# GENETIC VARIABILITY STUDIES USING PRINCIPAL COMPONENT ANALYSIS AND SINGLE LINKAGE CLUSTER ANALYSIS FOR GROWTH, YIELD AND QUALITY IN STRAWBERRY (*FRAGARIA* × *ANANASSA*) AT UPPER PULNEY HILLS OF SOUTHERN INDIA

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**Abstract.** Strawberry (*Fragaria* X *ananassa*), an important soft fruit of the world, is widely cultivated in temperate and subtropical zones of India. In the southern state seemingly s of India, however, its cultivation is limited due to non-availability of suitable cultivars adapted to the local agro-climate. In this study, we evaluated twenty vegetative, yield and fruit quality parameters in 14 strawberry genotypes having diverse eco-geographic origins at Kodaikanal, Tamil Nadu, India—a potential zone for strawberry cultivation. We assessed the genetic variability between the genotypes as a prerequisite for breeding improvement. Mean performance of the genotypes showed presence of variability. Highest fruit yield was observed in cultivars Nabila (1268.98 g), Katrain Sweet (1161.91 g) and Camarosa (1158.85 g). These genotypes also had better fruit quality parameters. In principal components analysis (PCA), four principal components (PC) with Eigen score > 1 accounted for 90.4% of the total variation. The PC1 explained 61.3% of total variability and mainly contributed by number of flowers, number of leaves, number of fruits per plant and leaflets per plant. In Mahalanobis $D^2$ analysis, the genotypes were grouped in five clusters. Cluster III had the highest intra cluster variability (intra cluster distance = 5248.16). Between clusters variability was the highest between clusters II and III (inter cluster distance = 8900.17). The genotypes in cluster IV (Nabila, Katrain Sweet and Camarosa) were better performers with high mean fruit yield


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per plant (1196.58 g) and other yield and quality parameters. Selection based on major contributing characters in PCA and the clustered strawberry genotypes in SCLA would be ideal. The genotypes Nabila, Katrain Sweet and Camarosa are best suited to this location and can be used in future breeding programmes.
**Keywords:** *strawberry, genetic variability, agroclimatic norms, principal components analysis, single linkage cluster analysis*

## Introduction

Strawberry (*Fragaria* × *ananassa*) is one of the popular soft fruits that belong to the botanical family Rosaceae. It is a stoloniferous perennial herb with octaploid sets of chromosomes (2n = 8x = 56) (Debnath and Teixeira Da Silva, 2007). Mainly it is a temperate crop but now widely grown in varied agro climatic zones such as mediterranean, temperate, subtropical and taiga zones (Hancock et al., 1991). In south India, although the demand for this crop is increasing, strawberry cultivation is limited due to non-availability of locally adapted cultivars, unavailability of good planting material, issues in production and marketing. In India, in spite of high demand, cultivation of strawberry (and other small fruits alike) has been limited to less than 10,000 ha (Sawant et al., 2023). Strawberry cultivars bred with high yield, fruit quality and adaptability to local climatic norms is essential to encourage cultivation in this region.

Assessing genetic variability of the strawberry germplasm is the prerequisite for breeding new cultivars (Mondal, 2003; Morrow and Darrow, 1952; Spangelo et al., 1971). In addition, narrow genetic base in strawberry cultivars due to continued reliance on a relatively small parent pool and high inbreeding has been reported before (Sjulin and Dale, 1987). To overcome, breeders study the extent of genetic diversity within a population that aid in selection of genetically diverse parents with desirable character combinations (Arunachalam, 1981; Samsuddin, 1985).

Characterization of the genotypes based on quantitative characters has been a successful approach to study variation at inter and intra-specific levels (Ariyo and Odulaja, 1991; Sneath and Sokal, 1973). The $D^2$ statistic is one such quantitative method used to classify accessions into groups and to choose diverse parents from different groups. However, if the number of dimensions of a data increases, $D^2$ statistic becomes complex to compute. Such complex set of data can be subjected to a powerful dimension reduction technique known as the Principal Component Analysis (PCA). PCA is a descriptive method that removes the inter-correlation among variables and shows multidimensional relationship in a two or three axes known as principal components (Hayman, 1967; Rhodes and Martin, 1972). Principal components contain information about the variables that contribute to the variance and is ranked by component scores and measured by Eigen values. Another technique that is often performed together with PCA is single linkage cluster analysis (SLCA) to classify variation and to study the relationship between the individuals of a population (Ariyo and Odulaja, 1991; Shalini et al., 2003). Together, these techniques will sort the accessions of the study population into groups and help in choosing the diverse lines for hybridization and breeding programs.

In this study we have studied fourteen strawberry genotypes and worked out the variation between them using $D^2$, PCA and SLCA in order to group them based on similarities and to identify the best parental lines from diverse groups. These lines would be introduced as suitable cultivars for the study region and also used as parents to develop improved cultivars in the future.


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## Materials and methods

### *Experimental site and design*

During 2021, fourteen strawberry genotypes viz. Atra, Selva, Elamanco, Vimarana, Nabila, Ceryerta, Chandler, Fern, Cambibe, Katrain Sweet, Winter Dawn, Camarosa, Festival, and Kodaikanal Local collected from G. B. Pant University of Agriculture and Technology, Uttarakhand and Regional Research Station, Bowali, India were grown at the Horticultural Research Station, Kodaikanal (10.20′N, 77.50′E; situated 2300 m above mean sea level), Tamil Nadu, India. Climate specifics of this location is given in *Table A1*. In short, the experimental site can be classified under warm temperate region with an average temperature of 20.8°C. Minimum temperature ranges between 15 to 20°C while the maximum temperature may range between 20 to 30°C. Daylight period in this region is usually around 12 h.

The experimental plot was designed as a randomized block design (RBD) with three replications. The field consisted of three blocks with 20 beds (2.1 × 0.9 m) each with a 0.5 m drainage channel between two blocks. Beds were mulched with plastic sheets and strawberry runners were planted with 30 × 20 cm spacing and accommodating 30 plants per bed. Irrigation and plant protection measures were properly followed.

Fruits at commercial maturity (>80% of the fruit surface is dark red) were harvested manually during early morning hours and healthy and undamaged fruits were sorted immediately. For fruit quality and biochemical characters uniform sized and uniformly colored fruits were chosen and observed.

### *Traits observed*

Twelve plants per bed were randomly selected and characterized for 20 qualitative and quantitative traits viz., plant height (cm), plant spread (cm), number of leaves per plant, leaf area index ($cm^2$), number of flowers per plant, flowering duration, fruiting duration, number of fruits per plant, length of fruit (cm), diameter of fruit (cm), fresh fruit weight (g), dry fruit weight (g), fruit yield per plant (g), volume of fruit (mL), total soluble solids (°brix), titratable acidity (%), reducing sugars (%), total sugars (%) and ascorbic acid vitamin C (mg/100 g fruit). Fruit quality traits were analyzed in 20 fruits per genotype. Dry fruit weight was estimated by drying under hot air oven. Volume of fruit, titratable acidity, reducing sugar, total sugars, and ascorbic acid were computed as per standard methods (Ruck, 1963). Erma hand refractometer and portable leaf area meter were used to estimate the total soluble solids (TSS) and leaf area index, respectively.

### *Data analysis*

Data were analyzed using SAS software (SAS software for Microsoft windows 9.2) (SAS Institute, 2011) by following the method reported earlier (Steel and Torrie, 1980). Mahalanobis' D2 analysis is a technique to measure the degree of divergence among different genotypes of a population. It uses multiple quantitative observations made on these genotypes to calculate genetic distance with which we can estimate the closeness or distant genetic relationship between them. Genetic diversity of the strawberry population was estimated (Mahalanobis, 1936); generalized distance ($D^2$) between the genotypes and clusters were estimated as extended by Rao (1952). Average intra-cluster distance was calculated by the formula suggested by Singh and Choudhary (1985). Average intra-cluster:


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$$D^2 = \sum D^2 \, i/n$$

where, ΣD² = Sum of distances between all possible combination) n (of the varieties/lines included in a cluster; n =all possible combinations to assess genotypes position in distinct group.

Principal Components Analysis (PCA) was used to extract the major components of variability and to measure the relative discriminative power of the primary axes; Single Linkage Cluster Analysis (SLCA) was followed to cluster and plot the genotypes on principal component axes.

## Results

### *Mean performance of the genotypes*

Mean performance of the fourteen strawberry genotypes showed presence of variability and an opportunity for selection (*Tables 1* and *A2*). Plant height ranged from 20.3 cm (Ceryerta) to 30.4 cm (Camarosa). Spread of plant ranged from 15.8 cm (Atra) to 22.4 cm (Camarosa). Highest number of leaves per plant was observed in Cambibe (14 leaves/plant) whereas lowest number of leaves was observed in the local cultivar (12/plant). However, the leaf area index, an important yield contributing trait was the highest in Camarosa (36.5 $cm^2$). Flowers per plant ranged from 8.2 to 9.3. Highest flowering and fruiting duration was recorded in the local cultivar (40 and 70 days respectively) and Elamanco (39.2 and 70.2 days respectively). Fruit morphological traits *viz.*, fruit length and fruit diameter also varied widely between the genotypes. Fruit length ranged from 2.9 cm (in local cultivar) to 5.2 cm in Nabila. Fruit diameter ranged from 3.1 cm (in Atra) to 4 cm (in Nabila and Camarosa). Average fruits per plant was 22.35 with highest number of fruits recorded in Nabila (24.6 fruits). Mean fruit yield per plant was 1021.9 g with highest yield recorded in Nabila (1269 g), followed by Katrain Sweet (1161.9 g) and Camarosa (1158.8 g). Fresh fruit weight ranged from 41.7 g (in local cultivar) to 51.5 g (in Nabila). Similarly, the dry fruit weight ranged from 39.6 g (in local cultivar) to 48.4 g (in Nabila). Best values for the traits volume of fruit (61.14 mL), reducing sugar (3.63%), total sugars (4.55), ascorbic acid (73.6 mg/100 g of fruit) and total soluble salts (21.1 °Brix) was also observed in the cv. Nabila. Next best performance was observed in Katrain Sweet and Camarosa.

### *Principal components analysis*

Principal component analysis (PCA) was conducted to extract the major contributors of variation within the population (*Table 2; Figs. 1* and *2*). Four principal components with Eigen values greater than one were the major contributors to variation. Altogether these components accounted for 90.4% of the total variation. Principal component 1 (PC1) accounted for 61.3% variation and mainly contributed by the traits flowering duration (0.221), fruiting duration (0.198) and titratable acidity (0.252) while the PC2 accounted for 13.9% variation and was contributed by number of flowers per plant (0.113), fresh fruit weight (0.128) and dry fruit weight (0.119). The relative discriminating power of the PCA was revealed by the Eigen values which were high in PC 1 (12.263) and lower in PC 4 (1.017).


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***Table 1.*** *Mean performance of strawberry genotypes for yield traits*

| Gentoypes | PH (cm) | SP (cm) | LPP | LAI ($cm^2$) | FLPP | FLD (days) | FRD (days) | FL (cm) | FD (cm) | FFW (g) | FRPP | DFW (g) | FYP (g) | FV (mL) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Atra | 23.4 | 15.8 | 12.6 | 14.8 | 8.5 | 37.5 | 68.0 | 3.0 | 3.1 | 42.3 | 21.2 | 40.2 | 899.1 | 43.81 |
| Selva | 21.1 | 14.0 | 12.8 | 15.8 | 8.4 | 36.3 | 69.5 | 3.1 | 3.1 | 43.9 | 21.1 | 42.0 | 929.1 | 43.01 |
| Elamanco | 27.5 | 19.3 | 13.2 | 28.4 | 8.7 | 39.2 | 70.2 | 3.9 | 3.5 | 45.8 | 22.4 | 46.4 | 1027.5 | 49.97 |
| Vimarana | 27.3 | 20.6 | 13.9 | 27.2 | 8.3 | 38.6 | 67.3 | 3.2 | 3.0 | 42.5 | 21.1 | 41.0 | 898.7 | 42.50 |
| Nabila | 28.7 | 20.4 | 13.2 | 31.3 | 9.3 | 35.8 | 65.8 | 5.2 | 4.0 | 51.5 | 24.6 | 48.4 | 1269.0 | 61.14 |
| Ceryerta | 20.3 | 17.7 | 13.7 | 10.9 | 9.0 | 37.3 | 68.8 | 4.9 | 3.8 | 47.7 | 23.0 | 47.5 | 1097.3 | 55.46 |
| Chandler | 26.2 | 20.3 | 14.0 | 25.2 | 9.0 | 37.4 | 67.5 | 4.9 | 3.9 | 44.6 | 23.1 | 43.8 | 1030.0 | 57.28 |
| Fern | 25.0 | 19.5 | 13.6 | 22.2 | 8.3 | 37.5 | 68.8 | 3.6 | 3.4 | 46.3 | 22.3 | 47.2 | 1033.2 | 49.59 |
| Cambibe | 24.9 | 19.1 | 14.3 | 24.0 | 8.6 | 38.2 | 67.3 | 3.5 | 3.2 | 43.2 | 21.5 | 41.7 | 928.4 | 45.22 |
| Katrain Sweet | 21.2 | 18.1 | 12.1 | 23.1 | 8.8 | 36.3 | 66.0 | 4.5 | 3.8 | 50.6 | 22.9 | 48.0 | 1161.9 | 51.11 |
| Winter Dawn | 23.6 | 19.7 | 13.3 | 21.6 | 8.8 | 37.2 | 68.8 | 4.3 | 3.6 | 44.6 | 22.7 | 43.8 | 1010.9 | 54.72 |
| Camarosa | 30.4 | 22.4 | 14.1 | 36.5 | 9.2 | 35.5 | 66.5 | 5.1 | 4.0 | 50.1 | 23.1 | 48.1 | 1158.8 | 59.67 |
| Festival | 29.6 | 21.4 | 14.0 | 34.8 | 8.2 | 38.4 | 69.5 | 3.2 | 3.5 | 43.6 | 21.9 | 41.3 | 953.1 | 44.29 |
| Local cultivar | 22.7 | 20.0 | 12.0 | 19.8 | 8.2 | 40.0 | 70.0 | 2.9 | 3.0 | 41.7 | 21.8 | 39.6 | 909.7 | 42.33 |
| **Mean** | **25.14** | **19.15** | **13.35** | **23.99** | **8.66** | **37.54** | **68.15** | **3.94** | **3.50** | **45.61** | **22.35** | **44.22** | **1021.9** | **50.01** |
| **S.E.** | **0.31** | **0.27** | **0.25** | **0.35** | **0.15** | **0.62** | **0.91** | **0.05** | **0.05** | **0.62** | **0.31** | **0.70** | **14.69** | **0.85** |
| **SE d** | **0.44** | **0.39** | **0.35** | **0.50** | **0.21** | **0.87** | **1.29** | **0.07** | **0.07** | **0.87** | **0.44** | **0.99** | **20.77** | **1.20** |
| **C.D. (5%)** | **0.90** | **0.79** | **0.72** | **1.03** | **0.42** | **1.80** | **2.66** | **0.14** | **0.14** | **1.80** | **0.91** | **2.04** | **42.79** | **2.48** |
| **CV (%)** | **2.13** | **2.47** | **3.22** | **2.56** | **2.90** | **2.85** | **2.32** | **2.11** | **2.41** | **2.35** | **2.43** | **2.74** | **2.49** | **2.95** |

PH-plant height; SP-spread of plant; LPP-leaves per plant; LAI-leaf area index; FLPP-Flowers per plant; FLD-flowering duration; FRD-fruiting duration; FL-fruit length; FD-fruit diameter; FFW-fresh fruit weight; FRPP-fruits per plant; DFW-dry fruit weight; FYP-fruit yield per plant; FV-fruit volume

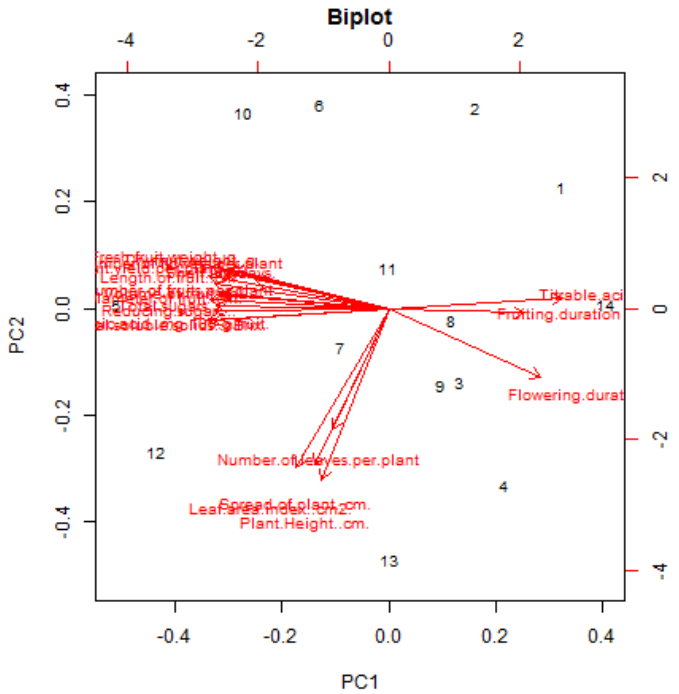


***Figure 1.*** *Biplot showing the spread of variables and the position of genotypes in relation to the variables drawn using the PC1 and PC2 of principal components analysis [Genotypes: 1) Atra, 2) Selva, 3) Elamanco, 4) Vimarana, 5) Nabila, 6) Ceryerta, 7) Chandler, 8) Fern, 9) Cambibe, 10) Katrain Sweet, 11) Winter Dawn, 12) Camarosa, 13) Festival, 14) Local cultivar]. Variable axis closely present are highly correlated. Genotypes present near the origin of the variable axes are usually highly influenced by these variables*


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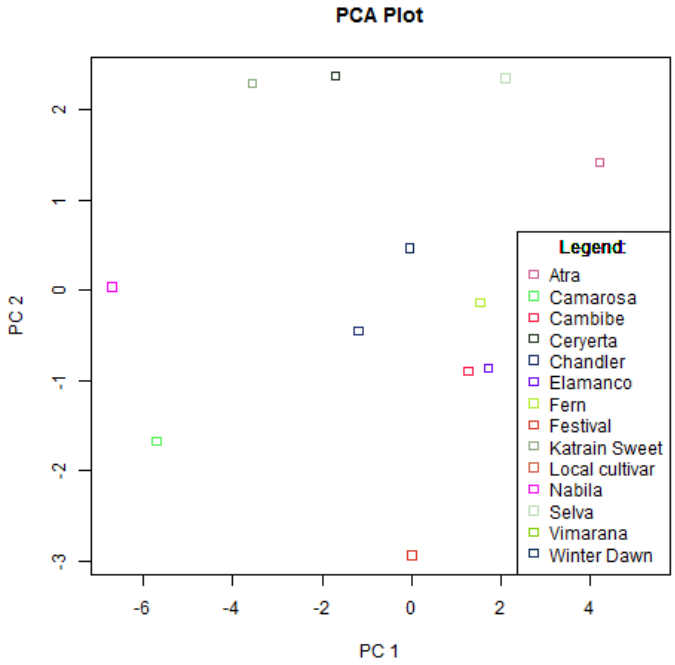


***Figure 2.*** *Biplot showing the position of genotypes in the plot drawn with PC1 and PC2*

***Table 2.*** *Principal component analysis of the strawberry showing the principal component scores, eigen values and percentage total variance accounted for by the first four principal component axes*

| Variables | PC1 | PC2 | PC3 | PC4 |
|---|---|---|---|---|
| Plant height (cm) | -0.098 | -0.526 | 0.054 | 0.096 |
| Spread of plant (cm) | -0.108 | -0.478 | 0.196 | 0.074 |
| Number of leaves per plant | -0.082 | -0.372 | -0.001 | -0.617 |
| Leaf area index ($cm^2$) | -0.136 | -0.487 | -0.038 | 0.233 |
| Number of flowers per plant | -0.241 | 0.113 | 0.198 | -0.219 |
| Flowering duration | 0.221 | -0.210 | 0.159 | 0.072 |
| Fruiting duration | 0.198 | -0.013 | 0.106 | -0.055 |
| Length of fruit (cm) | -0.254 | 0.075 | 0.266 | -0.193 |
| Diameter of fruit (cm) | -0.261 | 0.029 | 0.209 | -0.128 |
| Fresh fruit weight (g) | -0.259 | 0.128 | 0.096 | 0.272 |
| Number of fruits per plant | -0.244 | 0.046 | 0.295 | 0.081 |
| Dry fruit weight (g) | -0.228 | 0.119 | 0.250 | 0.156 |
| Fruit yield per plant (g) | -0.264 | 0.099 | 0.174 | 0.215 |
| Volume of fruit (mL) | -0.245 | 0.041 | 0.321 | -0.185 |
| Titratable acidity (%) | 0.252 | 0.033 | 0.303 | 0.053 |
| Reducing sugar (%) | -0.255 | -0.006 | -0.289 | 0.096 |
| Total sugars (%) | -0.252 | 0.007 | -0.262 | 0.168 |
| Ascorbic acid (mg/100 g fruit) | -0.265 | -0.036 | -0.242 | 0.089 |
| Total soluble solids (°Brix) | -0.257 | -0.038 | -0.294 | 0.062 |
| Shelf life (days) | -0.196 | 0.089 | -0.294 | -0.451 |
| Eigen values | 12.263 | 2.777 | 2.020 | 1.017 |
| Proportion | 0.613 | 0.139 | 0.101 | 0.051 |
| Cumulative proportion of variance | 0.613 | 0.752 | 0.853 | 0.904 |


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*Figure 1* shows the projection of agro morphological and fruit quality traits defined by principal components 1 and 2. Vectors, indicating the variables, which were positioned closely in the plot indicated high correlation between them whereas which were positioned distant from each other were less correlated. Titratable acidity, fruiting duration and flowering duration were highly correlated; number of leaves per plant, spread of plant, leaf area index and plant height were correlated. In the biplot, the genotypes were spread throughout the plot area showing its divergence.

### *Cluster analysis*

High polymorphism between the 14 strawberry genotypes was evident with high $D^2$ values observed in the analysis (*Table 3*). Highest intra cluster distance was observed for cluster III (5248.16) followed by cluster IV (5126.38). Lowest intra cluster distance was observed for cluster V (0.00). Genotypes in this cluster have high similarity. Between cluster distance (inter cluster) was the highest between cluster II and cluster III (8900.17) followed by between cluster I and II. Lowest inter cluster distance was observed between clusters I and III (2681.29). Number of genotypes per cluster varied between two to three (*Table 4*). Clusters I, III, IV and V consisted of 3 genotypes (21.43)% each and Cluster II consisted of 2 genotypes (14.29%). Also, the genotypes have spread equally among the clusters indicating high degree of divergence between them.

***Table 3.*** *Average Intra and Inter-cluster distance ($D^2$) of fourteen strawberry genotypes*

| Cluster | I | II | III | IV | V |
|---|---|---|---|---|---|
| I | **2917.05** | 6013.13 | 2681.29 | 2998.19 | 2798.36 |
| II | | **2543.61** | 8900.17 | 4826.43 | 3846.28 |
| III | | | **5248.16** | 3568.94 | 5378.44 |
| IV | | | | **5126.38** | 4692.08 |
| V | | | | | **0.00** |

Bold face figures indicate intra cluster distance and normal figures indicate inter cluster distance

***Table 4.*** *Strawberry genotypes grouped into five clusters*

| Cluster | No. of genotypes | Name of the genotypes |
|---|---|---|
| I | 3 | Atra, Selva, and Local cultivar |
| II | 2 | Elamanco and Fern |
| III | 3 | Vimarana, Cambibe and Festival |
| IV | 3 | Nabila, Katrain Sweet and Camarosa |
| V | 3 | Ceryerta, Chandler and Winter Dawn |

Based on the cluster means (*Tables A3* and *A4*), cluster IV was noted as important for leaf area index, number of flowers per plant, length of fruit, diameter of fruit, fresh fruit weight, number of fruits per plant, dry fruit weight, fruit yield per plant, volume of fruit, reducing sugar, total sugars, ascorbic acid, total soluble solids and shelf life. Genotypes in this cluster *viz.*, Nabila, Katrain Sweet and Camarosa were identified to be high yielding.


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The dendrogram drawn from the SLCA shows the relationship between the 14 genotypes (*Fig. 3*). The genetic similarity levels ranged from 0 to 20. At high similarity levels (>10) two major clusters were formed. First cluster consisting of Katrain Sweet, Nabila and Camarosa. The rest of the genotypes were clustered in the II group. At the similarity level of 10, the second cluster further divided into two subclusters. At the similarity level of 6, five clusters were formed consisting of three or two genotypes each. Of these clusters, genotypes in the I cluster are the most diverse.

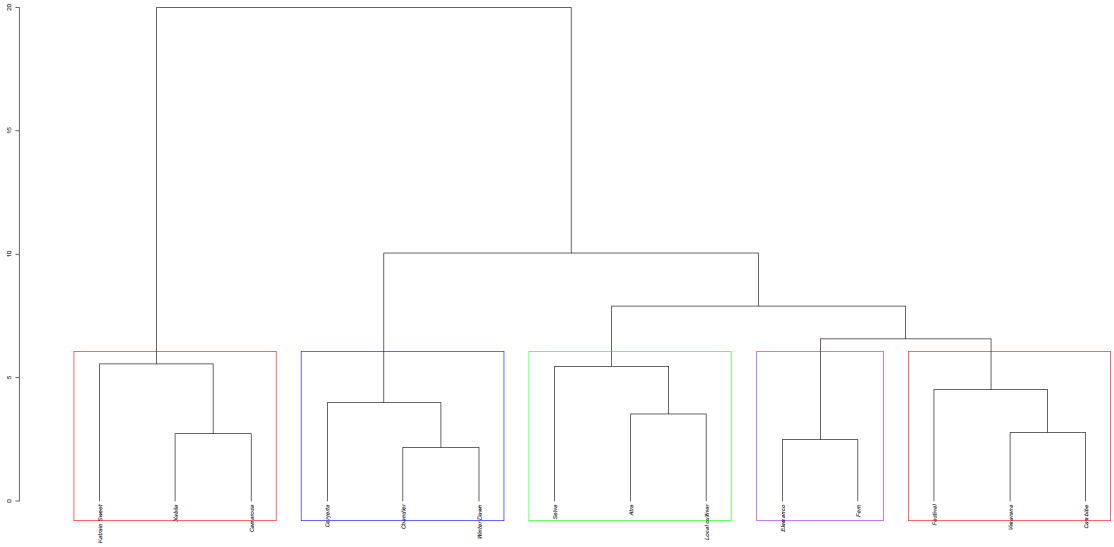

***Figure 3.*** *Dendrogram single linkage cluster analysis (SLCA) of the 14 strawberry genotypes. Genotype in Cluster I: Atra, Selva and Local Cultivar; Cluster II: Elamanco and Fern; Cluster III: Vimarana, Cambibe and Festival; Cluster IV: Nabila, Katrain Sweet and Camarosa; Cluster V: Ceryerta, Chandler and Winter Dawn*

## Discussion

Assessing suitability of fourteen strawberry genotypes and estimation of genetic diversity between these genotypes in Pulney hills, a potential zone for strawberry cultivation was the primary objective of this study. Genetic diversity is the fundamental requisite for planning a breeding program. Especially, the simultaneous evaluation of morphological, yield contributing and quality traits is important in the early stages of plant breeding (Barth et al., 2022). Also, diversity aids in adaptation of genotypes to varied agro climatic norms (Islam et al., 2013; Nascimento et al., 2023). The selection and adaptability of a suitable strawberry variety offer a potential means and an alternative for traditional temperate fruit crops like apple in the region thereby improving the socio-economic livelihood of the hill growers and tribal farming community in the Upper Pulney Hills.

Results of this shows that a wide variability existing between the genotypes studied. Variability for yield, yield contributing traits and fruit quality traits alike gives a chance for selection. Based on the yield and yield contributing traits, genotypes Nabila, Katrain Sweet and Camarosa were identified as better performers and thus highly suited to be cultivated in this region. In a similar experiment, Chowhan et al. (2016) observed that the cultivars Camarosa and Festival were the best genotypes with highest yield and other parameters in their study location. Similarly, Kumar et al. (2021) reported that cv.


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Chandler as the best suited genotype for North Indian plains. While Camarosa performed similar in our study location, cultivars Festival and Chandler lagged in yield and quality traits. This shows the influence of environment on the performance of strawberry genotypes and the importance of the evaluation studies. Similar observations were also made for other cultivars evaluated in this study (Rahman et al., 2015).

Other than yield, better fruit quality should also be targeted for commercial success. Quality traits such as pH, total soluble solids, acidity etc. decides end fruit quality (Temocico et al., 2019). Taste of the fruits has been mainly associated with the level of sugars and acids in it (Lal et al., 2013) and the ratio between them represents the balanced sweetness and acidity. In this study, it is also observed variability for different fruit quality traits *viz.*, volume of fruit, titratable acidity, reducing sugar, total sugar, ascorbic acid, total soluble solids and shelf life and gave a chance for selection (*Table A2*). Genotypes Nabila, Sweet Katrain & Camarosa showed better fruit quality in the experimental location. High yield combined with the better fruit quality in these genotypes indicate their better adaptability and suitability in this study location.

From the results, it is evident that even though, each cultivar had a different day length and temperature requirement, the ubiquity of the wide range of day length and temperature in the upper Pulney made the cultivars best adapted to the agro-climatic conditions of the region. Especially, the range in minimum and maximum temperature along with the optimum daylight period could have played a vital role for flower-bud formation, fruit setting and development in all the cultivars which in turn contemporarily made possible for comparative assessment for yield and quality characters.

Variability was also existent in strawberry plant architecture related traits such as plant height, spread of plant, leaf area index, flowering and fruiting duration. Traits such as leaf area index showed the health of the plant and indirectly indicate underlying physiological and biochemical processes (Ali and Aboelghar, 2019). High LAI observed in the genotypes such as Camarosa designate their high adaptability to the local agro-climate. This is important in selecting and designing plants for future improvement (Chhetri et al., 2017).

Principal components analysis (PCA) is a good method to identify major contributors of variation and to group the genotypes based on similarities (Barth et al., 2020). Similar analyses in strawberry have been reported before (Chhetri et al., 2017). With PCA, correlation between different variables and the similarities between the genotypes were elucidated. The high yielding cultivar Nabila was positively influenced by traits such as fruit yield, fruit dimensions and other quality traits. However, the other two high yielding types Camarosa and Katrain Sweet had balanced impact for all traits. Thus, relationship between variables and genotypes is identified from the biplot (*Fig. 1*). This information is useful to fix objectives in future plant breeding programs.

Genotypes in biplot were well spread in the plot area, indicating high divergence. Therefore, selections from any cluster group for fruit yield must take into consideration these traits as reported elsewhere in crops such as okra (Ariyo and Odulaja, 1991; Nwangburuka et al., 2011), cowpea (Aremu et al., 2007) and in coffee (Olika et al., 2011).

One of the objectives of this study was to group the selected strawberry genotypes based on their similarities and dissimilarities. Cluster analysis is a powerful statistical tool to study variability among breeding populations (Barth et al., 2022). $D^2$ analysis is one such method to study the degree of divergence between and within groups.


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Generally, genotypes between clusters (inter-cluster) have high diversity than the genotypes within the clusters (intra-cluster) (Uddin and Mitra, 1994). Genotypes from distant clusters can be chosen as parents in hybridization programs to get a better chance for selection (Ahmed et al., 2002; Chahal and Gosal, 2002; Samal and Jagadeb, 1996). Genotypes assessed here also showed a similar pattern. Highest intra-cluster distance was observed between the clusters II and III showing higher diversity between them.

Combination of the PCA and SLCA as multivariate analysis methods for strawberry genotypes was proven successful in this study. Together they revealed the extent of variability and relationship among the genotypes as also reported in cowpea and yam (Aremu et al., 2007; Onyilagha, 1980). They could also be useful in future collection, management and breeding programs. This study showed the presence of necessary diversity among the selected strawberry genotypes. Although, morphological descriptors alone, which are environmentally influenced, are not enough to identify the often ambiguous differences between strawberry genotypes, in the future, biochemical (Al-Said et al., 2009), as well as molecular (Jabir et al., 2008) markers will be used to evaluate and better estimate diversity among the strawberry genetic resources. Other genotypes such as Elamanco, Ceryerta, Chandler and Fern were also observed with above average yield but with some deficient qualities such as reduced dry fruit weight and other fruit qualities. Such genotypes, when evaluated with dense molecular markers will give more information regarding the diversity (Kaleybar et al., 2018).

## Conclusion

This study shows that the prevailing environmental conditions in higher Pulney hills are ideal for the cultivation of strawberry as observed by the performance of different genotypes. Three promising genotypes were identified (Nabila, Katrain Sweet and Camarosa), that could be immediately selected for cultivation after a short cycle of acclimatization. This is a first step in the wider adaptation of strawberry cultivation especially in the hilly regions of Tamil Nadu that has been limited due to multitude of reasons (Sawant et al., 2023). These genotypes having clustered together in $D^2$ analysis, can be utilized as one of the parents to be crossed with other genotypes of other clusters in future breeding programs. Utilization of molecular markers will further strengthen the understanding of diversity of these genotypes.

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## APPENDIX

***Table A1.*** *Specifics of study area*

| | |
|---|---|
| Area | Horticultural Research Station, Kodaikanal, Tamil Nadu, India |
| Location | 10.20 ′N, 77.50 ′E |
| Elevation | 2300 m above mean sea level |
| Maximum temperature | 28.0 °C |
| Minimum temperature | -2.5 °C |
| Average rainfall | 1700 mm per annum |
| Relative humidity | 40-100% |
| Soil type | Peaty and lateritic |
| Soil pH | 5.5 to 6.5 |

***Table A2.*** *Mean Performance of strawberry varieties for quality attributing characters*

| Traits | Titratable acidity (%) | Reducing sugar (%) | Total sugars (%) | Ascorbic acid (mg/100 g fruit) | Total soluble solids (°Brix) | Shelf life (days) |
|---|---|---|---|---|---|---|
| Atra | 0.81 | 3.26 | 4.19 | 63.58 | 18.68 | 1.0 |
| Selva | 0.75 | 3.42 | 4.32 | 67.48 | 19.77 | 2.0 |
| Elamanco | 0.79 | 3.29 | 4.20 | 64.25 | 18.92 | 1.0 |
| Vimarana | 0.77 | 3.32 | 4.24 | 66.06 | 19.44 | 1.0 |
| Nabila | 0.70 | 3.63 | 4.55 | 73.60 | 21.10 | 2.0 |
| Ceryerta | 0.74 | 3.45 | 4.40 | 67.55 | 19.85 | 2.0 |
| Chandler | 0.76 | 3.34 | 4.25 | 66.75 | 19.50 | 2.0 |
| Fern | 0.79 | 3.29 | 4.21 | 65.93 | 19.15 | 1.0 |
| Cambibe | 0.75 | 3.40 | 4.28 | 67.24 | 19.76 | 2.0 |
| Katrain Sweet | 0.71 | 3.55 | 4.49 | 71.10 | 21.00 | 2.0 |
| Winter Dawn | 0.76 | 3.36 | 4.25 | 66.82 | 19.56 | 2.0 |
| Camarosa | 0.71 | 3.58 | 4.52 | 72.00 | 21.02 | 2.0 |
| Festival | 0.72 | 3.51 | 4.44 | 69.42 | 20.49 | 2.0 |
| Local cultivar | 0.82 | 3.24 | 4.19 | 62.67 | 18.25 | 1.0 |
| **Mean** | **0.76** | **3.40** | **4.32** | **67.46** | **19.75** | **1.64** |
| **S.E.** | **0.01** | **0.05** | **0.08** | **0.89** | **0.30** | **0.03** |
| **SEd** | **0.02** | **0.08** | **0.11** | **1.26** | **0.43** | **0.04** |
| **C.D. (5%)** | **0.03** | **0.16** | **0.23** | **2.60** | **0.89** | **0.08** |
| **CV (%)** | **2.70** | **2.74** | **3.18** | **2.29** | **2.67** | **2.90** |


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***Table A3.*** *Cluster means of different yield traits*

| Clusters | Plant Height (cm) | Spread of plant (cm) | Number of leaves per plant | Leaf area index (cm2) | Number of flowers per plant | Flowering duration | Fruiting duration | Length of fruit (cm) | Diameter of fruit (cm) | Fresh fruit weight (g) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 22.4 | 16.6 | 12.4 | 16.8 | 8.4 | 37.9 | 69.2 | 3.0 | 3.1 | 42.7 |
| 2 | 26.2 | 19.4 | 13.4 | 25.3 | 8.5 | 38.4 | 69.6 | 3.7 | 3.4 | 46.1 |
| 3 | 27.3 | 20.4 | 14.0 | 28.7 | 8.4 | 38.4 | 68.0 | 3.3 | 3.2 | 43.1 |
| 4 | 26.8 | 20.3 | 13.2 | 30.3 | 9.1 | 35.9 | 66.1 | 4.9 | 3.9 | 50.7 |
| 5 | 23.4 | 19.2 | 13.7 | 19.3 | 8.9 | 37.3 | 68.3 | 4.7 | 3.8 | 45.6 |

***Table A4.*** *Cluster means of different fruit quality traits*

| Clusters | Number of fruits per plant | Dry fruit weight (g) | Fruit yield per plant (g) | Volume of fruit (mL) | Titrable acidity (%) | Reducing sugar (%) | Total sugars (%) | Ascorbic acid (mg/100 g fruit) | Total soluble solids (°Brix) | Shelf life(days) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 21.4 | 40.6 | 912.6 | 43.0 | 0.79 | 3.3 | 4.2 | 64.6 | 18.9 | 1.3 |
| 2 | 22.4 | 46.8 | 1030.3 | 49.8 | 0.79 | 3.3 | 4.2 | 65.1 | 19.0 | 1.0 |
| 3 | 21.5 | 41.4 | 926.7 | 44.0 | 0.75 | 3.4 | 4.3 | 67.6 | 19.9 | 1.7 |
| 4 | 23.6 | 48.2 | 1196.6 | 57.3 | 0.71 | 3.6 | 4.5 | 72.2 | 21.0 | 2.0 |
| 5 | 22.9 | 45.0 | 1046.1 | 55.8 | 0.75 | 3.4 | 4.3 | 67.0 | 19.6 | 2.0 |


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