	E (cm)	N (cm)	ABW (g)	TSS (%)	MY (q/ ha)	TY (q/ ha)
PH (cm)	Entire	1.000											
	Core	1.000											
NOL	Entire	0.714**	1.000										
	Core	0.725**	1.000										
Doubles (%)	Entire	-0.114	-0.071	1.000									
	Core	-0.084	0.040	1.000									
Bolters (%)	Entire	-0.044	0.021	0.088	1.000								
	Core	0.131	0.115	0.115	1.000								
DTH	Entire	-0.350	-0.250	0.082	0.053	1.000							
	Core	-0.525*	-0.245	0.003	0.104	1.000							
P (cm)	Entire	0.149	0.093	-0.139	-0.123	-0.387	1.000						
	Core	0.102	0.051	-0.236	-0.101	-0.343	1.000						
E(cm)	Entire	0.116	0.091	-0.042	-0.053	-0.347	0.810**	1.000					
	Core	0.068	-0.030	-0.060	-0.105	-0.301	0.763**	1.000					

Contd...

Table 8 contd...

Traits	Collection	PH (cm)	NOL	Doubles (%)	Bolters (%)	DTH	P (cm)	E (cm)	N (cm)	ABW (g)	TSS (%)	MY (q/ha)	TY (q/ha)
N (cm)	Entire	0.521*	0.483*	-0.142	0.015	0.008	-0.080	-0.042	1.000				
	Core	0.511*	0.495*	0.030	0.204	-0.007	-0.178	-0.068	1.000				
ABW (g)	Entire	-0.138	-0.063	0.018	-0.090	-0.147	0.519*	0.539*	-0.171	1.000			
	Core	-0.304	-0.367	-0.243	-0.249	0.022	0.529*	0.596*	-0.274	1.000			
TSS (%)	Entire	-0.178	-0.123	-0.064	-0.072	0.065	0.172	0.252	-0.073	0.196	1.000		
	Core	-0.075	0.009	-0.396	-0.218	0.025	0.013	0.054	-0.030	0.228	1.000		
MY (q/ha)	Entire	0.232	0.234	-0.304	-0.104	-0.254	0.546*	0.552*	0.085	0.677**	0.116	1.000	
	Core	0.038	-0.034	-0.421	-0.157	-0.140	0.610*	0.656*	-0.053	0.822**	0.344	1.000	
TY (q/ha)	Entire	0.229	0.266	-0.052	0.044	-0.220	0.482	0.522*	0.092	0.686**	0.107	0.943**	1.000
	Core	0.044	0.002	-0.132	0.083	-0.135	0.536*	0.611*	-0.029	0.768**	0.228	0.917**	1.000

*, **: Significance at 5% and 1%, respectively.

PH: Plant height (cm), NOL: No. of leaves, DTH: Days to harvesting, P: Polar diameter (cm), E: Equatorial diameter (cm), N: Neck diameter (cm), ABW: Average bulb weight (g), MY: Marketable yield (q/ha) and TY: Total yield (q/ha)

for biochemical and molecular characterisation and for core collection refinement. The identified diverse genotypes can be useful for hybrid breeding programme for achieving heterosis in onion.

AUTHORS' CONTRIBUTION

Conceptualization of research (AJG, VM, MS); Designing of the experiments (AJG, MS); Contribution of experimental materials (AJG); Execution of field/lab experiments and data collection (AJG); Analysis of data and interpretation (AJG, APB); Preparation of manuscript (AJG, APB, VM).

DECLARATION

The authors declare no conflict of interest.

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