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Morphological characterization and genetic divergence analysis of oil palm (Elaeis guineensis jacq.) hybrids

G. ROJA RAMANI

rojaramanigorle60@gmail.com

Dr. Y.S.R Horticultural University

M. KALPANA

Dr. Y.S.R Horticultural University

D. VENKATSWAMI

Dr. Y.S.R Horticultural University

B. KALYANBABU

ICAR-Indian Institute of Oil Palm Research

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Abstract

Genetic diversity was investigated in 10 oil palm hybrids at the Horticultural Research Station in Vijayrai, Andhra Pradesh, India. Morphological characteristics were recorded, among all hybrids, NRCOP-4 recorded highest values for all nine parameters and diversity was analyzed using Mahalanobis D^2 clustering and principal component analysis (PCA). The genetic diversity of ten hybrids were classified into four clusters. Clusters 1 and 3 were the largest of the four, each containing four hybrids. Intra and Inter cluster distance of clusters was analyzed by D^2. According to D^2 analysis maximum intra cluster distance was observed in Cluster 3, minimum in Cluster 2 and Cluster 4. The first three main principal components (PCS) have more Eigen values and explained 84.77% of the overall variability among the ten hybrids. These clusters have a greater genetic distance, and hybrids with more desirable features have the potential to grow into superior hybrids. Pearson correlation coefficient showed that bunch traits are strongly correlated with the bunch yield components.

Introduction

Oil palm (Elaeis guineensis Jacq.) is the highest oil yielding crop among oil seed crops. This oil contains the highest levels of Vitamin A and E (Maiti et al. 1988). To attain sustainable farming output in addition to food security contemporary research initiatives have been dedicated to systematic varietal enhancement programme to develop a superior population with enhanced efficiency. Current breeding projects are centered on the utilization of the country's limited genetic resources. A primary obstacle to the advancement of oil palm is the restricted genetic base in its developed types on one hand, and the very limited germplasm available in India on the other which requires substantial enrichment (Corley and Tinker 2003). Regardless of these constraints, to categorize or characterize germplasm bank collections, various attributes are necessary (Van Hintum et al. 2003). To widen the genetic foundation of current native oil palm materials, new sources of germplasm genes were introduced within current populations. To attain this new germplasm, sources from overseas were used to improve the current's genetic foundation indigenous breeding resources (Gowtham et al. 2015). Breeding attempts to enhance cultivars with high fresh fruit bunches (FFB) yields is a primary concern to increase palm oil output (Rance et al. 2001). The main concern of the hour is production of high yielding hybrids, dwarfness, tolerance to stresses, improved oil quality, resistance to pests and diseases and early maturity are important considerations (Mathur et al. 2005). Phenotypic selection, the foundation of traditional plant breeding, is highly successful, but it has significant drawbacks for complex traits (Mohammadi and Prasanna 2003). Due to this situation, oil palm breeders are placing a higher importance on studying the genetic resources of the Elaeis guineensis species in order to boost the genetic variability of base populations by combining them with populations from a variety of backgrounds (Diana et al. 2013). Looking at the bleak genetic resource situation in oil palm in India, and problems in obtaining germplasm from source nations, an exploratory effort was started to examine variability (Rethinam 1997) and performance evaluation of ten hybrids was done (Table 1).

Materials and methods

Sample collection and parameters analyzed

The inadequacy of genetic variability was felt which necessitated for enriching the existing breeding programme to ameliorate narrow genetic base and produce superior hybrid seeds suitable to different agro-climatic conditions (Murugesan et al. 2005). This paper outlines the morphological and genetic diversity studies of 10 oil palm hybrids. Indian Institute of Oil Palm Research, Palode, Kerala made 10 cross combinations which were collected and planted in Horticultural Research Station, Vijayrai, Eluru, West Godavari, Andhra Pradesh. Nine morphological features were recorded in all of the hybrids using a three replications of the randomized block design (RBD). Observations regarding morphological biometrics like palm height (PH), palm girth (PG), sex ratio (SR), bunch number (BN) average bunch weight (ABW), FFB yield (FFBY), FFB yield (t/ha), mesocarp to fruit ratio (MFR), oil to bunch ratio (OBR) were documented in accordance with the non-destructive method and experiment carried out between 2017 and 2022, as per Corley et al. (1971) and Kushairi et al. (1999).

Data Analysis

The statistical software WINDOSTAT 9.2, developed by INDOSTAT services Ltd. in Hyderabad, India, received the recorded morphological data and used it to perform genetic diversity investigations using principal component analysis (PCA) and generalized distance (D^2) cluster analysis, as described by Rao (1952) and Mahalanobis (1936).

Table 1
List of ten hybrids used in the study and their cross combination

S. No.	Hybrids	Cross combination
1	NRCOP-1	78 × 435
2	NRCOP-2	90 × 577
3	NRCOP 3	158 × 116
4	NRCOP-4	131 × 435
5	NRCOP-5	5 × 577
6	NRCOP-6	173 × 435
7	NRCOP-7	183 × 577
8	NRCOP-8	70 × 577
9	NRCOP-9	28 × 435
10	NRCOP-10	345 × 577

Results and discussions

Variance analysis indicated substantial variations between the ten hybrids. Out of the ten hybrids, the results show that NRCOP-4 had the highest palm height (3.36 meters), palm girth (3.11 meters), sex ratio (0.63), bunch number (13.73), average bunch weight (16.97 kilograms), FFB yield per kg/palm/year (197.95), FFB yield per ton (30.31), mesocarp to fruit ratio (79%), and oil to bunch ratio (25.41%). NRCOP-8 ranked second with the following metrics: mesocarp to fruit ratio (74.73%), oil to bunch ratio (22.18%), bunch number (12.16), sex ratio (0.58), FFB yield per kg/palm/year (168.64), and FFB yield per ton (24.24). Comparable to NRCOP-4, the other hybrids were also on par (Table 2), the findings of Murugesan et al. (2015) and Okwuagwu et al. (2008) are in line with the above studies. Ahmad (2007) examined tenera hybrids from several Dura crossed with AVROS pisifera and found that while mesocarp to fruit ratio and oil to bunch ratio varied greatly genetically, bunch number was not very variable among hybrids.

Association analysis is a significant approach in a breeding program because it determines the mutual association between numerous plant features and component characters that were selected for genetic improvement in yield. An elevated fresh fruit bunch (FFB) yield was attained with a high bunch number (BNO) and a moderate average bunch weight (ABWT).The product closely linked with oil to bunch ratio with mesocarp to fruit ratio and bunch weight. Bunch number, palm girth and palm height were negatively associated with oil to bunch ratio. Despite the substantial correlations, the magnitudes of the connections were minor between the oil-related features and mean fruit weight (MFW) (Table 3). The increases in oil content that have been achieved through breeding and selection are mostly in mesocarp to fruit ratio.

Maintaining a high mesocarp to fruit ratio is very important, as evidenced by the fact that bunches with high mesocarp and kernel contents would yield high amount of oil. When high mesocarp per bunch, kernel per bunch and fruit per bunch are combined, with high oil to bunch ratio and FFB yields would probably raise substantially. When high mesocarp per bunch, kernel per bunch and fruit per bunch are combined, with high oil to bunch ratio and FFB yields would probably raise substantially. When compared to fruits with high kernel yields, those with a high mesocarp would likely yield the highest amount of oil. Although fruit size has varying effects on bunch composition, bunch size is a significant factor linked to higher

FFB yield. In analyzing relationships in oil palm, Krualee et al. (2013) came to the unambiguous conclusion that oil yields might rise with improvements in bunch yields, single weight, fresh mesocarp per fruit, and fruit per bunch. A crucial characteristic for palm oil yield is bunch yield in particular.

Although there was a notable inverse connection between palm girth and height, the strength of the hereditary relationship was marginal. In addition, bunch traits strongly connected with the bunch yield components, and as a result, selection for bunch number would concurrently be done by selecting for sex ratio and average bunch weight, FFB traits. Phenotypic data subjected to a Pearson correlation analysis reveals variations in the direction and amplitude of the analysis (Cedillo et al. 2008). These relationships varied among populations, most likely because of genetic factors, given that the plants' ages and environmental conditions were the same when these populations were being assessed. For all of the hybrids under study, there is a strong and positive link between bunch total production and oil production. The oil content and the laboratory mesocarp to fruit extraction rate for these hybrids showed a strong positive association. This outcome holds great significance as the assessment of oil output relies on bunches along yield evaluations spanning at least four years, making it an arduous and expensive task.

Ten hybrids were divided into four clusters based on their D^2 clusters (Table 4 & Fig. 1). Cluster 1 and cluster 3 were the largest of the four clusters, each containing four hybrids.

Table 2
Mean performances of oil palm hybrids for different morphological and yield traits

Hybrids	Palm height (m)	Palm girth (m)	Sex ratio	No. of bunches/palm/year	Average bunch weight (kg)	FFB yield (kg/palm/year)	FFB yield (t/ha)	Mesocarp to fruit ratio (%)	Oil to bunch ratio (%)
NRCOP-1	2.83	2.93	0.53	10.73	16.58	166.97	23.87	69.50	20.24
NRCOP-2	2.15	2.79	0.52	11.63	12.27	140.75	20.13	72.74	20.81
NRCOP-3	2.29	2.86	0.48	10.46	14.23	145.40	20.79	68.09	18.97
NRCOP-4	**3.36**	**3.11**	**0.63**	**13.73**	**16.97**	**197.95**	**30.31**	**79.00**	**25.41**
NRCOP-5	2.54	3.07	0.54	11.35	14.21	159.73	22.84	73.13	19.24
NRCOP-6	2.38	2.86	0.52	11.52	14.21	161.54	23.10	69.35	19.04
NRCOP-7	2.63	2.91	0.51	10.28	14.16	142.03	20.30	68.34	21.37
NRCOP-8	2.82	2.95	0.58	12.16	15.91	168.64	24.24	74.73	22.18
NRCOP-9	2.35	2.90	0.49	11.16	14.95	164.18	23.47	69.92	19.36
NRCOP-10	2.32	2.79	0.37	10.14	12.75	124.49	18.65	65.40	17.09
Mean	**2.57**	**2.92**	**0.52**	**11.31**	**14.62**	**157.17**	**22.77**	**71.02**	**20.37**
S.E (m) ±	0.080	0.063	0.038	0.97	0.514	5.946	1.041	2.455	1.194
C.D. 5%	0.238	0.189	0.114	2.97	1.540	17.804	3.117	7.349	3.576

Table 3
Correlation coefficient among phenotypic traits of oil palm hybrids

Characters	HT	GR	SR	BN	ABW	FFB (kg)	FFB (t/ha)	MS/F	OC
HT	1	0.803**	0.724*	0.560NS	0.861**	0.803**	0.849**	0.659*	0.501NS
GR		1	0.766**	0.537NS	0.723*	0.803**	0.803**	0.501NS	0.517NS
SR			1	0.675*	0.687*	0.863**	0.824**	0.822**	0.859**
BN				1	0.360NS	0.693*	0.757*	0.714*	0.523NS
ABW					1	0.870**	0.847**	0.638*	0.635*
FFB (kg)						1	0.984**	0.700*	0.580NS
FFB (t/ha)							1	0.701*	0.554NS
MS/F								1	0.661*
OC									1

*Significant at 5% LOS ** Significant at 1%

HT = Palm height, GR = Palm girth, SR = Sex Ratio, BN = Bunch number, ABW = Average bunch weight, FFB (kg) = Fresh Fruit Bunch yield (kg /palm /year), FFB (t/ha) = Fresh Fruit Bunch yield /ton /hectare, MS/F = Mesocarp to fruit ratio (%), OC = Oil to bunch ratio (%)

Cluster 1 consists of hybrids namely NRCOP-2, NRCOP-3, NRCOP-9 and NRCOP-10 whereas cluster 3 consists of NRCOP-1, NRCOP-5, NRCOP-6 and NRCOP-7. The lowest number of hybrids was present in cluster 2 which consists of NRCOP-4 followed by cluster 4 which consists of NRCOP-8 respectively. Okoye et al. (2018) and Thanet et al. (2018) both are in agreement with literature reports for other populations of oil palm that the superior progenies of D × P were clustered together, indicating a close relationship among progenies in oil palm.

Geographic barriers that limit gene movement or intensive diverse and adaptive gene complexes may be the result of both human and natural selection for the establishment of different isolated clusters. This pattern of grouping has suggested that variety need not be necessarily related to geographical diversity and may be the product of numerous other processes such as natural selection, exchange of breeding material, genetic drift, and environmental variation (Diana et al. 2015). Thus, hybrid selection should be focused on genetic diversity rather than geographical diversity. The mean D^2 within and between clusters computed using the approach presented by Singh and Chowdhary (1977). The proximity and divergence of four clusters are illustrated in (Fig. 1). The mean intra-cluster D^2 values ranged from 0.00 to 3.55, with the largest intra-cluster distance being 3.55 within cluster III and 3.51 in cluster I, and zero in clusters II and IV. Peixoto et al. (2015) and Balakrishna et al. (2017) observed similar observations in oil palm. The inter-cluster distance was the smallest between clusters, indicating that the hybrids included in these groups had limited genetic diversity. Another privileged benefit of D^2 analysis is the role of numerous features (Fig. 2) in the manifestation of genetic variation. This investigation revealed the fact that the palm girth generated the most genetic difference in the material (46.67%, 21st ranked), followed by the mesocarp to fruit ratio (20%, 9 times ranked), oil to bunch ratio (17.78%, 8 times ranked), palm height (6.67%, 3 times ranked), bunch number and average bunch weight shared ranked 2 times equally (4.44%). With hierarchical cluster analysis, an additional benefit is discovering sub-clusters of the major group at multiple levels, allowing each small group to be evaluated critically using PCA scores (Diana et al. 2015).

As the greatest Euclidean intra cluster distance between two clusters is (14.72), while the inter cluster distance between two clusters is (70.18), according to Tocher's approach. Rahman and Al-Mansur (2009) found the fact that increased diversity of genes was associated with increased distances, between and within clusters in clusters, while genotype proximity was

associated with a minimum inter and intra cluster distance. PCA intends to identify the biggest contributor to the overall variance at each different location. The primary factor (PF) will be computed using the PCA approach, which excludes the need to assume that the population is distributed normally. Eigen values can be used to find the major principal component.

The first three main components (PCS) had more than one Eigen value and collectively explained 84.77% of the overall variability among 10 hybrids (Table 5). The first principal component or vector (PC1) contributed the most to variability (56.73%), followed by PC2 (15.84%) and PC3 (12.20%). PC1 has positive association with palm height (0.397), palm girth (0.402), sex ratio (0.308), bunch number (0.408), average bunch weight (0.302), FFB per ton (0.032), mesocarp per fruit (0.354) and oil to bunch ratio (0.382), respectively. PC2 substantial positive relationship between palm height (0.013), palm girth (0.148), sex ratio (0.161), FFB per kg (0.417), FFB per ton (0.744), and oil to bunch ratio (0.320). PC3 shows a strong positive correlation with palm height (0.211), palm girth (0.158), bunch number (0.204), and FFB per ton (0.323). PC4 has positive association with palm height (0.363), palm girth (0.309), average bunch weight (0.499), FFB per kg (0.279) and oil to bunch ratio (0.044), respectively. To examine the relationships between the ten hybrids, all of the hybrids were plotted in three dimensions for the first principal components (PCS) (Fig. 3).

Table 4
Mahalanobis d^2 analysis distribution of 10 hybrids of oil palm into different clusters

Cluster	No. of hybrids	Hybrids
I	4	NRCOP-2, NRCOP-3, NRCOP-9, NRCOP-10
II	1	NRCOP-4
III	4	NRCOP-1, NRCOP-5, NRCOP-6, NRCOP-7
IV	1	NRCOP-8

Table 5
Eigen values, variability percentage, and cumulative variability percentage for eight principal component analysis (pca)

S:	Eigene value (Root)	Vector 1	Vector 2	Vector 3	Vector 4
No	% Var. Exp.	5.10571	1.42645	1.09801	0.76083
	Cum. Var. Exp.	56.73012	15.84948	12.20008	8.45367
		56.73012	72.57961	84.77968	93.23334
1	Palm height	0.39792	0.01389	0.21159	0.36363
2	Palm girth	0.40294	0.14879	0.15874	0.30956
3	Sex ratio	0.30857	0.16165	-0.50470	-0.48117
4	Bunch number	0.40849	-0.01309	0.20413	-0.21133
5	Average bunch weight	0.30236	-0.19723	-0.33665	0.49946
6	FFB/Kg	-0.22961	0.41773	-0.60015	0.27912
7	FFB/ton	0.03204	0.74432	0.32341	-0.1576
8	Mesocarp	0.35448	-0.28496	-0.17809	-0.37702
9	Oil	0.38262	0.32054	-0.15431	0.04464

Conclusion

The hybrid NRCOP-4 (131 × 435) emerged as the best performer among all hybrids morphologically for all high yielding traits. As a result of selection pressure and genetic drift, hybrids from the same geographic area have grouped with genotypes from different geographic areas. This indicates a lack of correlation between geographic location and genetic diversity. The greatest cluster distances in the intra- and inter-cluster genotypes, as determined by D^2 and PCA analysis, have limited genetic diversity. In the same way, superior hybrids with the necessary traits can be produced by selecting PCS or vectors that exhibit larger positive significance towards palm height, palm girth, fresh fruit bunch production per ton, and oil to bunch ratio.

Declarations

Conflict of Interest

The authors declare that there is no conflict of interest.

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Author Contribution

The Authors M. Kalpana, Venkatswami and B.Kalyanababu conceived and designed the study. Data collection, experimentation and manuscript writing was done by Roja Ramani. All authors analyzed the data and critically revised the article. All authors contributed to editing and reviewing of the manuscript. All authors approved the manuscript.

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Figures

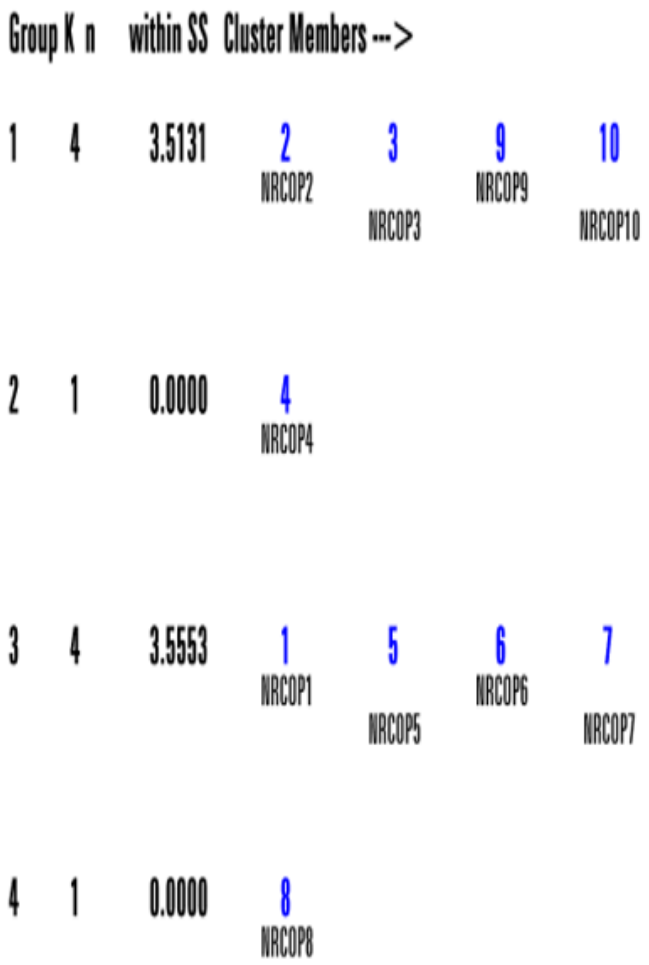


Figure 1

Ten hybrids were distributed into different clusters using the K clustering method and D^2 analysis.

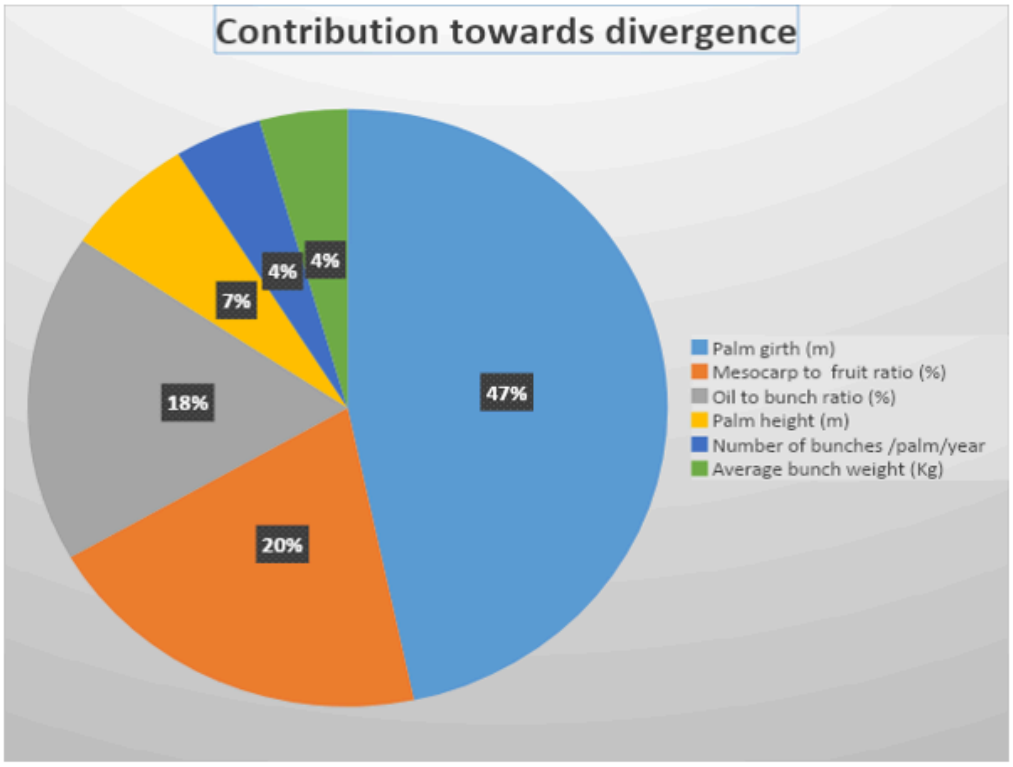


Figure 2

Percentage of different traits that contributed to the oil palm hybrids' divergence

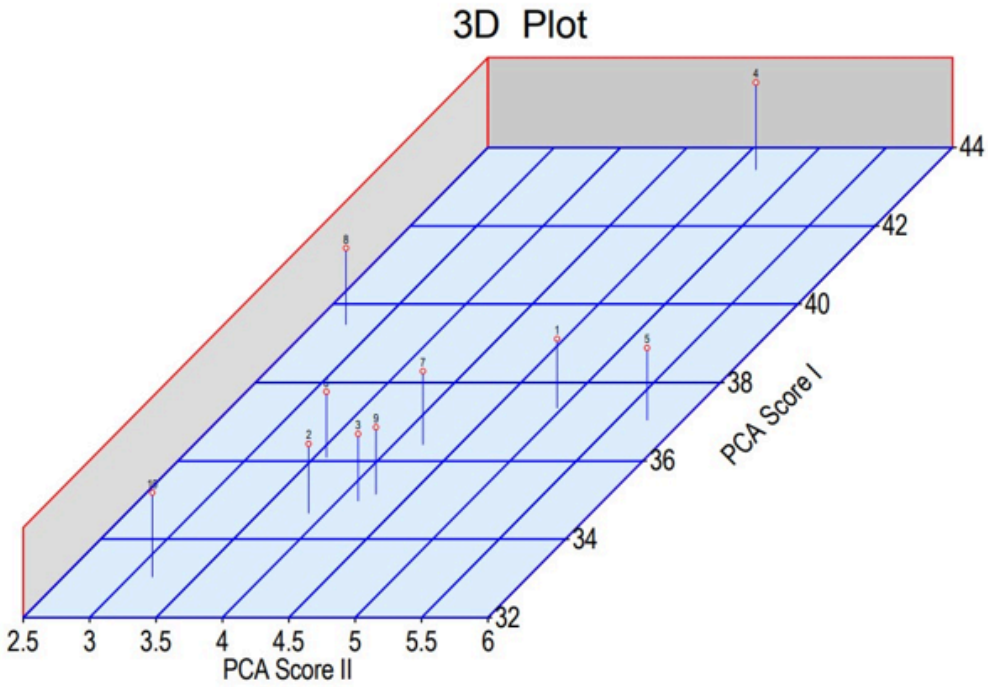


Figure 3

Ten hybrids 3D plots with their relative locations determined using PCA scores