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Variability assessment and trait relationships among confectionery sunflower inbreds

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Abstract

Fifty-eight sunflower inbreds were evaluated for seventeen morphological parameters during spring 2019 and 2020 to understand the relationships among different traits for facilitating the indirect selection of superior confectionery sunflower inbreds. For confectionery inbreds, seed length is an important trait for making selections since seed length exhibited a negative correlation with seed volume weight which is highly correlated with oil content. Thus inbreds having higher seed length had lower oil content which is a desirable trait for confectionery sunflowers. The investigation also helped in the identification of sunflower inbred EC734798 as superior for confectionery purposes based on principal component analysis and EC734792, EC734806, EC734808, EC734831, EC734866, EC734870 and EC734790 were identified as superior inbreds based on cluster analysis. Furthermore, inbreds EC734810, EC734816I, EC734817II, EC734837, and EC734867 can be utilized for improving seed length parameters among confectionery sunflowers.

Keywords clustering, confectionery, correlation, sunflower

Introduction

Sunflower is an important oilseed crop across the globe ranking fourth for acreage and production however, confectionery sunflower only accounts for less than 10 % of total sunflower production. Owing to this very limited research efforts are directed towards breeding superior hybrids or inbred for confectionery traits. Confectionery sunflower can enhance farmers' income since the market price for “in shell” confectionery sunflower (suitable for human consumption as a snack) is three times higher than the oilseed sunflower [1]. The non-oilseed sunflowers are different from oilseed sunflowers with respect to seeds and quality characteristics [2]. In general, market acceptance for large elongated seed with distinct stripped seed coat is there with respect to their suitability as table purpose sunflower. Moreover, the high proportion of hull content, low oil content (< 30%) along with high seed yield is also important breeding objectives for confectionery sunflower [3]. Evaluation of trait relationships between the yield component traits as well as other traits of interest like seed yield, seed length, oil content, hull content, and other agronomic traits assists in indirect selection for yield.

Correlation analysis provides an efficient tool to plant breeders for undertaking effective selections in the field for a complex trait indirectly by selecting for a desirable trait. Partial correlation coefficients are effective in understanding causation wherever multi co-linearity among variables is present [4-6]. On the other hand, the grouping of genotypes based on different parameters for which they express superiority allows the breeder to select the inbreds for accumulation of desirable alleles through recurrent selection cycles, maintenance of genetic diversity among their working germplasm and development of heterotic pools [7-9]. Principal Component Analysis is a well-known method of reducing of large number of variables present in the data set and thereby making the selection of genotypes based on key components, based on how much variability is represented by those principal components [6]. The k-Means clustering is a partitioning algorithm that differs in the determination of the number of clusters and the selection of the initial cluster centroid [10-12]. HCA is a multivariate analysis widely used to assess the relatedness and distance of any type of samples characterized by any type of descriptors which is routinely used to assess genetic diversity among breeding material. The present investigation was carried out to assess the association among several agronomic traits with respect to seed yield and other confectionery traits for assisting indirect selection for these traits and to select sunflower inbreds showing superiority for several confectionery traits.

Methodology

A set of 58 confectionery inbred lines procured from GKVK, University of Agricultural Sciences, Bangalore, and ICAR- Indian Institute of Oilseeds Research including three checks i.e. EC-734849-II EC-734790 and TSG-267 were included in the present investigation. The inbreds were categorized into high, medium, and low oil-yielding inbreds; bold, small to medium and small seeds based on seed size and also based on seed color as mentioned in Table 1.

Table 1. List of genotypes evaluated for agro-morphological parameters

Inbred	Oil content	Seed Colour	Seed Size
EC734792	Medium	White seeds with stripes	Medium
EC734798	Low	Black seeds with stripes	Small-medium
EC734799-IR	Medium	Black seeds	Bold
EC734800	Medium	Black seeds	Medium
EC734802	Medium	Variable	Medium
EC734803	Low	White seeds with stripes	Medium
EC734805-I	Medium	Black seeds with stripes	Medium
EC734806	Low	White seeds with stripes	Medium
EC734807	Low	Grey seeds with white stripes	Medium
EC734808	Low	Black seeds with stripes	Medium
EC734809	Low	Black seeds with stripes	Medium
EC734810	Low	Brown seeds with stripes	Medium
EC734813-I	Medium	Black seeds with stripes	Medium
EC734814	Medium	Black seeds with stripes	Medium
EC734816-I	Low	White seeds with stripes	Medium
EC734817-II	Medium	Black seeds with brown spots	Medium
EC734820	Low	Brown seeds with stripes	Small-medium
EC734821	Low	White seeds with stripes	Medium
EC734822I	Medium	Variable	Medium
EC734823	Low	Brown seeds with stripes	Bold
EC734825	Low	Brown seeds with stripes	Medium
EC734826	Medium	Black seeds with stripes	Medium
EC734828	Low	White seeds with stripes	Small-medium
EC734831	Low	Black seeds with stripes	Medium
EC734835	Medium	Variable	Small-medium
EC734837	Low	Black seeds with stripes	Medium
EC734839	Low	Black seeds with stripes	Medium
EC734840	Low	Black seeds with stripes	Medium
EC734841-I	Medium	Brown seeds with stripes	Small-medium
EC734841-II	Low	Variable	Medium

Continued Table 1

EC734842	Low	Variable	Medium
EC734843	Medium	White seeds with stripes	Medium
EC734844	Medium	Black seeds with stripes	Small-medium
EC734846	Medium	White seeds with stripes	Medium
EC734849I	Low	Black seeds	Medium
EC734850	High	Black seeds with stripes	Medium
EC734859	High	Brown seeds with stripes	Medium
EC734863-I	Medium	White seeds with stripes	Medium
EC734863-II	Medium	Brown seeds with stripes	Medium
EC734864	Medium	Black seeds with stripes	Medium
EC734865	Medium	Black seeds with stripes	Medium
EC734866	Low	Black seeds with stripes	Medium
EC734867	Low	Black seeds with stripes	Medium
EC734869	Low	Black seeds with stripes	Small-medium
EC734870	Low	White seeds with stripes	Medium
EC734872	Medium	Variable	Small-medium
EC734874	Medium	Variable	Small-medium
EC734876	High	White seeds with stripes	Medium
EC734877	High	White seeds with stripes	Medium
EC734879	Low	Brown seeds with stripes	Medium
EC734880	Medium	Grey seeds with white stripes	Bold
EC734881	Medium	Black seeds with stripes	Medium
EC734883	Medium	Black seeds with stripes	Small-medium
EC734884	Medium	Grey seeds with white stripes	Medium
EC734887	Medium	Black seeds with stripes	Small-medium
TSG267	Medium	Black seeds	Medium
EC734790	Medium	White seeds with stripes	Medium
EC734849II	Medium	Black seeds with stripes	Medium

Field experiments

The field experiment was conducted at the Sunflower Experimental area, Department of Plant Breeding and Genetics, Punjab Agricultural University, Ludhiana during the spring season with sowing carried out during the first fortnight of February 2019 and 2020. The experimental area is situated at 30∘ 54’N latitude, 75∘ 48’E longitude, and a mean height of 247 meters above sea level in the semi-arid northern plains of Punjab, India. The inbreds were evaluated in an augmented design with six blocks and three checks were repeated in each block. The blocks were divided into two rows and six columns having 12 plots each. The plot comprised of 3m long two rows with row to row spacing of 60 cm and plant to plant spacing of 30 cm.

Quantitative descriptors

We measured morphological variability for 17 parameters days to flower initiation (DFI), days to 50% flowering (DFF), days to maturity (DM), plant height in cm (PH), head diameter in cm (HD), head weight in grams (HW), stem girth in cm (SG), filled seeds/head (FSH), harvest index in percentage (HI), hull content in percentage (HC), biological yield in grams (BY), seed yield/plant in grams (SYP), seed volume weight in grams/ 100 ml (SVW), 100-seed weight in grams (HSW), seed length in centimeters (SL) and seed width in cm (SW). Oil content in percentage (OC) was estimated using the nuclear magnetic resonance (NMR) instrument Newport Analyzer MK 111 A.

Statistical analysis

Descriptive statistics viz., mean, range, standard deviation, and CV were obtained using the base package of R software. Pearson's correlation coefficients were calculated using the Hmisc package of R and partial correlation was computed using the ppcor package [13-14]. Principle component analysis and visualization were carried out using factoextra and factomineR [15-16] packages of R software. Kmeans clustering and agglomerative hierarchical clustering via estimating Euclidean distance and clustering done as per ward D2method was carried out on using FactomineR package. The optimum number of clusters was estimated using the NbClust package of R software.

Results and Discussion

The summary statistics for each variable given in Table 2 reveal that except for days to flower initiation, days to 50% flowering and days to maturity sample variation was present for the traits studied.

Table 2. Descriptive statistics for quantitative parameters included in the study

	Mean	SD	CV	Range
Days to flower initiation	56.12	3.42	6.09	51.5-66.0
Days to 50% flowering	68.41	2.86	4.18	62.0-73.0
Days to maturity	101.50	2.79	2.75	98.5-110.2
Plant height	102.91	20.93	20.34	68.0-153.0
Stem Girth	3.21	0.57	17.67	2.40-5.00
Head Diameter	9.57	2.80	29.30	4.10-14.90
Head Weight	137.41	112.34	81.76	23.10-556.40
Biological Yield	760.79	563.51	74.07	55.25-3359.85
Filled Seed per Head	178.76	114.09	63.83	11.0-549.60
Seed Yield per Plot	10.67	8.28	77.56	1.04-37.95
Seed Volume Weight	28.77	7.01	24.35	8.25-43.48
Harvest Index	1.82	1.18	64.60	0.10-5.36
Hundred Seed Weight	5.92	1.77	29.84	2.19-9.14
Hull Content	44.56	20.96	47.05	6.08-96.0
Seed Length	1.06	0.15	13.76	0.73-1.48
Seed Width	0.44	0.10	21.88	0.10-0.62
Oil Content	25.74	7.49	29.10	8.61-43.93

The analysis of variance also revealed significant differences among adjusted means among treatments except for days to flower initiation, days to 50% flowering, seed length, and seed width. High variability was present in the data for most of the traits however the differences among sunflower inbreds were also reported by several other researchers [17-20].

The correlation analysis revealed that a significant correlation exists between seed yield per plant and days to maturity (r= 0.47), plant height (r= 0.55), stem girth (r= 0.57), head diameter (r= 0.59), head weight (r= 0.71), biological yield (r= 0.60) and filled seeds per head (r= 0.83). Similarly, oil content had a significant positive association with volume weight (r= 0.67) as given in Table 3. Another important parameter for confectionery germplasm seed width revealed a positive significant correlation with seed length (r= 0.36). Estimation of simple linear correlation provides a good idea about relationships among several parameters however partial correlation takes in to account any multi colinearity among parameters. The partial correlation among the traits revealed that seed yield per plant has a positive correlation with filled seeds per head (r= 0.57), biological yield (r= 0.54), and harvest index (r= 0.52), keeping in view that, vif value estimates with these traits were 3.11, 3.22 and 2.16 respectively. The highest vif values were found among seed yield per plant and head weight (4.26), plant height (3.34), and Head diameter (3.32). Similarly oil content showed a high positive correlation with volume weight (r= 0.56). When tested for multi-colinearity it showed high vif value with seed yield per plant (7.52). A positive and significant partial correlation coefficient was

Table 3. Correlation coefficients (lower off diagonals) and partial correlation coefficients (upper off diagonals) among various parameters

	DFI	DFF	DM	PH	SG	HD	HW	BY	FSH	SYP	SVW	HI	HSW	HC	SL	SW	OC
DFI	1.00	-0.05	0.39*	-0.05	-0.11	-0.11	0.21	0.26	0.14	-0.20	-0.07	0.20	-0.09	0.11	-0.19	0.14	0.16
DFF	0.10	1.00	-0.24	-0.13	-0.02	0.01	0.26	0.24	0.16	-0.14	0.00	0.22	0.06	0.12	0.01	0.17	0.16
DM	0.43*	-0.09	1.00	0.00	0.15	0.05	-0.09	0.03	-0.01	0.16	0.01	-0.02	0.03	0.03	0.15	-0.07	0.00
PH	0.16	0.12	0.34*	1.00	0.19	0.30	0.29	0.27	-0.15	-0.02	0.11	-0.08	0.17	0.11	-0.08	-0.27	0.17
SG	0.14	0.21	0.38*	0.63*	1.00	0.29	0.21	-0.03	-0.15	0.23	0.05	-0.09	-0.14	-0.04	0.06	0.27	0.18
HD	0.12	0.23	0.33*	0.68*	0.67*	1.00	0.20	0.04	0.19	-0.11	-0.35*	0.12	0.15	-0.18	-0.10	-0.12	0.08
HW	0.24	0.37*	0.33*	0.62*	0.64*	0.71*	1.00	-0.20	0.26	0.17	-0.09	-0.12	0.03	-0.04	0.09	0.03	-0.26
BY	0.32*	0.26	0.39*	0.59*	0.53*	0.47*	0.52*	1.00	-0.05	0.54*	-0.05	-0.67*	0.01	-0.01	0.03	0.09	0.04
FSH	0.31*	0.35*	0.38*	0.46*	0.47*	0.53*	0.68*	0.52*	1.00	0.58*	0.28	-0.10	-0.17	0.06	-0.03	0.05	0.06
SYP	0.23	0.25	0.47*	0.55*	0.57*	0.59*	0.71*	0.6*	0.83	1.00	-0.05	0.52*	0.13	0.04	0.02	-0.17	-0.15
SVW	-0.01	-0.05	-0.05	-0.02	-0.11	-0.27*	-0.28*	-0.15	0.06	-0.09	1.00	-0.06	0.12	-0.25	-0.03	-0.31*	0.56*
HI	-0.01	0.07	0.02	-0.14	-0.11	0.03	0.01	-0.44*	0.17	0.22*	0.15	1.00	0.14	-0.03	0.13	-0.24	0.20
HSW	-0.02	0.2	0.08	0.25	0.22	0.3*	0.27*	0.2	0.11	0.22	-0.14	0.03	1.00	0.05	-0.02	0.37*	-0.08
HC	0.16	0.08	0.12	0.11	0	0.06	0.18	0.18	0.15	0.2	-0.33*	-0.04	0.05	1.00	-0.08	-0.12	-0.12
SL	-0.12	0.09	0.06	-0.14	0.1	-0.02	0.09	0.01	-0.02	0.04	-0.25	0.00	0.12	-0.04	1.00	0.30*	-0.13
SW	0.07	0.23	-0.1	-0.17	0.12	-0.06	0.00	0.14	-0.17	-0.21	-0.29*	-0.37*	0.26	-0.08	0.36*	1.00	0.22
OC	0.11	0.08	-0.04	0.03	0.03	-0.12	-0.27	-0.09	-0.02	-0.16	0.67*	0.12	-0.09	-0.33*	-0.22	-0.01	1.00

with seed volume weight (r= 0.55). Seed width is positively correlated with hundred seed weight having a partial correlation coefficient of 0.37 and with seed length having a partial correlation coefficient of 0.30 while negatively correlated with volume weight (r= -0.31). Based on simple and partial correlation analysis it can be inferred that seed yield per plant is showing association with filled seeds per head, biological yield, and harvest index. Positive and significant correlations among these traits have also been reported by Kholghi et al., [21] among confectionery sunflowers and [22-23, 6] among oilseed sunflower inbreds. Oil yield is strongly correlated with seed volume weight while seed width is positively correlated with seed length and negatively associated with seed volume weight which was in concordance with reports of [21, 24].

The principal component analysis of 58 inbreds based on 17 quantitative parameters reduced the 75.6% of the variability in the first six components. The first two principal components explained 44.11% of variability with 30.94% explained by PC1 and 13.18% explained by PC2 respectively Figure 1. The first principal component ordered the inbreds according to head weight (-0.89), seed yield per plant (-0.83), head diameter (-0.83), Filled seeds per head (-0.78), plant height (-0.73), stem girth (-0.73) and biological yield (-0.73) in negative direction with their contributions towards PC1 higher than 10%, while the traits with positive PC1 scores do not contribute towards this principal component significantly (Table 4). In the case of the second principal component, seed size contributes positively with eigenvectors of 0.64 for seed width and 0.47 for seed length while volume weight (-0.75), oil content (-0.63), and harvest index (-0.55) contributed in opposite direction. The rest of the traits contributed less than 10% towards PC2 (Figure 1). Biplot based on PC1 and PC2 suggests positive associations between seed yield and plant height, head diameter, Stem girth, filled seeds per head, head weight, biological yield, and days to maturity, days to flower initiation, days to fifty percent flowering, hundred seed weight and hull content.

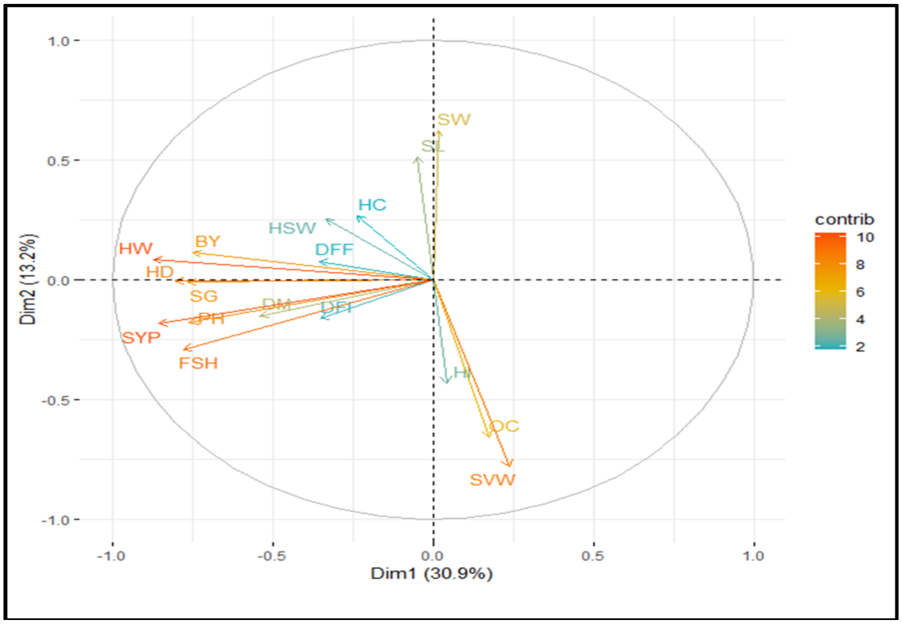

Figure 1. Contribution of different traits towards PC1 and PC2

Table 4. Eigen values, cumulative per cent variance and component loading of different characters in Sunflower inbreds

Traits	PC1	PC2	PC3	PC4	PC5	PC6
Standard deviation	2.29	1.50	1.28	1.20	1.10	1.04
Proportion of Variance	0.31	0.13	0.10	0.08	0.07	0.06
% cumulative Variance	30.94	44.11	53.78	62.24	69.35	75.68
DFI	-0.24	-0.08	0.04	-0.04	0.76	-0.40
DFF	-0.45	-0.02	-0.34	-0.33	0.43	0.36
DM	-0.48	-0.04	0.40	-0.24	0.04	-0.43
PH	-0.73	-0.16	-0.22	0.31	-0.27	-0.13
SG	-0.73	-0.02	-0.26	-0.07	-0.27	-0.15
HD	-0.83	-0.04	-0.05	0.03	-0.26	-0.18
HW	-0.89	0.03	0.04	-0.04	-0.03	0.05
BY	-0.73	0.18	-0.33	0.35	0.16	0.16
FSH	-0.78	-0.32	0.07	-0.09	0.18	0.28
SYP	-0.83	-0.24	0.23	-0.09	-0.02	0.23
SVW	0.29	-0.75	-0.35	-0.04	0.02	0.07
HI	-0.03	-0.55	0.50	-0.52	-0.03	-0.01
HSW	-0.36	0.21	-0.20	-0.32	-0.17	-0.32
HC	-0.29	0.26	0.44	0.32	0.40	-0.01
SL	-0.04	0.47	0.06	-0.62	-0.17	0.24
SW	0.03	0.64	-0.51	-0.34	0.20	-0.12
OC	0.22	-0.63	-0.56	-0.15	0.13	-0.19

For oil content positive correlation exists with volume weight and harvest index whereas, a negative association exists with seed length and seed width (Figure 2).

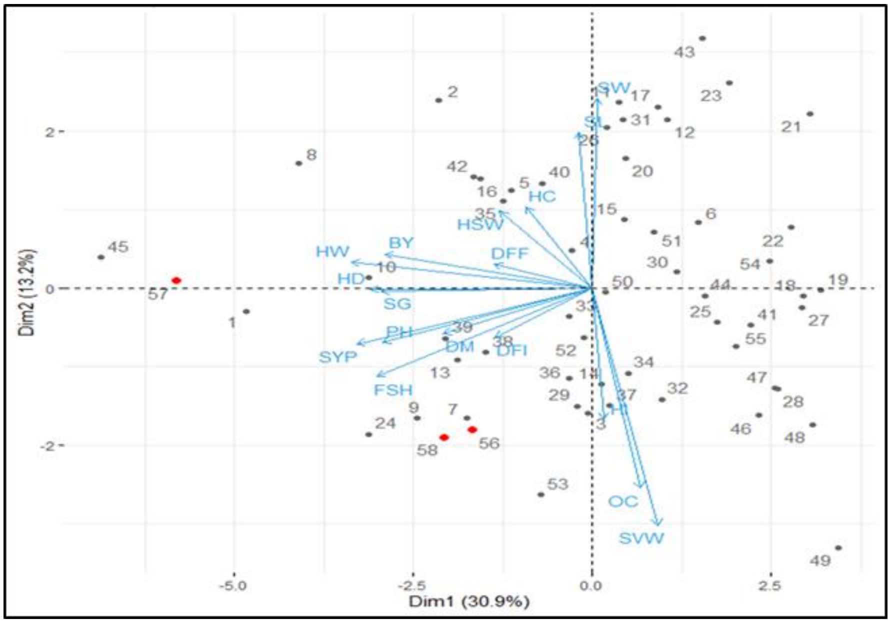

Figure 2. Biplot showing grouping of sunflower inbreds and trait associations Based on PC1 and PC2

Most of the inbreds are present in the top and bottom right quadrants whereas, the inbreds present on the left side of the quadrant are having high PC scores for yield and allied traits. For grain yield inbreds EC734870, EC734790, EC734806, EC734792, EC734831, EC734808, and EC734807 are found to be performing better and inbred EC734877 can be selected for high oil content. Since in the case of confectionery sunflower we are interested in inbreds with low oil content so inbreds EC734798, EC734828, EC734809, EC734867, EC734820, EC734837, EC734842 can be identified for confectionery purpose. Inbreds EC734809, EC734837, EC734820, and EC734842 are also selected for high seed length which is another important characteristic for confectionery sunflowers. Inbred EC734798 is identified as average yielding with good confectionery features. Keeping in view the above results inbred EC734798 was identified as superior confectionery sunflower inbred, however, other inbreds selected for different traits may be involved in crossing programs for developing superior hybrids. Previous studies by various authors also reported that higher value PC scores can be selected for further utilization in breeding programs and findings are confirmed with [25-26].

The 58 genotypes were categorized into four clusters (Figure 3) with 16 accessions in Cluster I, 18 accessions in Cluster II, 17 accessions in Cluster III and 7 accessions in Cluster IV (Table 5). The average cluster distance was maximum among Cluster I and Cluster IV (8.58) followed by Cluster III and IV (7.20). Cluster I and Cluster III exhibited the lowest average cluster distance (5.26) as mentioned in Table 6. While considering intra-cluster distances maximum intra cluster distance was observed in cluster IV (6.65) although it was the smallest cluster out of the four clusters. Cluster III exhibited least intra-cluster distance (4.07), followed by cluster I (4.25). Based on cluster means, the accessions grouped together in cluster IV were identified as superior for most of the agronomic traits such as plant height, stem girth, head diameter, head weight, biological yield, filled seeds per head, and seed yield per plot. Cluster IV was also found desirable for confectionery characteristics such as low oil content, low seed volume weight, and high hull content.

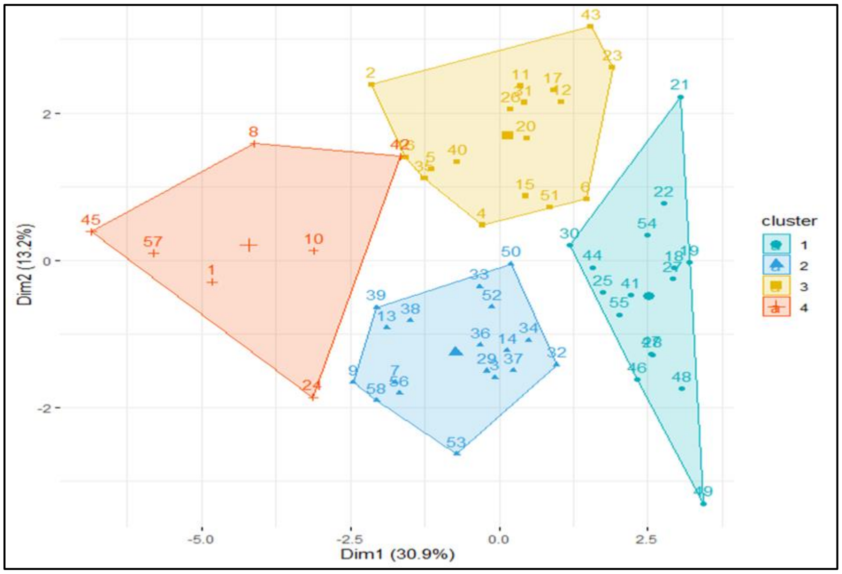

Figure 3. Clustering of sunflower inbreds into four clusters based on K-means clustering

Table 5. Grouping of sunflower inbreds based on k-means clustering

Cluster I	EC734821, EC734822I, EC734825, EC734826, EC734835, EC734839, EC734840, EC734841II, EC734865, EC734869, EC734872, EC734874, EC734876, EC734877, EC734884, EC734887
Cluster II	EC734799IR, EC734805I, EC734807, EC734813I, EC734814, EC734841I, EC734843, EC734844, EC734846, EC734850, EC734859, EC734863I, EC734863II, EC734879, EC734881, EC734883,TSG267,EC734849II
Cluster III	EC734798, EC734800, EC734802, EC734803, EC734809, EC734810, EC734816I, EC734817II, EC734820, EC734823, EC734828, EC734837, EC734842, EC734849I, EC734864, EC734867, EC734880
Cluster IV	EC734792, EC734806, EC734808, EC734831, EC734866, EC734870, EC734790

Table 6. Inter intra cluster distances among groups formed as per k-means clustering

	Cluster I	**Cluster II**	**Cluster III**	**Cluster IV**
Cluster I	4.25			
Cluster II	5.62	4.78		
Cluster III	5.26	5.29	4.07	
Cluster IV	8.58	6.95	7.20	6.65

However, for seed length and width, the superior inbreds were placed in cluster III. Accessions grouped in Cluster I were having superiority for earliness (Table 7). The dendrogram based on Ward D2 hierarchical cluster analysis when cut off at Euclidean distance coefficient of 13.25 (Figure 4a and 4b) divides the inbreds into three groups. Cluster I contains 15 inbreds while Cluster II contains 28 inbreds and the rest of the 15 inbreds are present in the third cluster (Table 8). Average cluster variance was maximum for cluster I (6.33), followed by cluster II (4.48) and cluster III (4.25) as mentioned in Table 9. Maximum inter-cluster distance was seen among Cluster I and Cluster III (7.30) while minimum cluster distance was present among Cluster II and Cluster III (5.20).

Table 7. Average performance of each cluster formed based on kmeans clustering for the quantitative parameters included in the study

	DFI	DFF	DM	PH	SG	HD	HW	BY	FSH	SYP	SVW	HI	HSW	HC	SL	SW	OC
Cluster I	55.16	66.81	100.09	85.29	2.80	6.39	40.95	332.29	101.94	4.11	32.01	1.90	4.25	38.34	1.02	0.42	27.68
Cluster II	56.70	68.95	102.26	113.52	3.34	10.85	152.62	769.00	228.60	13.31	32.95	2.36	6.47	35.87	0.99	0.40	29.96
Cluster III	55.47	68.97	100.53	99.02	3.17	9.86	130.59	846.23	128.99	7.66	23.96	1.13	6.99	49.33	1.16	0.52	22.20
Cluster IV	58.36	69.32	105.19	125.36	3.90	12.88	335.32	1511.59	347.02	26.17	22.25	1.92	5.72	69.56	1.08	0.38	19.01

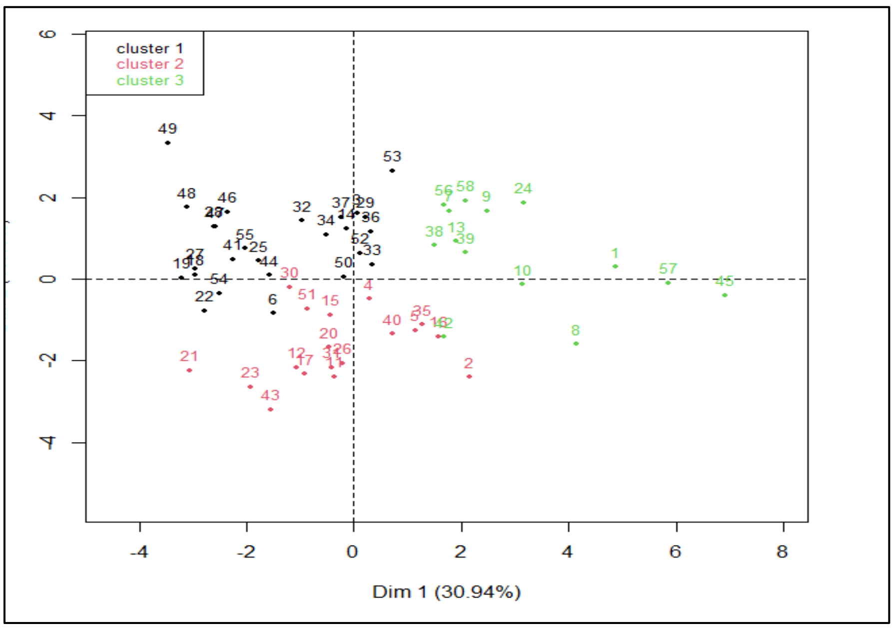

Figure 4a. Clustering of sunflower inbreds into three clusters based on Hierarchical clustering

Table 8. Grouping of sunflower inbreds based on hierarchical clustering

Cluster I	EC734792, EC734805I, EC734806, EC734807, EC734808, EC734813I, EC734831, EC734863II, EC734866, EC734870, EC734879, EC734883, TSG267, EC734790, EC734849II
Cluster II	EC734798, EC734799IR, EC734800, EC734802, C734803, EC734809, EC734810, EC734814, EC734816I, EC734817II, EC734820, EC734823, EC734828, EC734837, EC734841I, EC734842, EC734844, EC734846, EC734849I, EC734850, EC734859, EC734863I, EC734864, EC734867, EC734880, EC734881, EC734884, EC734887
Cluster III	EC734821, EC734822I, EC734825, EC734826, EC734835, EC734839, EC734840, EC734841II, EC734843, EC734865, EC734869, EC734872, EC734874, EC734876, EC734877

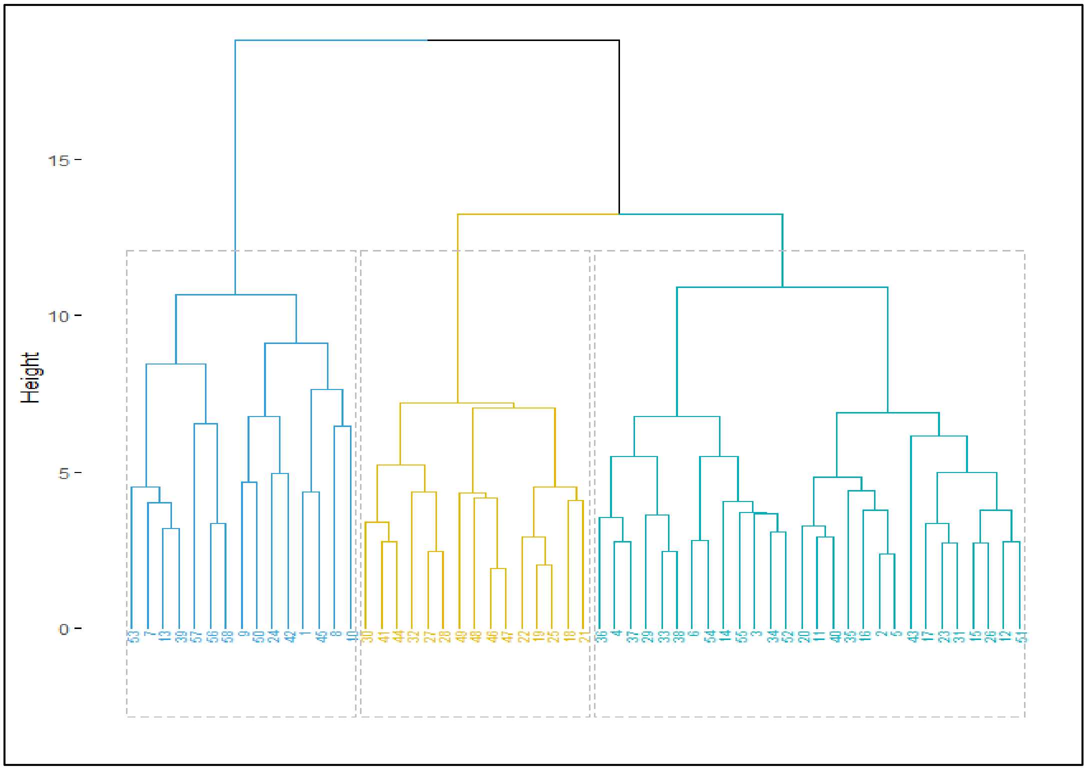

Figure 4b. Dendrogram showing grouping of sunflower inbreds into three clusters based on Hierarchical clustering

Based on the cluster means and the desirability of sunflower inbreds for confectionery purposes the inbreds in cluster I can be selected for higher plant height (123.8 cm), stem girth (3.66 cm), head diameter (12.26 cm), head weight (245.26 g), biological yield (1324.94 g), filled seeds per head (307.21) and seed yield per plant (21.03 g).

Table 9. Inter intra cluster distances among groups formed as per hierarchical clustering

	Cluster I	**Cluster II**	**Cluster III**
Cluster I	6.33		
Cluster II	6.35	4.48	
Cluster III	7.30	5.20	4.25

These inbreds were also desirable owing to lower oil content (24.22 %) and seed volume weight (27.77 g/100ml) which was at par with cluster II (Table 10). Clustering based on the K-means and Ward D2 hierarchical method the accessions were grouped into four and three clusters respectively. EC734792, EC734806, EC734808, EC734831, EC734866, EC734870, and EC734790 were identified as superior inbreds as per both k-means clustering and HCA. The inbreds found superior for seed size were EC734810, EC734816I, EC734817II, EC734837, and EC734867.

Table 10. Average performance of each cluster formed based on hierarchical clustering for the quantitative parameters included in the study

	DFI	DFF	DM	PH	SG	HD	HW	BY	FSH	SYP	SVW	HI	HSW	HC	SL	SW	OC
Cluster I	57.54	68.93	103.87	123.81	3.66	12.26	245.26	1324.94	307.21	21.03	27.77	1.80	5.73	48.60	1.02	0.38	24.22
Cluster II	55.77	69.36	100.95	99.58	3.18	9.78	129.03	663.44	154.30	8.69	27.10	1.97	6.82	45.61	1.11	0.49	25.33
Cluster III	55.33	66.13	100.20	88.24	2.82	6.49	45.18	378.34	95.96	4.01	32.88	1.58	4.43	38.56	1.00	0.41	28.02

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