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G × E Interaction for Growth, Yield and Quality Characters of Strawberry (*Fragaria ananassa* Duch.) under Bangladesh Conditions

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Abstract. A multi location trial with five promising strawberry genotypes *viz*., Sweet Charlie, Festival, Camarosa, FA 008 and BARI Strawberry-1 was conducted under different sub tropical climatic conditions of Bangladesh to study their G × E interaction. Location were Gazipur, Rajshahi and Chittagong during the period from August 2009 to May 2011. Combined analysis of variance indicated significant variation among the genotypes as well as location for almost all the characters studied. Genotype × environment studies indicated different response of genotypes over locations for most of the characters suggesting location wise environmental variation. Stability parameter revealed that a particular genotype did not perform consistently for all the characters. The genotype Festival considered as stable for most of the characters except days to flowering and ascorbic acid content of fruits, and considered as stable over different locations. For this reason, the genotype 'Festival' could be well thought-out and less receptive to the environmental conditions and might be recommended for all environments. On the other hand, environmental indices indicated that the environment of Rajshahi was found to be most favourable for strawberry cultivation followed by that of Gazipur and Chittagong.

Keywords: G × E interaction, strawberry, environmental indices, adaptability, phenotypic index

Introduction

Strawberry (*Fragaria ananassa* Duch.) belonging to the family *Rosaceae* is an exotic fruit with high market potentiality in Bangladesh. At present, it is successfully cultivated in Bangladesh. According to WHO, per capita requirement of fruits in Bangladesh is 115 g but it is only 78 g, much below than minimum requirement. Most of the fruits become unavailable in Bangladesh during November to April. While, strawberries become on hand in this country from October to April. Hence, strawberry may help to increase the availability of fruits in this lean period of the year (Ahmad and Uddin, 2012). However, introduction of strawberry plants in a new area like Bangladesh need significant environmental interaction as yield stability under a wide range of environmental condition is very important for the adaptation of a new variety.

The yield of a crop plant is a quantitative character and generally influenced by environmental variation (Islam *et al*., 2011). An ideal variety is one that has high mean yield but a low degree of fluctuation in performance when grown over diverse environment (Sabaghpour *et al*., 2012). Hence, testing for genotype × environment interaction has become an important task in most of the breeding programmes. The growth, yield and quality of strawberry in response to different production sites are genotype specific (Crespo, 2010). On the other hand, level of stability for a particular genotype is not consistent for all the characters (Alam *et al*., 1996; Mondol and Alam, 1992). Moreover, recent studies for yield and fruit quality suggested that the genotype specific environmental response is very important (Carbone *et al*., 2009; Davik *et al*., 2006). Therefore, genotypes × environment interaction studies are important for selecting widely adopted and location specific varieties. The genotype × environment interaction effect of a variety is partitioned into two components, a) the linear response to environmental effects and the b) deviation from the linear response. Assessment of stability of a genotype under

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different environments is useful for recommending cultivars for known conditions of cultivation (Scapim *et al*., 2000). Stability parameters are useful tools for identification of genotypes with specific and wide adaptations, and contrasting the role played by genotype, environment and their interaction in multi location trials of variety (Bantayehu, 2009).

Thus genotype environment interactions may play an important role and help to select widely adapted as well as location specific varieties more efficiently. Hence, the present study was undertaken to study the genotypes × environment interaction as well as stability performance of selected strawberry genotypes in Bangladesh.

Materials and Methods

Experimental site, design and layout. Five promising strawberry genotypes- Sweet Charlie, Festival, Camarosa, FA 008 and BARI Strawberry-1 were cultivated in three different locations of Bangladesh *viz*. Fruit Research Field of Pomology Division, Horticulture Research Centre, BARI, Gazipur; Fruit Research Station, Binodpur; Rajshahi and Agricultural Research Station, Pahartali; Chittagong during the period from August 2011 to May 2012. The geographical locations, climatic conditions and characteristics of soils at three different locations are given in Table 1. The experiment was laid out in a randomised complete block design (RCBD) with four replications. The unit plot size was 100 × 280 cm and the plants were spaced at 50 × 40 cm on beds. Beds were raised 30 cm above the main field with 50 cm drain in-between 2 beds. Each plot contained double row accommodating 14 plants. Daughter plants of strawberry were planted on September 17, 2011.

Establishment of daughter plants. The daughter plants were raised from the runners of mother plants. After 15-20 days the runners were collected and established in poly bags filled up with sterilised 33% sand, 33% coco dust and 33% decomposed cow dung. The established daughter plants were used as saplings. The saplings were categorised according to the age, size, shape and number of leaves. The saplings of 30 to 35 days old were selected for planting in the experimental field.

Observations recorded. Data were collected from guarded plants from each row to avoid border effect. In each unit plot, five plants were selected randomly for data capture. The data were recorded on different parameters such as:

Fruits per plant. The average value of the total number of fruits per plant harvested at different dates from the five selected plants was counted and taken as fruits per plant.

Table 1. Soil and climatic conditions of different locations in strawberry cultivation

Factors	District		
	Site-1 Gazipur	Site-2 Rajshahi	Site-3 Chittagong
Geographical location			
Altitude (m)	14.33	21.64	16.46
Latitude	23° 59' N	24° 22' N	22° 21′ N
Longitude	90° 24' E	88° 39' E	91° 48′ E
Climatic condition during cropping period			
Cumulative rainfall (mm)	108	69.4	98
Moisture content (%)	79.4	76.3	72.6
Mean temperature (Max.) °C	25.89	25.43	30.63
Mean temperature (Min.) °C	17.05	16.38	21.54
Characteristics of soil			
AEZ*	28	11	23
Soil tract	Madhupur tract	High Ganges river flood plain	Chittagong costal plains
Lad type	High	Medium	High
Texture	Clay loam	Sandy loam	Silt loam
pH	4.8-5.5	6.1-7.9	5.5-6.2
Organic matter	Low	Low	Very low
Nitrogen	Very low	Low	Low
Phosphorus	Very low	Low	Low
Potassium	Low	Medium	Medium

*AEZ = agro ecological zones; source: BBS (2011); BARC (2005).

Days to flowering. It was estimated as the number of days required from planting to first flower opening of the 50% plants per plot of each replication.

Harvest duration. It was estimated as the number of days required from first fruit harvest to completion of fruit harvest of 5 randomly selected plants from each plot under different genotypes and means were calculated.

Plant mortality (%). The dead plants were recorded from each plot at 10 days after planting to 10 days before last harvesting and the plant mortality was calculated by using the following formula:

$$\text{Plant mortality (\%)} = \frac{\text{Dead plants during 10 days after planting to 10 days before last harvest}}{\text{Total number of plants being planted}} \times 100$$

Yield (t/ha). Total weight of fruits from 5 randomly selected plants from each plot under different genotypes was counted and then average value was calculated after that it was converted at tonne per hactare.

Ascorbic acid. For ascorbic acid measurement, 10 g pulp tissue was homogenised in 50 mL of 3% cold metaphosphoric acid (HPO_3) using a blender for 2 min and filtered through Whatman filter paper No. 2. The clear supernatant was collected for assaying ascorbic acid by 2, 6-dichlorophenolindophenol titration following the method of Rangana (1986). Aliquot (10 mL) was titrated with 0.1% 2,6-dichlorophenolindophenol solution until the filtrate changed to pink colour persisted for at least 15 sec and the titration volume was recorded. Prior to titration 2, 6-dichlorophenolindophenol solution was calibrated by ascorbic acid standard solution. Ascorbic acid content was calculated according to the titration volume of 2, 6-dichlorophenolindophenol and results were expressed as mg/100 g fresh weight.

Data analysis. The data were subjected to combined analysis and then stability parameters *viz*. phenotypic index (P_i), regression co-efficient (b_i) and deviation from regression (S^2_{di}) and environmental index (I_j) were estimated following Eberhart and Russell's model (1966). The model to study the stability of genotypes under different locations was as follows:

$$Y_{ij}=m+b_iI_j+\delta_{ij}$$

where:

Y_{ij} = Mean of the i^{th} genotype in j^{th} location
m = Mean of all the varieties over the locations
b_i = The regression co-efficient of the i^{th} genotype on the environmental index which measures the response of this genotype to varying environments
I_j = The environmental index which is defined as the deviation of the mean of all the genotypes at a given location from the overall mean
δ_{ij} = The deviation from regression of the i^{th} genotypes at j^{th} environment.

The environmental index was estimated as follows:

$$I_j = \frac{\sum_i Y_{ij}}{t} - \frac{\sum_i\sum_j Y_{ij}}{ts}$$

where:

t = Number of genotypes
m = Mean of all the varieties over the locations
s = Number of locations.

The regression coefficient was estimated as follows:

$$b_i = \sum_i Y_{ij} I_j \Big/ \sum_j I_j^2$$

where:

$\sum_j Y_{ij} I_j$ = is the sum of the product
$\sum_j I_j^2$ = is the sum of squares

Deviation from regression was estimated as follows:

$$S^2_{di} = \frac{\sum_j \delta_{ij}}{(S-2)} - \frac{S_e^2}{r}$$

where:

$$\sum \delta_{ij} = [\sum_j Y^2_{ij} - Y^2_j \big/ t] - (\sum Y_{ij} I_j)^2 \Big/ \sum_j I_j^2$$

S_e^2 = the estimate of pooled error.

Results and Discussion

Combined analysis of variance. The results pertaining to combined analysis of variances for stability are presented in Table 2. The mean squares for the genotypes and environments (locations) were significantly different from each other which revealed the presence of genetic variability under studied characters (Islam *et al*., 2011). The genotype × environment interactions for all the characters except days to flowering were noted significant when tested against pooled error. The significant genotypes × environment interactions indicated the presence of differences among the regression of the

Table 2. Combined analysis of variance for growth, yield contributing, yield and quality characters of strawberry

Source of variation	df	Mean sum of squares for different characters					
		Fruits/plant	Days to flowering	Harvest duration	Plant mortality	Yield (t/ha)	Ascorbic acid (mg/100 g)
Environment (Locations)	2	52.87**	207.62**	423.72**	12.29**	17.86*	22.22 ns
Genotype	4	88.46**	355.36**	207.73**	3.40**	162.87**	9.500 ns
Genotype x Environment	8	16.47**	2.28 ns	14.88**	33.51**	9.67**	194.08**
Environment + (G × E)	17	4.96**	3.27*	3.08**	11.92 ns	1.17*	4.32*
Environment (linear)	1	6.41*	3.99*	3.63*	15.32*	1.59*	5.52*
G × E (linear)	5	1.83*	5.22*	8.63**	0.80**	4.99*	2.35 ns
Pooled deviation	9	0.79*	0.14**	0.06*	4.24**	0.08 ns	0.51 ns
Pooled error	16	0.66	0.58	0.49	0.84	0.33	0.69

**, * = significant at 1%, 5% level, respectively; ns = non-significant.

genotypes on environmental indices (Islam *et al*., 2011). The presence of significant genotype × environment interaction showed the inconsistency of performance of strawberry genotypes across the environments suggesting the data might be extended for stability analysis (El–Hashash and El-Absy, 2013). The mean squares for all the characters except plant mortality were significant for location + (genotype × location) which indicated very minute deviation from regression (Islam *et al*., 2011). While insignificant plant mortality indicated that locations were not statistically diverse and the genotypes did not perform differently across the dissimilar locations for this character (Alam *et al*., 1996). Sarker *et al*. (2002) also found similar results on stability for grain yield of rice.

Significant mean squares due to environments (linear) indicated the difference between the locations. Both linear portion of environment as well as G × E interaction were found significant for characters studied indicated that the genotypes responded well under seasonal fluctuation (b_i) and to their stability (S^2_{di}). Significant linear component indicated the presence of differences among the regression values of the genotypes on the environmental indices (Islam *et al*., 2011). These results were confirmed with earlier studies of Makanda *et al*. (2009) who observed the influence of seasonal differences on yield. The significant environment as well as genotype × environment suggest relatively complex kind of interaction (Mahendra, 2012). Most of the traits found significant for the non linear components (pooled deviation) except yield (t/ha) and ascorbic acid content (mg/100 g). Insignificant non linear components for the traits indicated the stability of the genotypes with the change of location. Chaudhary *et al*. (1994) stated that pooled deviation were significant when tested against pooled error mean square indicating that both linear and nonlinear portions accounted for G × E interaction. The non-linear component was also found insignificant for all the characters in upland cotton (Alam *et al*., 1996).

Stability analysis. Regression coefficient and deviation from regression of a variety on the environmental indices, measure the response of varieties in various environments (El-Hashash and El-Absy, 2013). Eberhart and Russell (1966) emphasized the need of considering both linear (b_i) and non-linear (S^2_{di}) components of genotype × environment interaction for assessing the stability. Contrarily Jatasra and Paroda (1980) had the opinion that the linear regression (b_i) could simply be related merely as a measure of response whilst its deviation (S^2_{di}) should be a better measure of stability. The stability parameters mean ($\bar{x}$), phenotypic index (P_i), regression co-efficient (b_i) and deviation from regression (S^2_{di}) for the characters are presented in Table 3. According to the method of Eberhart and Russell (1966), the genotype is stable if its yield is high, the regression co-efficient is around unit (b_i=1) and least deviation from the regression (S^2_{di}=0).

Fruits/plant. Considering fruits per plant, Sweet Charlie exhibited highest (3.42) and BARI Strawberry-1 lowest (-2.08) phenotypic index (p_i) value for fruits/plant. The regression co-efficient (b_i) values of Camarosa and BARI Strawberry-1 were significantly different from unity ($b_i \neq 1$) and were sensitive to adverse environment (Mahendra, 2012). On the other hand Sweet Charlie, Camarosa and BARI Strawberry-1 were significantly different from zero, indicating linear prediction of these genotypes was not possible (Rahman, 2004). Among

Table 3. Estimates of mean and stability parameters for growth, yield contributing, yield and quality characters of strawberry

Genotype	Stability component	Fruits/plant	Days to flowering	Harvest duration	Plant mortality	Yield (t/ha)	Ascorbic acid (mg/100 g)
Sweet Charlie	$\bar{x}$	39.17	74.42	90.17	15.25	16.55	78.75
	p_i	3.42	0.85	3.77	1.50	2.18	4.55
	b_i	1.00	0.88	1.00	0.96	0.93	0.23*
	S^2_{di}	3.42**	0.39	3.77**	1.56*	2.34*	19.45**
Festival	$\bar{x}$	35.75	76.83	90.08	16.50	15.68	77.25
	p_i	0.00	3.27	3.68	2.75	1.31	3.05
	b_i	0.99	0.92	1.00	0.99	0.91	0.96
	S^2_{di}	0.00	3.84**	0.69	0.60	0.62	3.18*
Camarosa	$\bar{x}$	36.83	78.00	81.33	14.33	16.13	73.25
	p_i	1.08	4.43	-1.25	0.58	1.76	-0.95
	b_i	0.47**	0.94	0.95	0.97	0.86*	0.99
	S^2_{di}	2.33*	4.69**	-0.62	2.78**	2.05*	-0.96*
FA 008	$\bar{x}$	33.33	68.08	81.33	10.33	11.21	71.33
	p_i	-0.33	-2.42	-1.25	-200	-1.09	0.92
	b_i	1.00	0.98	0.95	0.97	0.99	0.90
	S^2_{di}	-0.33	-2.48*	-2.02*	-2.06**	-2.09*	1.02*
BARI Strawberry-1	$\bar{x}$	33.67	70.50	82.58	12.33	12.30	70.42
	p_i	-2.08	-3.07	-3.82	-1.42	-2.08	-3.78
	b_i	0.82*	0.59**	0.97	1.00	0.39**	0.80*
	S^2_{di}	-2.56*	-5.22**	-3.95**	-1.42*	-5.28**	-4.73**

**, * = significant at 1%, 5% level, respectively.

the genotypes, Festival exhibited acceptable mean ($\bar{x}$), minimum p_i (0.00) value and deviation from regression (S^2_{di}) was 0, with regression co-efficient (b_i) near to unity (0.99) and considered to be highly adaptive at any environments which is in line with Abdelrahman and Abdalla (2006). FA 008 had excellent regression co-efficient (b_i=1) and deviation from regression was least (-0.33) but minimum mean ($\bar{x}$) indicating poor yielder with less responsive to unusual change in the location (Table 3) and considered to be adapted to poor environments (Islam *et al*., 2011).

Days to flowering. Among the five strawberry genotypes, FA 008 and BARI Strawberry-1 exhibited negative phenotypic index (p_i) for days to flowering suggesting the earliness, whereas remaining genotypes had positive phenotypic index for this trait (Rahman, 2004). Based on days to flowering, none of the genotype was found fairly stable, because deviation from regression (S^2_{di}) of most of the genotypes was significantly different from zero and linear prediction of these genotypes was not possible. Only Sweet Charlie exhibited insignificant and considered as stable under diverse environment (Mahendra, 2012). The b_i of Sweet Charlie, Camarosa and FA 008 was insignificant and near to unity ($b_i \approx 1$) indicating stable to environmental change (Islam *et al*., 2011). The genotypes Sweet Charlie was considered as comparatively stable to environmental variation for days to flowering due to acceptable mean ($\bar{x}$), considerable phenotypic index, regression co-efficient and insignificant deviation from regression ($S^2_{di} \approx 0$). While, Festival, Camarosa and FA 008 were also noted stable due to insignificant b_i value ($b_i \approx 1$) but their significant S^2_{di} invalided its stability prediction (Table 3). In an earlier study, Mahendra (2012) considered S^2_{di} to be the most appropriate criterion for measuring phenotypic stability in an agronomic sense.

Harvest duration. Out of five, three genotypes namely; Camarosa, Festival and BARI Strawberry-1 had negative p_i, indicating shorter harvest duration. The remaining genotypes, exhibited positive phenotypic index (p_i) confirming longer harvest duration. Rahman (2004) stated that positive p_i indicates the favourable environment for harvest duration. The genotypes Sweet Charlie, FA 008 and BARI Strawberry-1 exhibited regression coefficient near to unity (b_i=1), but S^2_{di} were significantly different from zero, so linear prediction of these two genotypes was not possible indicating the responsiveness of the genotypes to unusual change in the location (Rahman, 2004). Among the genotypes Festival and Camarosa were more stable for harvest duration due to maximum mean ($\bar{x}$) couple with b_i near to unity and insignificant S^2_{di} (S^2_{di}≈0). According to Mahendra (2012) and Abdelrahman and Abdalla (2006) an ideal cultivar is the one with a high mean, a unity regression coefficient (b_i=1) and low deviation from regression (S^2_{di}=0).

Plant mortality(%). Among the five strawberry genotypes, FA 008 and BARI Strawberry-1 exhibited negative p_i for plant mortality. It represent the survival of plants to adverse climatic condition, remaining genotypes had positive phenotypic index for this trait. Based on plant mortality (%), no one genotype was found fairly stable except Festival. The S^2_{di} value of most of the genotypes was significantly different from zero, so liner prediction of these genotypes was not possible. Only Festival was insignificant and was stable under environmental changes. The b_i value of all the genotypes was insignificant and near to unity (b_i≈1) indicating stable to environmental change (Islam *et al*., 2011). The genotype Festival was found comparatively stable to environmental variation for percent plant mortality due to satisfactory mean value ($\bar{x}$), considerable p_i, insignificant b_i and S^2_{di} (Table 3). The genotypes having high mean value, b_i near to unity (b_i=1) with minimum S^2_{di} are considered as stable for this trait (Abdelrahman and Abdalla, 2006).

Yield (t/ha). According to the method of Eberhart and Russell (1966), the genotype is stable if its yield is high, the regression coefficient is around unit (b_i≈1) and the deviation from the regression is as small as possible (S^2_{di}≈0). Based on yield t/ha, three genotypes namely Sweet Charlie, Festival and Camarosa exhibited positive p_i, while rest two genotypes had negative p_i (Table 3). Rahman (2004) stated that positive phenotypic index is responsible for higher yield in snake gourd, which is in agreement with the present findings. Fruit yield is the main character and among the genotypes, Festival exhibited acceptable mean (15.68), minimum p_i value (1.31) and S^2_{di} was close to 0, with b_i near to unity (0.91) and considered to be highly adaptive at any environment. The genotype Camarosa exhibited acceptable mean ($\bar{x}$), insignificant b_i but the S^2_{di} was not significantly different from 'zero' indicating less fluctuation of genotype to change in environments (Lin *et al*., 1986). Considering yield (t/ha), Sweet Charlie produced higher mean ($\bar{x}$), the b_i value nearer to 'unity' but S^2_{di} was high, indicating responsiveness of the genotype to unusual changes in the location (Mahendra, 2012; Alam *et al*., 1996).

Ascorbic acid. Among the genotypes, the p_i was found to be positive for fruit weight of Sweet Charlie, Festival and FA 008 indicating rich in ascorbic acid content. Considering ascorbic acid content, among the genotypes Festival, Camarosa and FA 008 had considerably higher mean ($\bar{x}$) and insignificant b_i differed from unity and considered to be less affected by environments for ascorbic acid content. But, in all the genotypes, S^2_{di} were significantly different from zero (Table 3), indicating wide fluctuation to change in environments.

Environmental component. The estimates of environmental indices (I_j) of the studied characters are presented in Table 4. The performance of crops was directly reflected by the favourable and unfavourable environments in terms of positive and negative I_j, respectively. The environmental index (I_j) for fruits/plant, days to flowering, harvest duration, plant mortality (%), yield

Table 4. Estimates of environmental index and environmental mean for plant growth and fruit yield of strawberry

Location	Environmental component	Fruit/plant	Days to flowering	Harvest duration	Plant mortality	Yield (g/plant)	Ascorbic acid (mg/100 g)
Gazipur	E. mean (e_j)	37.20	72.85	85.85	17.15	13.96	73.00
	E. index (I_j)	1.45	-0.72	-0.55	3.40	-0.42	-1.20
Rajshahi	E. mean (e_j)	36.55	76.25	91.00	1150	15.98	75.05
	E. index (I_j)	0.80	2.68	4.60	-2.25	1.60	0.85
Chittagong	E. mean (e_j)	33.50	71.60	82.35	12.60	13.19	74.55
	E. index (I_j)	-2.25	-1.97	-4.05	-1.15	-1.19	0.35

(t/ha) and ascorbic acid content of fruits ranged from 1.45 to -2.25, 2.68 to -1.97, 4.60 to -4.05, 3.40 to -2.25, 1.60 to -1.19 and 0.85 to -1.20, respectively thus confirming distinct existence of location wise environmental variation. Furthermore, environmental mean indicated that Rajshahi was the most favourable environment followed by that of Gazipur for the characters studied while Chittagong had the poorest environment (Table 4) for these characters.

Conclusion

For improvement in strawberry cultivation/yield in Bangladesh, growth of five genotypes was studied under different subtropical climatic conditions. Observing the stability parameter, it was found that level of stability for a particular genotype was not consistent for all the characters. But the genotype Festival considered as stable for most of the characters except days to flowering and ascorbic acid content of fruits over locations. For these reasons, the genotype Festival could be considered more adaptive to environmental conditions and might be recommended for all environments.

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