Electronic Journal of Plant Breeding, 9 (1) : 169 - 182 (Mar 2018) DOI: 10.5958/0975-928X.2018.00021.2
ISSN 0975-928X

**Research Article**

# Genetic variability and association analysis in strawberry (*Fragaria x ananassa* Duch)

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(Received: 2 Aug 2017; Revised: 22 Jan 2018; Accepted: 27 Feb 2018)

**Abstract**
Thirteen genotypes of strawberry were subjected to genetic variability and association analysis. The study revealed highly significant differences for all the characters studied, indicating the presence of substantial genetic variability. Phenotypic and genotypic coefficient of variation (PCV and GCV) was maximum for yield/hectare (42.58 and 42.27) followed by yield /plant (42.57 and 42.26), non-reducing sugar (34.44 and 34.39), number of flower/plant (29.37 and 29.09). While high heritability found in non-reducing sugar (99.7%) followed by fruit initiation (98.6%), yield/plant (98.6%), yield/hectare (98.6 %),average berry weight (98.4%), flower /plant (98.1%), fruit/plant (97.9%), TSS (97.6%), titratable acidity (97.6%), days taken from planting to harvest (96.4%) and anthocyanin content (95.2 %). High heritability coupled with high genetic advance as percent of mean was observed for yield/hectare (86.55%) among fruit yield followed by yield/plant (86.43%), non-reducing sugar (70.75%). However, significant positive correlation on yield/plant was recorded with plant spread, plant height, leaves/plant, petiole length, days taken from planting to harvest, flower/plant, fruit length, fruit breadth, fruit /plant, titratable acidity, non-reducing sugar and average berry weight. Whereas, positive direct effect on yield/plant was found to be highest for number of flower /plant (0.949) followed by fruit breadth (0.206), anthocyanin content (0.103), fruit length (0.100), average berry weight (0.097) and plant spread (0.068) indicating that these should be considered as selection criteria for increasing fruit yield/plant in a breeding program.

**Key words**
Genetic Variability, Correlation, Path Coefficient, Strawberry, Yield

## Introduction

Strawberry (*Fragaria* x *ananassa* Duch.) belonging to the Rosaceae family, is a herbaceous perennial plant. It is one of the most widely cultivated fruit plants in the world and is a natural hybrid derived from its parental species (octoploid, 2n = 56), Fragaria virginiana Duch. and *Fragaria chiloensis* (L.) Duch.(Degani *et al.*,1998). Owing to the high demand and important economic values of strawberry, its output is ranked first among small berries in global terms (Monfort, 2014).The cultivated strawberry, *Fragaria* × *ananassa*, is an octaploid (2n = 8x = 56) (Nathewet *et al*., 2010).Strawberry is good source of carbohydrate, antioxidant compound, such as flavanoids and phenolics, besides it is most attractive color and taste (Cordenunsi *et al.*, 2002). Strawberry fruits are rich source of vitamin C (39 to 86/100g of fruit) and minerals. The strawberry is the good source of Vitamin A (60 IU/100g), pectin, potassium, calcium and phosphorous (Sharma *et al.*, 2002).

Numerous strawberry breeding programs have been developed to generate new cultivars with improved taste and flavor or extended harvest period and shelf life (Capocasa *et al.*, 2008; Faedi *et al.*, 2000). Traditionally, the identification of strawberry cultivars was determined by the examination of differences in morphological or physiological characteristics such as leaf, flower, fruit parameters, and flowering habit (Nielsen and Lovell, 2000). However, such methods are unsuitable for cultivated strawberries as genetic and phenotypic variations be-tween cultivars are minimal. The direct selection for fruit yield is not sufficiently effective, as yield is poly-genetically controlled and associated with number of related traits. Therefore, indirect selection is desirable for improvement of yield. Correlation alone does not provide information on the contribution of related characters, which necessitates the study of cause and effect relationship of different characters among themselves. It has been observed that path coefficient analysis reveals the exact relationship of characters thereby providing more information than simple correlation analysis, suggesting that correlation analysis, is a weaker tool compared to path coefficient analysis (Dewey and Lu.,1959).Yield is a complex trait and it is difficult to exploit various yield contributing characters merely through the knowledge of correlation which is simply a measure of association between yield and the yield components (Lungu, 1978). Heritability, gene action, and correlation among traits are very important in determination of parent and selection of progeny. The objective of this study was to find out the genetic variability, correlation and the direct and indirect contribution of each character by using path coefficient analysis on fruit yield of strawberry.

**Materials and Methods**

The present investigation was carried out during 2015-16 at Research Farm, Mata Gujri College, Fatehgarh Sahib, Punjab. The material comprised of thirteen genotypes of strawberry which were collected from National Bureau of Plant Genetic Resources, Shimla and were grown in a Randomized Block Design (RBD) with three replications, keeping row to row distance of 30 centimeter with and distance between plants 25 centimeter in each replication. The thireen genotypes used were Belrubi, Confictura, Sweet Charlie, Chandler, Etna, Selva, Sea Scape, Dana, Gorella, Brighton, Ventana, Douglus and Pajaro. Recommended agronomic package of practices were followed to raise a good and healthy crop. Randomly five selected plants were observed for different morphological and biochemical attributes. Data were recorded for plant height (cm), plant spread (cm), number of leaves, petiole length (cm), days taken to produce first flower, number of flowers, days taken from planting to harvest, number of fruits, the weight of entire fruit unit harvested from each plot was recorded for each cultivar and yield/plant and yield/hectare was calculated. The size of the fruit was measured in terms of length and breadth. The weight of the representative fruits of each cultivar from each plant was recorded and average berry weight was worked out. Total soluble solid, of the ripe fruit was determined with the help of hand refractometer (0-32$^0$ Brix) by putting few drops of juice on the prism. A standard procedure given by A.O.A.C, (2002) was used to determine chemical parameters. Anthocyanin pigments of berry were determined by the methods given by Harborne, (1973).

The data recorded on 19 traits from experiment was utilized for analysis of variance (ANOVA) following Panse and Sukhatme (1967). Genotypic and phenotypic coefficients of variation were estimated by the formula suggested by Burton and De Vane (1953) for each character. Heritability in broad sense and estimates of appropriate genetic variance components were substituted for the parameters to predict expected genetic gain. Correlated characters are of interest to find the genetic causes of correlation through the pleiotropic action of genes, to know the level of selection for one character that will cause simultaneous effect in other characters and find out correlation between character and their fitness. Genotypic coefficient of correlation ($r_g$) and phenotypic coefficient of correlation ($r_p$) were computed as per Robinson *et al*., (1951) and tested for statistical significance against the correlation table values at 5% and 1% levels of significance (Fisher and Yates, 1963). A path coefficient was measure of direct and indirect effects of each character on fruit yield was estimated using a partial regression coefficient, as suggested by Dewey and Lu, (1959).

**Results and Discussion**

The economic traits are influenced to a great extent by environments and hence mostly polygenically controlled. The nature of genotypic variability and their magnitude determined the extent of improvement in such characters. A perusal of the data revealed that the genotypes differed highly significantly for the characters under investigation. Kumar *et al*. (2012) found that analysis of variance of parent strawberry was highly significant for all the characters under study. Singh *et al*. (2011), Gawronski (2011), Ara *et al*. (2009) and several other workers also found highly significant differences among these traits studied, yield and yield contributing traits exhibited the scope for the improvement through selection and hybridization, which reflects the presence of considerable amount of variability among the traits.

Among yield traits wide range and mean of variation was estimated for anthocyanin content (0.14–0.42 OD and 0.29 OD) followed by titrable acidity (0.55 – 1.13 % and 0.93 %), non-reducing sugar (0.90 – 2.53 % and 1.51 %), reducing sugar (3.45 – 5.71 % and 4.70 %), total sugar (5.79 – 6.82 % and 6.24 %), petiole length (6.01 – 10.19 cm and 7.82 cm), TSS(6.20 – 10.77 $^0$B and 8.74 $^0$B), average berry weight (6.35 – 8.67 g and 7.30 g), yield/hectare (6.50 – 32.43 MT and 17.53 MT), plant height (9.00 -16.00 cm and 11.87 cm), flower/plant (11.33 – 30.22 and 20.87), fruit per plant (12.33 – 28.33 and 19.62), fruit breadth (14.39 – 22.89 mm and 18.20 mm), leaf/plant (14.50 -32.92 and 24.55), plant spread (17.00 – 25.00 cm and 22.08 cm), fruit length (20.55 – 35.63 mm and 27.89 mm), flower initiation (45.00 – 91.33 and 70.23), yield/plant (54.24 - 270.28 g and 146.13 g) and days taken from planting to harvest (116.97 – 128.23 and 123.49).The highest fruit yield/plant was recorded for genotype Douglus. Kumar *et al*. (2012) recorded wide ranges and mean of variation for plant height, plant spread, number of leaves/plant, number of flower/plant, number of fruit/plant, fruit length, fruit breadth, fruit yield/plant, average berry weight, TSS and titrable acidity.

The amount of genotypic and phenotypic variability that exists in a species is the utmost importance in breeding better varieties and in initiating a breeding program. The estimates of genetic variability parameters for all the traits were worked out. It was evident from the result that the phenotypic variance is greater than genotypic variance indicating the influence of environment. Among the yield attributes maximum PCV and GCV was depicted by yield/hectare (42.58 and 42.27) followed by yield/plant (42.57 and 42.26), non-reducing sugar (34.44 and 34.39), number of flower/plant (29.37 and 29.09), anthocyanin content (29.13 and 28.43), number of fruit/plant (27.54 and 27.26) and flower initiation (21.81 and 21.65) (Table-3).The high values of PCV and GCV indicating that selection may be effective on these traits. The estimates of PCV were moderate for the characters *viz.* number of leaf/plant (19.85 and 17.29), plant height (19.41 and 16.61), petiole length (17.79 and 16.25), TSS (17.09 and 16.88), titrable acidity (15.71 and 15.52), reducing sugar (13.75 and 13.37), fruit length (13.16 and 12.68), plant spread (13.09 and 10.67), fruit breadth (12.96 and 12.08) and average berry weight (10.11 and 10. 04). The lowest value for PCV and GCV was shown by total sugar (6.17 and 5.95) and days taken from planting to harvest (2.77 and 2.72) indicating less scope of selection as they are under less influence of environment. The value of genotypic and phenotypic coefficient of variability that exists in a species is the utmost importance in breeding better varieties and in initiating a breeding program; Ara *et al*. (2009). Among all traits, higher values of PCV and GCV were observed for yield/hectare followed by yield/plant, non-reducing sugar, number of flower/plant, anthocyanin content, number of fruit/ plant and flower initiation, respectively and suggested the scope for improving these traits by selection. Kumar *et al*. (2012) that phenotypic correlation variance was higher than genotypic correlation coefficient of variation for all the traits viz. plant height, plant spread, number of leaves/plant, number of flower/plant, number of fruit/plant, fruit length, fruit breadth, fruit yield/plant, average berry weight, TSS, Titrable acidity. Low estimates of PCV and GCV were observed for days taken for first flowering and early maturity.

Heritable variation is useful for permanent genetic improvement (Singh, 2000). The proportion of genetic variability which is transmitted from parents to offspring is reflected by heritability. The present study of heritability reflects that the characters like non-reducing sugar (99.7%) followed fruit initiation (98.6%), yield/plant (98.6%), yield/hectare (98.6 %), average berry weight (98.4%), flower/plant (98.1%), fruit/ plant (97.9%), TSS (97.6%), titrable acidity (97.6%), days taken from planting to harvest (96.4%), anthocyanin content (95.2 %), reducing sugar (94.5%), total sugar (93%), fruit length (92.8%), fruit breadth (86.9%), petiole length (83.4%), leaves per plant (75.9%), plant height (73.3%) and plant spread (66.4%).The findings were almost supported by Kumar *et al*. (2012) who observed high estimates of heritability for number of leaves/plant, number of flower/plant, number of fruit/plant, fruit breadth, fruit yield/plant, average berry weight, TSS, titratable acidity. Ara *et al*. (2009) also, observed high value of heritability with respect to trait like plant height, number of flower/plant and fruit yield /plant, similar results have also been reported by Karim, (2007). High value of heritability was observed in number of leaves/plant, number of flower/plant, number of fruit/plant, TSS, titrable acidity, reducing sugar, total sugar, fruit length, fruit breadth, fruit weight and fruit yield/plant reported by Mishra *et al*. (2015) and similar result was found by Sah *et al*. (2010).

Breeder should consider heritability estimates along with the genetic advance because heritability alone is not a good indicator of the usable genetic variability as reported by Masood, (1986). Estimate of genetic advance was highest for yield/plant (126.30) followed by flower initiation (31.09), yield/hectare (15.15), flower/plant (12.39), fruits /plant (10.90), leaves/ plant (7.62), fruit length (7.02), days taken from planting to harvest (6.79), fruit breadth (4.22), plant spread (3.96), plant height (3.48), TSS (3.01), petiole length (2.39), average berry weight (1.49), reducing sugar (1.26), non-reducing sugar (1.07), total sugar (0.73), titrable acidity (0.29), anthocyanin content (0.17). Genetic advance as percent of mean was highest for yield/hectare (86.55%) (Table-3) followed by yield/plant (86.43%), non-reducing sugar (70.75%), number of flower/plant (59.35%), anthocyanin content (57.16%), fruit/plant (55.56%), flower initiation (44.28%), TSS (34.36%), titrable acidity (31.57%), leaves/plant (31.05%), petiole length (30.55%), plant height (29.29%), reducing sugar (26.78%), fruit length (25.16%), fruit breadth (23.20%), average berry weight (20.50%), plant spread (17.91%), total sugar (11.82%), days taken from planting to harvest (5.50%). High values and moderate values of genetic advance and genetic advance percent of mean were also reported by Kumar *et al*. (2012), where they found high values for number of flower/plant, number of leave/plant, number of fruit/plant, fruit breadth, average fruit weight, fruit yield/plant, TSS, titrable acidity, moderate values for plant spread and fruit length. Mishra *et al.*, (2015) reported high genetic advance for fruit yield/plant and moderate to low genetic advance for number of fruit weight, number of leaves/plant, plant spread and plant height as similar as close agreement of present finding.

The phenotypic correlation includes a genotypic and environmental effect, which provides information about total association between the observable characters Kumar *et al*. (2012). Plant spread were significantly positive correlation with plant height (0.553), average berry weight (0.328) and petiole length (0.558). Plant height showed positively correlation with plant spread (0.0553), petiole length (0.699), flower initiation (0.438), flower/plant (0.654), fruit breadth (0.606), non-reducing sugar (0.352) and average berry weight (0.329). Leaves/plant were observed significantly positive correlated with petiole length (0.341), fruit breadth (0.411) and non-reducing sugar (0.421). Petiole length was show positive and significant correlation with plant spread (0.558), plant height (0.699), leaves/plant (0.341), flowers/plant (0.512), fruit breadth (0.329) and fruit/plant (0.399). Flower initiation was observed significant positively correlated with fruit length (0.537). Days taken from planting to harvest was significantly and positively correlated with titrable acidity (0.169). Number of flower/ plantshows positive significant correlation with leaves/plant (0.269), petiole length (0.512), fruit breadth (0.662), number of fruit/plant (0.927), titrable acidity (0.347), non-reducing sugar (0.455), and average berry weight (0.4418). Fruit length was observed to be significantly positive correlated with flower initiation (0.537). Fruit breadth also shows positively and significantly correlated with plant height (o.557), number of leaves/plant (0.411), petiole length (0.329), number of flower/plant (0.679), non-reducing sugar (0.645) and average berry weight (0.555). Number of fruit/plant showed significantly positive correlation with plant height (0.606), petiole length (0.398), number of flower/plant (0.927), fruit breadth (0.679), titrable acidity (0.454), non-reducing sugar (0.398) and average berry weight (0.464) indicating that with the increase in number of these characters, number of fruit increases. Further total sugar also showed significant and positive correlation with reducing sugar (0.549). Titratable acidity showed significantly positive correlation with number of flower/plant (0.347) and number of fruit/plant (0.454). Reducing sugar showed significant positive correlation with total sugar (0.549). Average berry weight showed positive significant difference with non-reducing sugar (0.626), plant spread (0.382), plant height (0.329), number of flower/plant (0.442), fruit breadth (0.556), number of fruit/plant (0.464) and non-reducing sugar (0.625). Correlation coefficient of fruit yield/plant and yield contributing characters revealed that the genotypic correlation coefficient in most of the cases were higher than their phenotypic correlation coefficients indicating the effects of environment suppressed the phenotypic relationship between the characters found by Ara *et* al. (2009). Fruit yield was significantly associated with the most of the characters except plant spread (canopy size) and days of flowering. Similar results have been observed by Biswas *et al*. (2007). Strong vegetative growth expressed through many branches may also weaken yield, which is also emphasized by Gawronski, (2011), similar to present study where plant spread was significantly positive correlation with plant height and petiole length. Takeda *et al*. (2004) observed that the use of larger plant increase the total plant production of strawberry fruit. The number of berries/plant had a high positive correlation with berry size (fruit length and fruit breadth) and berry weight had a positive correlation with each other, while they had no significant correlation with yield by Karimi and Gholami, (2014). Emdad *et al*. (2013) observed significant correlation between the number of flower/plant with number of fruit/plant and fruit breadth. Positive correlations of number of flower/plant with number of fruit/plant at genotypic and phenotypic level suggested that selection of higher number of strong may be done by selecting higher number of fruits (Salika *et. al*. 2007). Similar results were found by the Ara *et al*. (2009) have also reported that positive correlation between number of flower/plant with number of fruits.

**Path-Coefficient Analysis-** Path coefficient analysis is an important tool for portioning the genotypic and phenotypic correlation coefficient into direct and indirect effect of independent variable on dependent variables and provides the cause and effects of chain relationships of different yield contributing characters with yield. Using phenotypic correlation, analysis revealed that magnitude of direct effect on yield/plant was found to be highest for number of flower/plant (0.949) followed by fruit breadth (0.206), anthocyanin content (0.103), fruit length (0.100), average berry weight (0.097) and plant spread (0.068) indicating true relationship between these traits as good contributors to fruit yield and suggesting the importance of direct selection for these traits. On the other hand, the highest negative direct effect of titrable acidity (-0.233) followed by days taken from planting to harvest (-0.223), flower initiation (-0.222), TSS (-0.148), total sugar (-0.094), petiole length (-

DOI: 10.5958/0975-928X.2018.00021.2
ISSN 0975-928X

0.080), plant height (-0.068), non-reducing sugar (-0.059), number of leaf/plant (-0.038) and number of fruit/plant (-0.007) was found on fruit yield/plant.

Plant spread exhibited indirect positive effect on yield/plant through petiole length (0.038) and plant height (0.038) whereas, exhibited indirect negative effect *via* anthocyanin content (-0.027) and days taken from planting to harvest (-0.020). Plant height had positive indirect effect through reducing sugar (0.037) and anthocyanin content (0.029), whereas it governs negative indirect effect via petiole length (-0.059) and number of flower/plant (-0.055).Number of leaves per plant governs positive indirect effect *via* fruit breadth (0.012) and reducing sugar (0.011). The positive indirect effect of petiole length days exhibited by anthocyanin content (0.047) and number of flower/plant (-0.055).Number of leaves/plant governs positive indirect effect via fruit breadth (0.012) and reducing sugar (0.011). The positive indirect effect of petiole length days exhibited by anthocyanin content (0.047) and 0.023 plant height (0.006) whereas negative indirect effect exhibited by plant height (-0.056) and plant spread (-0.045).Flower initiation showed positive indirect effect on number of fruit/plant (0.127) and number of flower/plant (0.115) and indirect negative effect was observed with fruit length (-0.119) and anthocyanin content (-0.070). Days taken from planting to harvest showed positive indirect effect on fruit length (-.109) and flower initiation (0.100).Whereas, the indirect negative effect on number of flower/plant (-0.056) and number of fruit/plant (-0.055).

Number of flower per plant indirectly positively affected number of fruit/plant (0.879) and fruit breadth (0.628). Fruit length showed positive indirect effect on flower initiation (0.053) and total sugar (0.030), which showed negative indirect effect on days taken from planting to harvest (-0.049) and number of leaves/plant (-0.032). Fruit breadth showed positive indirect effect on number of fruit/plant (0.139) and number of flowers plant (0.136) and negative indirect effect govern on reducing sugar (-0.125) and flower initiation (-0.064). Positive indirect effect on number of fruit/plant govern on flower initiation (0.004) and reducing sugar (0.003) and negative indirect effect on fruit breadth (-0.004) and days taken from planting to harvest (-0.006).

TSS positive indirect effect on days taken from planting to harvest (0.066) and titrable acidity (0.057) exhibited indirect negative effect on non-reducing sugar (-0.044) and total sugar (-0.043). A positive indirect effect on titrable acidity was observed for flower initiation (0.116) and non-reducing sugar (0.092) and negative indirect effect for number of fruit/plant (-0.106) and number of flower/plant (-0.081). A negative indirect effect of total sugar through TSS (-0.028) and titrable acidity (-0.024) whereas positive indirect effect on number of fruit/plant (0.021) and plant height (0.016). A positive indirect effect was observed for reducing sugar through number of leaves/plant (0.029) and plant height (0.097) and negative indirect effect on non-reducing sugar (-0.041) and fruit breadth (-0.032).

Non-reducing sugar exhibited positive indirect effect through reducing sugar (0.046) and titrable acidity (0.007) and negative indirect effect for fruit breadth (-0.038) and average berry weight (-0.037). Anthocyanin content exhibited positive indirect effect through flower initiation (0.032) and fruit length (0.019) whereas the negative indirect effect observed on petiole length (-0.060) and number of fruit/plant (-0.041).At last average berry weight exhibited positive indirect effect through fruit breadth (0.054) and number of fruit/plant (0.045) whereas the negative indirect effect through reducing sugar (-0.0483) and anthocyanin content (-0.006).

Path coefficient analysis screens the components of correlations coefficient into direct and indirect effects and indicates the relationship in more meaningful way Emdad *et al*. (2013). Early flowering bring the fruiting period forward in the cool climate, which extend the fruiting period result improve fruit size and increase yield and the warm climate, which limit the fruiting period, resulting in lower yield; Karimi and Gholami, (2014). Plant height having higher positive indirect effect on fruit yield, also showed high indirect positive effect through number of leaves per plant, days from planting to flowering (flower initiation), number of fruit/plant and number of flower/plant by way of indirect contribution in enhancing the fruit yield of strawberry reported by Ara *et al*. (2009).

All characters of the maximum value of PCV and GCV were observed for yield/hectare and contributing traits and higher values of PCV and GCV indicate that effect of environmental factors on the expression of the trait. As the characters are correlated, character showing highly significant positive correlation are the main yield attributing character and selection for these characters or selection in one of the trait can directly be followed for immediate improvement of strawberry crop. Path coefficient analysis (phenotypic) showed that positive direct effect was to be highest on yield/plant was found to be highest most of the traits indicating true relationship between these traits as good contributors to fruit yield and suggesting the importance of direct selection for these traits for increasing fruit yield per plant in a breeding program. A plant breeder should therefore, emphasize on these traits while practicing selection of high yielding strawberry.

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ISSN 0975-928X

**Table1. Mean performance of 13 strawberry genotypes**

| Character / Genotypes | Plant Spread (cm) | | Leaves/ Plant | Petiole Length (cm) | Flower Initiation (days) | Days Taken From Planting to harvest | Flowers / Plant | Fruit Length (mm) | Fruit Breadth (mm) | Fruits/ Plant | TSS (°Brix) | Titratable Acidity (%) | Total Sugar (%) | Reducing Sugar (%) | Non-reducing Sugar (%) | Anthocyanin Content (O D) | Average Berry Weight (g) | Yield/ Plant (g) | Yield/ hactare (t/ha) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Belrubi | 23.33 | 12.00 | 29.67 | 9.37 | 47.33 | 125.96 | 19.44 | 20.55 | 17.21 | 15.89 | 9.03 | 0.91 | 6.44 | 5.18 | 1.26 | 0.17 | 7.05 | 110.06 | 13.20 |
| Confictura | 21.00 | 12.33 | 23.50 | 8.91 | 69.67 | 126.82 | 30.17 | 30.20 | 18.97 | 28.22 | 8.10 | 1.13 | 5.85 | 4.55 | 1.30 | 0.14 | 7.06 | 200.23 | 24.02 |
| Sweet charlie | 23.67 | 11.33 | 20.53 | 8.17 | 90.67 | 116.97 | 13.89 | 35.63 | 14.39 | 12.33 | 9.97 | 0.87 | 6.74 | 5.71 | 1.04 | 0.37 | 6.76 | 88.29 | 10.59 |
| Chandler | 21.67 | 10.67 | 24.42 | 6.18 | 67.67 | 122.06 | 20.89 | 31.48 | 19.48 | 19.78 | 9.13 | 0.94 | 6.82 | 4.57 | 2.24 | 0.36 | 8.67 | 171.67 | 20.59 |
| Dana | 17.00 | 9.00 | 25.75 | 6.01 | 85.67 | 126.64 | 15.67 | 26.07 | 15.17 | 13.56 | 6.20 | 0.85 | 5.84 | 4.32 | 1.52 | 0.41 | 6.67 | 89.26 | 10.71 |
| Selva | 23.00 | 9.67 | 24.58 | 7.25 | 91.33 | 123.36 | 17.33 | 29.33 | 19.21 | 16.55 | 10.70 | 0.55 | 6.27 | 4.25 | 2.02 | 0.27 | 7.87 | 130.81 | 15.69 |
| Sea scape | 24.00 | 12.00 | 23.50 | 7.86 | 89.67 | 120.85 | 15.67 | 28.64 | 17.93 | 13.67 | 8.17 | 1.01 | 5.99 | 4.97 | 1.01 | 0.24 | 6.70 | 88.78 | 10.65 |
| Brighton | 17.67 | 10.33 | 25.17 | 6.70 | 65.33 | 126.57 | 20.67 | 27.56 | 18.94 | 19.44 | 10.10 | 0.97 | 6.80 | 5.57 | 1.23 | 0.33 | 6.35 | 124.30 | 14.91 |
| Gorella | 23.00 | 12.00 | 26.17 | 8.17 | 66.33 | 125.27 | 24.11 | 25.55 | 16.72 | 21.83 | 6.57 | 0.91 | 6.45 | 5.12 | 1.33 | 0.29 | 7.03 | 169.17 | 20.29 |
| Etna | 20.00 | 10.00 | 21.17 | 6.40 | 67.33 | 122.11 | 11.33 | 24.68 | 16.72 | 16.99 | 9.43 | 1.06 | 5.79 | 4.88 | 0.91 | 0.42 | 6.81 | 54.24 | 6.50 |
| Ventana | 25.00 | 14.00 | 14.50 | 7.39 | 45.00 | 128.23 | 25.63 | 27.61 | 18.37 | 24.89 | 7.27 | 1.09 | 6.17 | 4.62 | 1.27 | 0.25 | 8.33 | 206.61 | 24.78 |
| Douglus | 22.67 | 15.00 | 32.92 | 9.02 | 62.33 | 119.57 | 30.22 | 27.44 | 22.89 | 27.22 | 8.23 | 1.04 | 5.99 | 3.92 | 2.07 | 0.33 | 8.20 | 270.29 | 32.43 |
| Pajaro | 25.00 | 16.00 | 27.33 | 10.19 | 64.67 | 121.02 | 26.33 | 27.94 | 20.66 | 24.67 | 10.77 | 0.86 | 5.99 | 3.45 | 2.54 | 0.27 | 7.37 | 195.97 | 23.51 |
| **Mean** | **22.08** | **11.87** | **24.55** | **7.82** | **70.23** | **123.49** | **20.87** | **27.89** | **18.21** | **19.62** | **8.74** | **0.94** | **6.24** | **4.70** | **1.52** | **0.29** | **7.29** | **146.13** | **17.53** |
| C.V. | 7.59 | 10.03 | 9.73 | 7.25 | 2.60 | 0.53 | 4.06 | 3.53 | 4.68 | 3.96 | 2.64 | 2.45 | 1.63 | 3.23 | 1.75 | 6.36 | 1.28 | 5.11 | 5.11 |
| F ratio | 6.93 | 9.22 | 10.47 | 16.04 | 208.67 | 81.16 | 155.24 | 39.69 | 20.98 | 143.10 | 123.79 | 121.04 | 41.09 | 52.34 | 1161.42 | 60.99 | 184.03 | 205.97 | 206.46 |
| F Prob. | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| S.E. | 0.97 | 0.69 | 1.37 | 0.33 | | 0.38 | 0.49 | 0.57 | 0.49 | 0.45 | 0.13 | 0.01 | 0.06 | 0.09 | 0.02 | 0.01 | 0.05 | 4.31 | 0.51 |
| C.D. 5% | 2.82 | 2.01 | 4.03 | 0.95 | 3.08 | 1.09 | 1.43 | 1.66 | 1.44 | 1.31 | 0.39 | 0.04 | 0.17 | 0.26 | 0.04 | 0.03 | 0.16 | 12.59 | 1.50 |
| C.D. 1% | 3.83 | 2.72 | 5.46 | 1.29 | 4.17 | 1.48 | 1.93 | 2.25 | 1.95 | 1.77 | 0.53 | 0.05 | 0.23 | 0.35 | 0.06 | 0.04 | 0.21 | 17.06 | 2.05 |
| Range Lowest | 17.00 | 9.00 | 14.50 | 6.01 | 45.00 | 116.97 | 11.33 | 20.55 | 14.39 | 12.33 | 6.20 | 0.55 | 5.79 | 3.45 | 0.91 | 0.14 | 6.35 | 54.24 | 6.50 |
| Range Highest | 25.00 | 16.00 | 32.92 | 10.19 | 91.33 | 128.23 | 30.22 | 35.63 | 22.89 | 28.22 | 10.77 | 1.13 | 6.82 | 5.71 | 2.54 | 0.42 | 8.67 | 270.29 | 32.43 |

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ISSN 0975-928X

**Table 2. Analysis of variance in 13 genotypes of Strawberry**

| Source of Variation | d.f. | Mean sum of square | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Plant height | Plant spread | No. of leaf /plant | Petiole length | Flower initiation | No. of flower /plant | Days taken from planting to harvest | Fruit length | Fruit breadth |
| **Replication** | 2 | 2.6410 | 1.0000 | 5.6427 | 0.3056 | 0.9231 | 0.6320 | 0.0291 | 0.1547 | 0.2839 |
| **Treatment** | 12 | 13.0855** | 19.4530** | 59.8057** | 5.1582** | 696.9103** | 111.3258** | 34.2949** | 38.5118** | 15.2367** |
| **Error** | 24 | 1.4188 | 2.8056 | 5.7126 | 0.3215 | 3.3397 | 0.7171 | 0.4225 | 0.9704 | 0.7263 |

*Significant at p=0.05
**Significant at p=0.01

| Source of Variation | d.f. | Mean sum of square | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | No. of fruit /plant | Average berry weight | Yield per plant | TSS | Total sugar | Reducing sugar | Non-reducing sugar | Anthocyanin Content | Titratable acidity | Yield /hectare |
| **Replication** | 2 | 0.0260 | 0.0032 | 8.0861 | 0.1510 | 0.0039 | 0.0263 | 0.0009 | 0.0000 | 0.0007 | 0.1178 |
| **Treatment** | 12 | 86.3778** | 1.6183** | 11498.1201** | 6.5913** | 0.4240** | 1.2092** | 0.8194** | 0.0217** | 0.0641** | 165.5504** |
| **Error** | 24 | 0.6036 | 0.0088 | 55.8245 | 0.0532 | 0.0103 | 0.0231 | 0.0007 | 0.0004 | 0.0005 | 0.8019 |

Contd……
*Significant at p=0.05
**Significant at p=0.01

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ISSN 0975-928X

**Table 3. Estimates of genetic parameter for various traits of 13 strawberry genotypes**

| Paremeters / Characters | Mean ± S.E. | Range | | $\sigma^2_p$ | $\sigma^2_g$ | PCV (%) | GCV (%) | $h^2_{bs}$ (%) | GA | GA as % of Mean |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Min. | Max. | | | | | | | |
| Plant spread (cm) | 22.076±1.367 | 17.00 | 25.00 | 8.35 | 5.55 | 13.09 | 10.67 | 66 | 3.95 | 17.91 |
| Plant height (cm) | 11.872±0.972 | 9.00 | 16.00 | 5.31 | 3.88 | 19.41 | 16.61 | 73 | 3.48 | 17.91 |
| No. of leaf per plant | 24.553±1.951 | 14.50 | 32.91 | 23.74 | 18.0 | 19.84 | 17.29 | 0.76 | 7.62 | 31.05 |
| Petiole length (cm) | 7.82±0.463 | 6.01 | 10.19 | 1.93 | 1.61 | 17.79 | 16.24 | 0.83 | 2.39 | 30.56 |
| Flower initation | 70.231±1.492 | 45.00 | 91.33 | 234.52 | 231.19 | 21.81 | 21.65 | 0.99 | 31.10 | 44.28 |
| Days taken from planting to harvest | 123.494±0.530 | 116.96 | 128.2 | 11.7133 | 11.290 | 2.77 | 2.72 | 0.96 | 6.80 | 5.50 |
| Flower/plant | 20.873±0.69 | 11.33 | 30.22 | 37.59 | 36.87 | 29.37 | 29.09 | 0.98 | 12.39 | 59.35 |
| Fruit length (mm) | 27.898±0.804 | 20.55 | 35.62 | 13.48 | 12.51 | 13.16 | 12.51 | 0.93 | 7.02 | 25.16 |
| Fruit breadth (mm) | 18.205±0.695 | 14.39 | 22.89 | 5.56 | 4.84 | 12.95 | 12.08 | 0.87 | 4.22 | 23.20 |
| No of fruit per plant | 19.618±0.634 | 12.33 | 28.22 | 29.19 | 28.59 | 27.54 | 27.25 | 0.98 | 10.90 | 55.56 |
| Average berry weight (g) | 7.298±0.076 | 6.35 | 8.67 | 0.55 | 0.54 | 10.12 | 10.03 | 0.98 | 1.50 | 20.51 |
| TSS ($^0$Brix) | 8.744±0.188 | 6.20 | 10.77 | 2.23 | 2.22 | 17.09 | 16.88 | 0.98 | 3.00 | 34.36 |
| Titratable acidity (%) | 0.938±0.019 | 0.55 | 1.13 | 0.02 | 0.02 | 15.71 | 15.52 | 0.98 | 0.30 | 31.58 |
| Total sugar (%) | 6.242±0.082 | 5.79 | 6.82 | 0.15 | 0.14 | 6.17 | 5.95 | 0.93 | 0.74 | 11.82 |
| Reducing sugar (%) | 4.702±0.124 | 3.45 | 5.71 | 0.42 | 0.40 | 13.76 | 13.37 | 0.94 | 1.26 | 26.78 |
| Non-reducing sugar (%) | 1.519±0.022 | 0.91 | 2.54 | 0.27 | 0.27 | 34.44 | 34.39 | 0.99 | 1.07 | 70.76 |
| Anthocyanin content (OD) | 0.297±0.015 | 0.14 | 0.42 | 0.01 | 0.01 | 29.13 | 29.13 | 0.95 | 0.17 | 57.16 |
| Yield per plant (g) | 146.129±6.101 | 54.24 | 270.28 | 3869.92 | 3814.09 | 42.57 | 42.26 | 0.99 | 126.30 | 86.43 |
| Yield/ hectare (MT) | 17.53±0.7311 | 6.50 | 32.43 | 55.72 | 54.92 | 42.58 | 42.27 | 0.99 | 15.16 | 86.45 |

**Table 4. Phenotypic correlation for yield and quality traits among strawberry genotypes**

| Characters | Plant Spread (cm) | Plant Height (cm) | Leaves/ Plant | Petiole Length (cm) | Flower Initiation (days) | Days Taken From Planting to harvest | Flowers/ Plant | Fruit Length (mm) | Fruit Breadth (mm) | Fruits/ Plant | TSS (°Brix) | Titretable Acidity (%) | Total Sugar (%) | Reducing Sugar (%) | Non-reducing Sugar (%) | Anthocyanin Content (OD) | Average Berry Weight (g) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Plant Spread (cm) | **1.000** | 0.552** | -0.101 | 0.558** | -0.150 | -0.294 | 0.223 | 0.121 | 0.144 | 0.178 | 0.150 | -0.039 | 0.006 | -0.133 | 0.177 | -0.388* | 0.382* |
| Plant Height (cm) | | **1.000** | 0.192 | 0.699** | -0.438** | -0.182 | 0.653** | 0.024 | 0.556** | 0.606** | 0.014 | 0.303 | -0.176 | -0.434** | 0.352* | -0.349* | 0.329* |
| Leaves/ Plant | | | **1.000** | 0.341* | -0.022 | -0.177 | 0.260 | -0.315 | 0.410** | 0.108 | 0.069 | -0.157 | -0.063 | -0.277 | 0.421** | -0.030 | -0.022 |
| Petiole Length (cm) | | | | **1.000** | -0.260 | -0.213 | 0.512** | -0.105 | 0.328* | 0.399* | 0.172 | 0.074 | -0.143 | -0.286 | 0.228 | -0.589** | 0.021 |
| Flower Initiation (days) | | | | | **1.000** | -0.449** | -0.516** | 0.537** | -0.308 | -0.570** | 0.136 | -0.499** | -0.049 | 0.072 | -0.050 | 0.315 | -0.328* |
| Days Taken From Planting to harvest | | | | | | **1.000** | 0.249 | -0.494** | -0.074 | 0.247 | -0.447** | 0.169 | -0.103 | 0.050 | -0.197 | -0.365* | -0.062 |
| Flowers/ Plant | | | | | | | **1.000** | -0.009 | 0.661** | 0.927** | -0.182 | 0.347* | -0.112 | -0.466 | 0.455** | -0.523** | 0.442** |
| Fruit Length (mm) | | | | | | | | **1.000** | -0.021 | -0.033 | 0.256 | -0.104 | 0.300 | 0.086 | 0.134 | 0.193 | 0.164 |
| Fruit Breadth (mm) | | | | | | | | | **1.000** | 0.679** | 0.241 | 0.110 | -0.108 | -0.608** | 0.645** | -0.261 | 0.555** |
| Fruits/ Plant | | | | | | | | | | **1.000** | -0.113 | 0.454** | -0.225 | -0.495** | 0.398* | -0.399* | 0.464** |
| TSS (°Brix) | | | | | | | | | | | **1.000** | -0.386* | 0.297 | -0.023 | 0.298 | 0.018 | 0.011 |
| Titratable Acidity (%) | | | | | | | | | | | | **1.000** | -0.258 | 0.139 | -0.395* | -0.119 | -0.034 |
| Total Sugar (%) | | | | | | | | | | | | | **1.000** | 0.549** | 0.022 | 0.107 | 0.099 |
| Reducing Sugar (%) | | | | | | | | | | | | | | **1.000** | -0.779** | 0.081 | -0.500** |
| Non-reducing Sugar (%) | | | | | | | | | | | | | | | **1.000** | 0.017 | 0.626** |
| Anthocyanin Content (OD) | | | | | | | | | | | | | | | | **1.000** | -0.066 |
| Average Berry Weight (g) | | | | | | | | | | | | | | | | | **1.000** |
| **Yield/ Plant (g)** | **0.299** | **0.657** | **0.243** | **0.416** | **-0.463** | **0.074** | **0.941** | **0.094** | **0.739** | **0.892** | **-0.137** | **0.248** | **-0.063** | **-0.543** | **0.585** | **-0.351** | **0.65** |

Electronic Journal of Plant Breeding, 9 (1) : 169 - 182 (Mar 2018) DOI: 10.5958/0975-928X.2018.00021.2
ISSN 0975-928X

**Table 5. Direct and indirect effect (phenotypic) of eighteen component characters on fruit yield per plant in strawberry**

| Character | Plant Spread (cm) | Plant Height (cm) | Leaves/ Plant | Petoiole Length (cm) | Flower Initation (days) | Days taken from planting toharvest | Flowers / plant | Fruit Length (mm) | Fruit Breadth (mm) | Fruits/ Plant | TSS (°Brix) | Titratable Acidity (%) | Total Sugar (%) | Reducing Sugar (%) | Non-reducing Sugar (%) | Anthocyanin Content (O D) | Average Berry Weight (g) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Plant Spread (cm) | **0.068** | 0.036 | -0.006 | 0.038 | -0.010 | -0.020 | 0.015 | 0.008 | 0.0098 | 0.012 | 0.010 | -0.003 | 0.001 | -0.009 | 0.012 | -0.026 | 0.026 |
| Plant Height (cm) | -0.047 | **-0.085** | -0.016 | -0.059 | 0.037 | 0.015 | -0.055 | -0.002 | -0.0472 | -0.051 | -0.001 | -0.026 | 0.014 | 0.037 | -0.029 | 0.029 | -0.028 |
| Leaves/ Plant | 0.004 | -0.007 | **-0.038** | -0.013 | 0.001 | 0.007 | -0.010 | 0.012 | -0.0156 | -0.004 | -0.003 | 0.006 | 0.002 | 0.011 | -0.016 | 0.001 | 0.001 |
| Petoiole Length (cm) | -0.045 | -0.056 | -0.027 | **-0.079** | 0.021 | 0.017 | -0.041 | 0.008 | -0.0262 | -0.032 | -0.014 | -0.006 | 0.011 | 0.023 | -0.018 | 0.046 | -0.002 |
| Flower Initation (days) | 0.033 | 0.097 | 0.005 | 0.058 | **-0.223** | 0.099 | 0.115 | -0.119 | 0.0686 | 0.127 | -0.030 | 0.111 | 0.011 | -0.016 | 0.011 | -0.070 | 0.073 |
| Days Taken From Planting to harvest | 0.065 | 0.040 | 0.039 | 0.047 | 0.100 | **-0.223** | -0.056 | 0.110 | 0.0166 | -0.055 | 0.099 | -0.038 | 0.023 | -0.011 | 0.044 | 0.081 | 0.014 |
| Flowers/ Plant | 0.212 | 0.620 | 0.247 | 0.486 | -0.491 | 0.237 | **0.949** | -0.009 | 0.6281 | 0.879 | -0.173 | 0.329 | -0.107 | -0.443 | 0.431 | -0.496 | 0.419 |
| Fruit Length (mm) | 0.012 | 0.002 | -0.032 | -0.011 | 0.054 | -0.049 | -0.010 | **0.100** | -0.0021 | -0.003 | 0.026 | -0.010 | 0.030 | 0.008 | 0.013 | 0.019 | 0.016 |
| Fruit Breadth (mm) | 0.029 | 0.115 | 0.085 | 0.068 | -0.064 | -0.015 | 0.136 | -0.004 | **0.2058** | 0.140 | 0.049 | 0.023 | -0.022 | -0.125 | 0.133 | -0.0534 | 0.114 |
| Fruits/ Plant | -0.001 | -0.004 | -0.001 | -0.003 | 0.004 | -0.002 | -0.006 | 0.001 | -0.0045 | **-0.001** | 0.001 | -0.003 | 0.002 | 0.003 | -0.003 | 0.003 | -0.003 |
| TSS (°Brix) | -0.022 | -0.002 | -0.010 | -0.026 | -0.020 | 0.066 | 0.027 | -0.038 | -0.0358 | 0.02 | **-0.148** | 0.057 | -0.044 | 0.003 | -0.044 | -0.003 | -0.002 |
| Titratable Acidity (%) | 0.009 | -0.071 | 0.037 | -0.017 | 0.116 | -0.039 | -0.081 | 0.024 | -0.0256 | -0.11 | 0.089 | **-0.233** | 0.060 | -0.033 | 0.092 | 0.027 | 0.008 |
| Total Sugar(%) | -0.001 | 0.016 | 0.006 | 0.013 | 0.005 | 0.010 | 0.011 | -0.028 | 0.0101 | 0.021 | -0.028 | 0.024 | **-0.094** | -0.051 | -0.002 | -0.010 | -0.009 |
| Reducing Sugar (%) | -0.007 | -0.023 | -0.015 | -0.015 | 0.004 | 0.003 | -0.025 | 0.005 | -0.0324 | -0.026 | -0.001 | 0.007 | 0.029 | **0.053** | -0.041 | 0.004 | -0.027 |
| Non-reducing Sugar (%) | -0.010 | -0.021 | -0.025 | -0.013 | 0.003 | 0.012 | -0.027 | -0.008 | -0.0378 | -0.023 | -0.018 | 0.023 | -0.001 | 0.046 | **-0.059** | -0.001 | -0.037 |
| Anthocyanin Content (o D) | -0.039 | -0.036 | -0.003 | -0.060 | 0.032 | -0.037 | -0.054 | 0.020 | -0.0267 | -0.041 | 0.002 | -0.012 | 0.011 | 0.008 | 0.002 | **0.103** | -0.007 |
| Average Berry Weight (g) | 0.036 | 0.032 | -0.002 | 0.002 | -0.032 | -0.006 | 0.043 | 0.014 | 0.0536 | 0.045 | 0.001 | -0.003 | 0.009 | -0.048 | 0.060 | -0.006 | **0.097** |
| **Yield/ Plant (g)** | **0.298** | **0.657** | **0.243** | **0.416** | **-0.465** | **0.074** | **0.941** | **0.094** | **0.7388** | **0.892** | **-0.137** | **0.248** | **-0.063** | **-0.544** | **0.586** | **-0.351** | **0.654** |
| Partial $R^2$ | 0.020 | -0.056 | -0.009 | -0.033 | 0.103 | -0.016 | 0.893 | 0.009 | 0.1521 | -0.006 | 0.020 | -0.058 | 0.004 | -0.029 | -0.034 | -0.036 | 0.063 |

R SQUARE = 0.9899 RESIDUAL EFFECT = 0.10