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Genetic variability, heritability, and genetic advance in strawberry (*Fragaria* × *ananassa* Duch.)

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Abstract: Strawberry (*Fragaria* × *ananassa* Duch.) genotypes were evaluated to study genetic variation and the relationship between yield and its component using a randomized complete block design during 2013/14. The results showed significant variance among genotypes of all traits. The phenotypic coefficient of variation (PCV) for all the characters was slightly higher than genotypic coefficient of variation (GCV), which signified the presence of environmental influence to some degree in the phenotypic expression of characters. Dry fruit weight had the highest PCV (52.47) and GCV (48.26). The estimates of narrow sense heritability (h^2) were observed to be lower than those of broad sense heritability (H^2) for all the characters. Genetic advance was recorded as maximum for fruit yield per plant (76.84), whereas genetic advance as percent of mean was highest for dry fruit weight (84.09). Highest heritability (H^2, 98.44) was coupled with higher genetic advance (76.84) estimated for fruit yield per plant, which indicated that the character is controlled by additive genes and therefore further improvement could brought by selection. Fruit yield was significantly and positively associated with most of the characters except number of leaves per plant, titratable acidity, and ascorbic acid at both genotypic and phenotypic levels; therefore, these are important prerequisites to formulate a successful improvement program.

Key words: Correlation, coefficient of variations, genetic variability, genetic advance, heritability, strawberry

1. Introduction

Strawberry (*Fragaria* × *ananassa* Duch.) is one of the most delicious fruits of the world, as a rich source of vitamins and minerals with a tantalizing aroma (Kher et al., 2010). *Fragaria* × *ananassa* (Duch.) is a natural hybrid of the South American *Fragaria chiloensis* (L.) and the North American *Fragaria virginiana* (Duch.). This intermingling of genetic characteristics has resulted in a fruit of great variety in taste and color with a cropping ability and season of such versatility that it can be grown from the tropics to the cool temperate regions of the world. Strawberry requires 22–23 °C day temperature and 7–13 °C night temperature for better growth and development (Shoemaker, 1954). It is no wonder that the strawberry is the most popular soft fruit. Two other species, *F. vesca* L. (2n = 14) and *F. moschata* Duch. (2n = 42), are also grown commercially, but on a much smaller scale (Graham et al., 1996).

For any crop improvement program, germplasm collection and assessment of genetic variability is an important step. Being a complex character, yield is influenced by a number of yields and yield-attributing characters, by environment, and by polygenes. Thus, the variability in the collections for these characters is the sum total of heredity effects of concerned genes and the influence of the environment. Hence, it is very essential to partition the observed variability into heritable and nonheritable components measured as genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), narrow sense heritability (h^2), broad sense heritability (H^2), genetic advance (GA), and genetic advance expressed as percent mean (GAM%).

Surveys of genetic variability with the help of suitable parameters such as GCV, heritability estimates, and GA are absolutely necessary to start an efficient breeding program (Atta et al., 2008). Heritability value alone may not provide clear predictability of the breeding value. Heritability in conjugation with genetic advance over mean (GAM) is more effective and reliable in predicting the resultant effect of selection (Patil et al., 1996; Ramanjinappa et al., 2011). GA is also of considerable importance because it indicates the magnitude of the expected genetic gain from one cycle of selection (Hamdi et al., 2003).

Correlation studies help in finding out the degree of interrelationship among various characters and in evolving selection criteria for improvement. The practical utility of selection of a given character as a measure of improving another character depends on the extent to which they are related and this relation depends not only on genotypic

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correlation but also on phenotypic correlation and variance (Imtiyaz et al., 2012).

Achieving a superior cultivar with satisfactory yield along with good fruit quality is an important objective for selection and further improvement. Thus, the present study was conducted in 20 genotypes of strawberry to evaluate genetic variation and correlation among 17 morphological and biochemical characters.

2. Materials and methods

2.1. Experimental site

The field experiment was conducted at the Horticultural Research Farm of Babasaheb Bhimrao Ambedkar University (26°46′N, 80°55′E, 129 m a.s.l.), Lucknow, Uttar Pradesh, India, during 2013 and 2014. The area is in the subtropical region of North India, having hot summers (May–July) and mild winters (November–January). The experimental site received rainfall of between 0 mm (November 2013) and 47 mm (January 2014) with average minimum and maximum temperature ranging between 8 °C (December 2013 and January 2014) and 31 °C (October 2013 and March 2014) (Figure). The soil of the experimental field was slightly saline with pH 7.5 and 1.5% organic matter.

2.2. Experimental design and layout

The experiment was laid out under a randomized block design with three replications. The experimental area was prepared by ploughing 30 cm deep, disk harrowing, and proper leveling. The experimental area was then divided into three blocks and each block consisted of 20 beds (2.1 × 0.9 m each) with a 0.5-m drainage channel between two blocks. The strawberry runners were planted at distances of 30 × 20 cm. Each bed contained 6 ridges (raised 20 cm above the main field) with 5 plants in each ridge, thus accommodating 30 plants in each bed.

2.3. Treatments

Twenty promising genotypes, Sweet Charlie, Winter Dawn, Camarosa, Chandler, Red Coat, Addie, Swiss, IC 319127, Gorella, Jucunda, IC 318915, Sweet Heart, Mecharenj, Fern, Red Ground, Pusa Early Dwarf, IC 319153, CH III- 40, Belruby, and IC 318916, were collected from the National Bureau of Plant Genetic Resources Regional Station (Indian Council of Agriculture Research), Nainital (29°24′N, and 79°30′E, 1480 m a.s.l.), India, and were kept for 1 day for proper acclimatization. The strawberry runners were planted during the last week of October 2013.

2.4. Intercultural operations

Intercultural operations were done frequently for getting better growth and yield. Straw mulch was applied around the strawberry plants to conserve soil moisture and to restrict weed populations. Irrigation was applied at weekly intervals in order to maintain proper moisture for better growth and development of plants. Plant protection measures were also applied uniformly for all the plots during the period of the experiment.

2.5. Harvesting

The strawberry fruits were harvested manually (hand-picking) at commercial maturity when >80% of the fruit surface turned dark red, at an interval of 3–4 days during early morning hours while the environment was cool. After harvesting, fruits were sorted immediately to get healthy and undamaged fruits. Uniform sizes and colors of fruits were selected for observation and further biochemical analysis.

2.6. Observations recorded

The observations were recorded from inner plants of each row to avoid border effects. In each bed, 12 plants were selected randomly for observations on different morphological and biochemical attributes. Data were recorded for height of plant (cm), spread of plant (cm), number of leaves per plant, leaf area index (cm^2), number

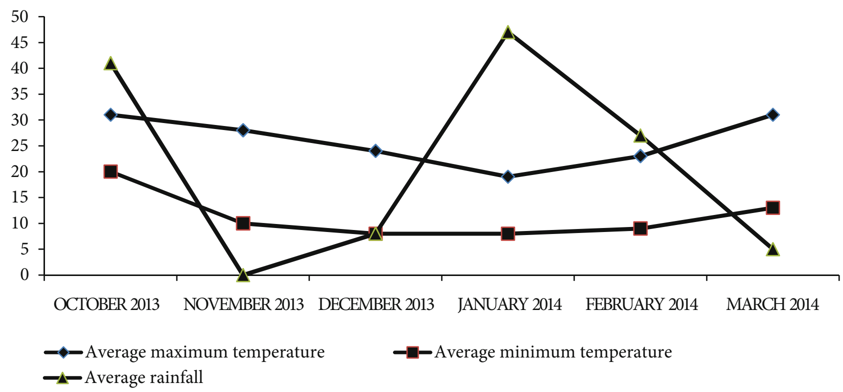

Figure. Average maximum temperature, average minimum temperature, and mean rainfall during cropping period (October 2013 to March 2014).

of flowers per plant, number of fruits per plant, total soluble solids (°Bx), titratable acidity (%), reducing sugar (%), total sugars (%), ascorbic acid (vitamin C, mg/100 g fruit), length of fruit (cm), diameter of fruit (cm), fresh fruit weight (g), volume of fruit (mL), dry fruit weight (g), and fruit yield per plant (g).

Height of plant, spread of plant, and length and diameter of fruit were recorded with the help of a digital vernier caliper, whereas number of leaves, flowers, and fruits per plant were counted very carefully from each plant kept for observation purposes. Fruit yield per plant and fresh fruit weight were measured with the help of an analytical balance. For estimating dry fruit weight, the fresh fruits were dried in a hot air oven and measured by analytical balance until no further weight loss occurred. Volume of fruit, titratable acidity, reducing sugar, total sugars, and ascorbic acid were computed as per the method suggested by Ranganna (1986). Total soluble solids (TSS) and leaf area index were determined by Erma hand refractometer and portable leaf area meter, respectively.

2.7. Data analysis

Analysis of variance using a randomized block design was done for all the characters by Windows-based computer software SPAR 1.0 (Statistical Package for Agricultural Research Ver. 1.0). Heritability in the narrow sense (h^2) and heritability in the broad sense (H^2) were estimated according to Falconer (1989). GCV and PCV to compare the variations among the traits were computed as per the method suggested by Singh and Chaudhury (1985). GA and GAM% were calculated as per the procedure recommended by Singh and Chaudhury (1985) and Allard (1960). Phenotypic and genotypic correlations were estimated using the standard procedure suggested by Miller et al. (1958) and Kashiani and Saleh (2010) from the corresponding variance and covariance components.

3. Results

The analysis of variance for characters studied during the experiment was found significant ($P < 0.05$) among the 20 strawberry genotypes (Table 1). The mean values of the characters, ranges, genotypic mean sums of squares, f-values, standard error (SE) of means, and coefficients of variation (Table 1) also showed sufficient amounts of variation for morphological and biochemical components of strawberry genotypes. The extent of variability (Table 2) among genotypes was determined in terms of PCV and GCV. The PCV for all the characters was slightly higher than the GCV. PCV was recorded as highest for dry fruit weight (52.47), followed by fresh fruit weight (45.24) and volume of fruit (44.29). Similarly, GCV was observed as highest for dry fruit weight (48.26), followed by volume of fruit (42.34) and fresh fruit weight (41.75), indicating a higher degree of genetic variability among different genotypes for these characters.

Estimates of narrow sense heritability (h^2) were recorded as generally lower than those for the broad sense among all the characters studied. The highest estimate of narrow sense heritability was found for leaf area index (73.63), whereas the highest estimate of broad sense heritability (H^2) was observed for length of fruit (98.61), followed by fruit yield (98.44) and leaf area index (97.90). GA was found maximum for fruit yield per plant (76.84), followed by leaf area index (18.11) and volume of fruit (13.40), whereas GAM% was observed highest for dry fruit weight (84.09), followed by volume of fruit (83.39) and fresh fruit weight (79.39). Highest heritability (H^2) (98.44) coupled with higher GA (76.84) was recorded for fruit yield per plant.

Fruit yield was significantly and positively associated with most of the characters except number of leaves per plant, number of fruits per plant, titratable acidity, and ascorbic acid, both at genotypic and phenotypic level (Table 3). At the genotypic level, strong positive and significant associations of plant spread, number of flowers per plant, number of fruits per plant, total sugars, and diameter of fruit were recorded with fresh fruit weight. Height of plant showed the highest positive and significant correlation with leaf area. Total soluble solids, fruit length, fresh fruit weight, and fruit volume had strong positive and significant correlations with dry fruit weight. Titratable acidity and reducing sugar showed the highest positive significant associations with reducing sugar and total sugars, respectively. On the contrary, height of plant, spread of plant, leaf area, total soluble solids, reducing sugar, and total sugars indicated strong negative and significant correlations with ascorbic acid. Similar associations was also observed between number of leaves per plant and reducing sugar, titratable acidity, and total sugars, and between ascorbic acid and fresh fruit weight.

At the phenotypic level, strong positive and significant correlation of height of plant and spread of plant was observed with leaf area. Leaf area, titratable acidity, reducing sugar, and fruit volume had strong positive and significant associations with total soluble solids, ascorbic acid, total sugars, and dry weight, respectively. Total soluble solids and fruit length indicated strong positive and significant correlations with diameter of fruit, whereas total sugars, diameter of fruit, and fresh fruit weight indicated similar associations with fruit volume. On the other hand, height of plant, spread of plant, and leaf area showed the highest negative and significant correlations with titratable acidity, whereas total soluble solids, reducing sugar, and total sugars showed similar correlations with ascorbic acid. Number of fruits per plant and titratable acidity had strong negative and significant associations with total soluble solids and total sugars, respectively.

Table 1. Analysis of variances for different morphological and bio-chemical traits in strawberry.

S. no.	Characters	Mean	Range		Genotypic mean sum of square	F-value	SE	CV
			Minimum	Maximum				
1	Height of plant (cm)	9.68	8.04	10.59	1.55	5.96	0.2944	5.27
2	Spread of plant (cm)	20.65	18.07	22.39	3.42	12.18	0.3059	2.56
3	Number of leaves per plant	10.31	9.47	10.73	2.81	11.08	0.2911	4.88
4	Leaf area index (cm^2)	26.36	6.94	37.57	237.82	135.65	0.7644	5.02
5	Number of flowers per plant	8.88	8.18	9.29	1.42	13.34	0.1889	3.68
6	Number of fruits per plant	5.99	4.84	6.73	0.84	9.84	0.1691	4.88
7	Total soluble solids (°Bx)	8.09	6.48	9.45	2.25	51.35	0.1208	2.58
8	Titratable acidity (%)	0.73	0.70	0.82	0.0032	22.57	0.0070	1.63
9	Reducing sugar (%)	3.51	3.24	3.63	0.037	19.97	0.025	1.23
10	Total sugars (%)	4.44	4.19	4.55	0.035	21.78	0.023	0.91
11	Ascorbic acid (mg/100 g fruit)	66.9	62.67	73.6	24.76	10.87	0.8715	2.25
12	Length of fruit (cm)	4.3	3.38	5.35	0.91	89.18	0.0585	2.36
13	Diameter of fruit (cm)	3.01	2.03	4.09	0.94	113.35	0.0527	3.02
14	Fresh fruit weight (g)	16.11	3.66	29.71	143.70	18.26	1.61	17.40
15	Volume of fruit (mL)	16.07	3.57	29.60	143.33	18.04	1.62	17.53
16	Dry fruit weight (g)	1.32	0.30	2.56	1.14	12.29	0.1764	23.54
17	Fruit yield per plant (g)	109.85	23.27	139.59	4261.77	193.85	2.70	4.26

Table 2. Estimates of genetic parameters for morphological and biochemical components in strawberry.

S. no.	Characters	PCV	GCV	h^2	H^2	GA	GAM%
1	Height of plant (cm)	8.58	6.78	31.39	62.44	1.07	11.05
2	Spread of plant (cm)	7.01	5.06	32.83	52.10	1.56	7.52
3	Number of leaves per plant	9.39	8.96	67.45	90.97	1.76	17.08
4	Leaf area index (cm^2)	34.07	33.71	73.63	97.90	18.11	68.70
5	Number of flowers per plant	7.77	7.47	54.37	92.42	0.90	10.21
6	Number of fruits per plant	9.97	8.39	47.65	74.81	0.90	15.03
7	Total soluble solids (°Bx)	10.99	10.64	56.10	93.73	1.72	21.26
8	Titratable acidity (%)	4.75	4.39	47.82	85.42	0.06	8.22
9	Reducing sugar (%)	3.35	3.07	48.57	83.98	0.20	5.70
10	Total sugars (%)	2.56	2.40	47.76	87.89	0.21	4.73
11	Ascorbic acid (mg/100 g fruit)	4.67	4.09	33.59	76.70	4.94	7.38
12	Length of fruit (cm)	12.92	12.83	64.21	98.61	1.13	26.28
13	Diameter of fruit (cm)	18.80	18.04	49.56	92.08	1.14	37.87
14	Fresh fruit weight (g)	45.24	41.75	51.42	85.17	12.79	79.39
15	Volume of fruit (mL)	44.29	42.34	61.20	91.39	13.40	83.39
16	Dry fruit weight (g)	52.47	48.26	39.17	84.60	1.11	84.09
17	Fruit yield per plant (g)	34.49	34.22	65.34	98.44	76.84	69.95

PCV: Phenotypic coefficient of variation, GCV: genotypic coefficient of variation, h^2: narrow sense heritability, H^2: broad sense heritability, GA: genetic advance, GAM%: genetic advance as percent of mean.

Table 3. Genotypic and phenotypic correlation coefficients of 17 traits in strawberry genotypes.

		PH	PS	NL	LA	NF	NFr	TSS	TA	RS	TS	AA	FrL	FrW	FrWt	FrV	DW	YP
PH	G	1	0.926 **	−0.827*	0.997**	0.692**	0.456*	0.962**	−0.874**	0.981**	0.987**	−0.889**	0.805**	0.831**	0.910**	0.894**	0.824**	0.622**
	P	1	0.721**	−0.149	0.792**	0.154	−0.353	0.693**	−0.635**	0.785**	0.699**	−0.579**	0.627**	0.632**	0.640**	0.666**	0.639**	0.794**
PS	G		1	0.771**	0.945**	0.581**	−0.570**	0.939**	0.944**	0.905**	0.922**	−0.811**	0.892**	0.917**	0.995**	0.986**	0.847**	0.504**
	P		1	0.091	0.681**	0.221	−0.329	0.644**	−0.590**	0.657**	0.573**	−0.522**	0.634**	0.657**	0.626**	0.637**	0.568**	0.718**
NL	G			1	−0.747**	0.494*	−0.654**	−0.315	0.811**	−0.849**	−0.467*	0.686**	0.911**	0.738**	0.122	0.209	0.321*	−0.778**
	P			1	−0.095	0.135	−0.125	0.031	0.219	−0.188	−0.291	0.268	0.101	0.054	0.071	0.061	0.137	−0.168
LA	G				1	0.524**	−0.583**	0.896**	0.791**	0.895**	0.858**	−0.763**	0.825**	0.847**	0.897**	0.886**	0.876**	0.945**
	P				1	0.177	−0.519**	0.856**	−0.732**	0.811**	0.802**	−0.663**	0.809**	0.828**	0.823**	0.845**	0.768**	0.926**
NF	G					1	0.738**	0.623**	−0.311	0.451*	0.383*	0.252	0.781**	0.805**	0.868**	0.861**	0.818**	0.527**
	P					1	0.418*	0.229	−0.082	0.082	0.056	−0.032	0.281	0.275	0.291	0.295	0.274	0.204
NFr	G						1	−0.788**	0.141	−0.251	−0.151	0.182	0.563**	0.535**	0.683**	0.678**	−0.480*	0.542**
	P						1	−0.664**	0.139	−0.195	−0.139	0.123	0.429*	0.415*	0.514**	0.444*	−0.325*	0.444*
TSS	G							1	−0.617**	0.783**	0.693**	−0.693**	0.922**	0.919**	0.925**	0.914**	0.934**	0.861**
	P							1	−0.568**	0.708**	0.627**	−0.605**	0.882**	0.888**	0.814**	0.830**	0.781**	0.821**
TA	G								1	0.991**	−0.963**	0.909**	−0.582**	−0.605**	−0.701**	−0.694**	−0.584**	−0.919**
	P								1	−0.825**	−0.827**	0.741**	−0.533**	−0.536**	−0.569**	−0.587**	−0.447	−0.839**
RS	G									1	0.979**	−0.988**	0.642**	0.655**	0.742**	0.734**	0.649**	0.975**
	P									1	0.886**	−0.842**	0.589**	0.609**	0.617**	0.633**	0.540**	0.887**
TS	G										1	−0.906**	0.596**	0.613**	0.713**	0.708**	0.613**	0.952**
	P										1	−0.773**	0.556**	0.582**	0.622**	0.641**	0.471*	0.894**
AA	G											1	−0.527**	−0.534**	−0.604**	−0.599**	−0.524**	−0.852**
	P											1	−0.456	−0.463	−0.481	−0.497	−0.394	−0.756**
FrL	G												1	0.832**	0.977**	0.963**	0.981**	0.807**
	P												1	0.976**	0.896**	0.917**	0.863**	0.795**
FrD	G													1	0.991**	0.977**	0.989**	0.826**
	P													1	0.880**	0.903**	0.833**	0.808**
FrWt	G														1	0.507**	0.982**	0.875**
	P														1	0.988**	0.934**	0.803**
FrV	G															1	0.989**	0.869**
	P															1	0.921**	0.820**
DW	G																1	0.802**
	P																1	0.705**
YP	G																	1
	P																	1

*, **: Significant at 0.05 and 0.01 levels, respectively.

PH: Height of plant, PS: spread of plant, NL: number of leaves per plant, LA: leaf area index, NF: number of flowers per plant, NFr: number of fruits per plant, TSS: total soluble solids, TA: titratable acidity, RS: reducing sugar, TS: total sugars, AA: ascorbic acid, FrL: length of fruit, FrD: diameter of fruit, FrWt: fresh fruit weight, FrV: fruit volume, DW: dry fruit weight, YP: fruit yield per plant.

4. Discussion

The significant value of the genotypic mean sum of squares indicating the presence of environmental influence resulted in variation for all the characters among genotypes of strawberry, which can be improved by further breeding techniques. Heritable variation is useful for permanent genetic improvement (Singh, 2000). The most important function of heritability in the genetic study of quantitative characters is its predictive role to indicate the reliability of the phenotypic value as a guide to breeding value (Dabholkar, 1992; Falconer and Mackay, 1996). The GCV, along with heritability estimates, provides reliable estimates of the amount of GA to be expected through phenotypic selection (Burton, 1952).

PCV was found higher than GCV for all the characters studied, which signifies the presence of environmental influence to some degree in the phenotypic expression of characters. High GCV, along with high heritability and high GA, provides better information than single parameters alone (Baye et al., 2005). PCV and GCV with higher value specified that the genotypes show evidence of much variation among themselves with respect to morphological and biochemical characters. Lowest values of PCV and GCV indicate that the genotypes do not show much variation among themselves with respect to these morphological and biochemical characters. Similar findings were reported by Singh et al. (2008) and Punetha et al. (2011). The variation in different characters studied indicates the presence of environmental influence. Hancock and Bringhurst (1988) determined sufficient variation for fruit size in different strawberry cultivars. Similar results are also confirmed with the findings of Recupero et al. (1989). Moore et al. (1970) reported that differences in fruit size are primarily due to plant vigor, competition among fruits in the inflorescence, number and size of developed achenes, differences in activity among the achenes in the production of growth material, climatic conditions, irrigation, and plant nutrients. Estimates of narrow sense heritability were lower than those for broad sense heritability among all the characters studied, suggesting a significant nonadditive genetic contribution to total genetic variance. This nonadditive component could consist of dominance, epistatic, or maternal variance (Lynch and Walsh, 1998). High heritability estimates for the characters indicate less influence of the environment, and so there is a good scope for the improvement of these traits through direct selection (Kumar et al., 2012). Higher heritability (H^2) coupled with high GA was observed for fruit yield per plant, which may be due to the additive gene action, and thus selection would be effective for this character. Similar results were also reported by Sah et al. (2010). Ara et al. (2009) reported that the high heritability (H^2) coupled with high GA for number of flowers and number of fruits in each year indicated that these characters were controlled by additive genes and effective selection could be made for these parameters. The estimate of GA is more useful as a selection tool when considered jointly with heritability estimates (Johnson et al., 1955). High values of GA are indicative of additive gene action, whereas low values are indicative of nonadditive gene action (Singh and Narayanan, 1993). Thus, the heritability estimates will be reliable if accompanied by high GA.

The genotypic correlation coefficients of fruit yield per plant and yield-contributing characters were higher than phenotypic correlation coefficients in most cases, indicating that the effects of environment suppressed the phenotypic relationship between these characters. In earlier studies, fruit yield was significantly and positively associated with most of the characters (Lacey, 1973; Webb et al., 1974; Guttridge and Anderson, 1981; Nielson and Eaton, 1983; Olsen et al., 1985; Strik and Proctor, 1988; Biswas et al., 2007). Mir et al. (2009) also observed positive and significant correlations between yield per plant and height of plant, spread of plant, fruit weight, fruit diameter, fruit volume, and number of fruits per plant. Rai et al. (2001) also observed positive and significant correlations between yield/plant and fruit length, fruit girth, and fruit weight of litchi. Similar reports were also suggested by Chaubey and Singh (1994) and Ojo et al. (2006). In a few cases, phenotypic correlation coefficients were the same as or higher than the genotypic correlation coefficients, indicating that both environmental and genotypic correlations in these cases acted in the same direction and finally maximized their expression at the phenotypic level.

Consequently, the present study illustrated the existence of wide ranges of variations for most of the characters among the strawberry genotypes, which provides opportunities for genetic gain through selection or hybridization. Fruit yield per plant, volume of fruit, fresh fruit weight, and diameter of fruit had high heritability along with high GA and, therefore, further improvement could be brought about by selection. Fruit yield showed strong positive and significant correlations with most of the characters. Thus, selection may be possible for these characters for improving yield.

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