

Detection and Estimation of Genetic and Environmental Parameters through Model Fitting of Ten Bulb Yield Contributing Traits in Onion

Anil Chandra DEB¹  Rumman ARA² 

¹ Department of Genetic Engineering and Biotechnology, University of Rajshahi, Rajshahi-6205, Bangladesh

² Bangladesh Agricultural Research Institute (BARI), Joydebpur, Dhaka, Bangladesh

Article History

Received 21 March 2021

Accepted 29 May 2021

First Online 08 June 2021

Corresponding Author

E-mail: debac@ru.ac.bd

Keywords

Allium cepa L.

Bulb yield

G × E interaction

Genetic parameters

Onion

Abstract

Two onion varieties P₂ and P₃ and their products F₁ and F₂ were evaluated in summer and winter seasons for this investigation. Estimated mean values of different traits showed variations from generation to generation in each season. Values of six-parameters viz., \hat{m} , [d], [h], e₁, gd₁, gh₁ for all the characters were significant except gd₁ for a number of leaves, leaf length and bulb volume and also [d] for leaf length and neck length. Overall means ' \hat{m} ' had the highest magnitude than [d], [h], e₁, gd₁ and gh₁ for all the characters. Environmental parameter 'e₁' also exhibited higher magnitude than [d], gd₁ and gh₁. As the values of [d] and gd₁ were found to be non-significant, 4-parameter model was considered for leaf length only. Five-parameter model was considered for neck length, number of leaves and bulb volume and for rest of the traits 6-parameter model was considered. The goodness of fit test showed that 4, 5 and 6-parameter models were not adequate except bulb length and neck length. Therefore, for the development of these two traits in consideration of genotype × environment (G × E) interaction proper design and analysis needs to be done. Due to significant χ^2 values for other characters the situations becoming more complex as G × E interaction model is inadequate, so for their exact genetic explanation G × E model needs to be extended to include linkage and non-allelic parameters.

1. Introduction

Onion (*Allium cepa* L.) a member of the family Alliaceae is one of the most important spice crops grown all over the world. The use of onion is not limited to any climate or associated with nationality. It is popularly used both at immature and mature bulb stages as a vegetable and as a spice. Onion compared with other fresh vegetables, are relatively higher in food energy, intermediate in protein content, and rich in calcium and riboflavin. Onion has diuretic properties, beneficial to the digestive tract, good for the eyes, to act as a heart stimulant and useful as an anti-rheumatic remedy. It is a slow-growth, shallow-rooted crop with non-shading habitus and therefore its productivity is highly dependent on water availability in the soil, proper fertilization and weed control (Sekara et al., 2017).

As most commonly grown vegetable onion is on the list of 15, with respect to its importance, it has been provided the second rank following tomato and with respect to production, it takes the fourth rank in the world (Jahromi and Amirizadeh, 2015). Among the spice grown in Bangladesh, onion is grown in 172 460 ha and produced 1 802 868 metric tons (Mt) in terms of area and production during the year of 2018-2019 (BBS, 2019). Still, now Bangladesh is not sufficient in onion production though the per hectare yield and production increases but area decreases in the subsequent year (BBS, 2019). In this country, the average bulb yield of onion is 10 447 kg ha⁻¹ (BBS, 2019). World dry bulb onion production increased 2.34 times between 1978 and 2002, whereas the population increased 1.45 times. The area under cultivation increased by a factor of 1.90 to 2.95 million ha in

this interval, and the world average yields increased from 14.04 to 17.40 t ha⁻¹ (Brewster, 2008). Due to lack of quality seeds and improved varieties as well as improper cultural practices the yield level of onion is quite low (approximately 370-500 kg ha⁻¹) as compared to the higher yield (1000-1200 kg ha⁻¹) produced in other countries (Mila and Parvin, 2019). World production of onions and shallots (as green produce) was 4.5 million tons, led by China with 22% of the world total, and Japan, Mali and South Korea as secondary producers (FAO, 2019). Looking to the importance and production of this crop greater attention is needed for its improvement. Therefore, efforts should be made to develop high yielding varieties through breeding research. But the success of the breeding plan depends on the knowledge of genetic variability of population, about the nature and different gene actions governing the various quantitative traits. The breeder should be able to determine in predicting the magnitude and extent of the effects of genotype \times environment (G \times E) interaction as an expression of genes, which are mostly related to environmental features.

The study of quantitative traits becomes complicated when more than one environment is included because changes in gene expression may occur with changes in environments. These changes, observable as G \times E interaction in biometrical analysis, has long been recognized as an important source of phenotypic variation (Immer et al., 1934; Yates and Cochran, 1938; Mather, 1949). For specifying, estimation and correcting the effects of G \times E interaction two main approaches have been used under regression.

The first one purely statistical analysis originally proposed by Yates and Cochran (1938) which was later on modified by Finlay and Wilkinson (1963) and Eberhart and Russell (1966). The second approach is based on fitting of models which specifying the contribution of genetic and environmental effects and G \times E interaction to generation mean and variance due to the contributions of additive, dominance and epistatic gene effects on the genetic and interaction components. This approach has been used by Mather (1949) and Jinks and Mather (1955), followed by Bucio Alanis (1966a), Bucio Alanis and Hill (1966b) and Perkins and Jinks (1968).

The study of G \times E interaction in its biometrical aspects are important not only from genetic and an evolutionary point of view but also necessary to the agricultural production problem in general and particularly for plant breeding problems (Breese, 1969). Comstock and Moll (1963) reported that selection is impeded due to large effect of G \times E interaction, knowledge about the description, prediction and inheritance of genotype interaction would provide more information and help the breeders to select better genotypes.

The breeding of adaptable onion varieties requires genotypes that have high stability for one

or more quantitative traits. Information about adaptive potential and gene effects in onion are scanty for large scale exploitation inbreeding program. Although several information on genetical work in onion is available in the world but it is very few on G \times E interaction following genetical approach based on first degree statistics.

In Bangladesh, no investigation on G \times E interaction through weighted least square technique has been performed regarding onion. Therefore, the present investigation was undertaken to study G \times E interaction on the basis of weighted least square technique for ten bulbs yield contributing traits of two onion varieties in two seasons to investigate the G \times E interaction model is adequate or not.

2. Materials and Methods

The location of the experimental site is at 24°51' N latitude and 89°22' E longitude at an elevation of about 18 m from the average sea level. The experimental field was high land and non-calcareous grey / brown flood plain soils. The soil type was sandy to loam. Organic matter of the soil was 1.1 % with a pH value of 6.8. It is situated in Northern Bogra belonging to the Tista Meander Flood Plain which is under Agro-Ecological Zone (AEZ) number 3 (Anonymus, 1988).

The study was conducted at the central farm of Spices Research Center (SRC), Bangladesh Agricultural Research Institute (BARI), Shibgonj, Bogra, Bangladesh. Seeds were sown on May 05 and seedlings were transplanted on June 15, 2005.

Two released onion varieties such as BARI Piaz-2 (P₂) and BARI Piaz-3 (P₃), their product F₁ (P₂ \times P₃) and F₂ produced in two seasons viz., summer (S) and winter (W) of the year 2005, were the materials in this study. Twenty cross combinations for F₁ (including reciprocals) bulb production and twenty for F₂ (including reciprocals) bulb production as well as 5 parents (produced by selfing) of onion were considered as 45 treatments in this trial.

The experiment was set up in a randomized complete block design with three replications. The size of each plot was 3.0 \times 1.0 m. The space between row and plant was 15 \times 10 cm. The treatments were distributed at random within each of the blocks.

Selfing was done by putting individual bamboo-made frame with cotton net (20 mesh) over the plants as soon as the first flower opened. Then flies were introduced to ensure pollination. Besides, after anthesis the umbels were rubbed against each other daily for a few days to ensure self-pollination. This rather inexpensive method of selfing is used when only a small quantity of seeds is needed (Jones and Mann, 1963).

Data on ten characters viz., bulb diameter, bulb length, neck diameter, neck length, plant height, number of leaves, leaf length, bulb weight, bulb

volume and bulb yield /plot were taken from 20 and 25 randomly selected plants for F_1 and F_2 , respectively. Collected data were analysed through the standard biometrical techniques in the following sub-heads.

2.1. Detection and estimation of genetic and environmental parameters

The approach based on fitting models, the specification of the environmental contribution to the phenotypes depending on the experimental design was given by Mather and Jones (1958). It was further extended by Bucio Alanis and Hill (1966b) and Bucio Alanis et al., (1969). Following them, the phenotypic values in a particular environment of the following generation may be written as:

$$\begin{aligned} P_{ij} &= \hat{m} + [d] + e_j + gd_j \\ P_{2j} &= \hat{m} - [d] + e_j - gd_j \\ F_{1j} &= \hat{m} + [h] + e_j + gh_j \\ F_{2j} &= \hat{m} + 1/2 [h] + e_j + 1/2 gh_j \end{aligned}$$

The model was fitted consisting of \hat{m} , $[d]$, $[h]$, e_1 , gd_1 and gh_1 by weighted least squares and testing its goodness of fit using chi-square (χ^2) for 2, 3 and 4 df (df= number of generations – number of parameters used). Among the parents and seasons, P_3 and winter season were arbitrary and considered as increasing, and those P_2 and the summer season was considered as decreasing. The six-parameter $G \times E$ interaction model is given Table 1.

$$\hat{m} = \frac{1}{8}(1 \times \bar{P}_3 + 1 \times \bar{P}_3 + 1 \times \bar{P}_2 + 1 \times \bar{P}_2 + 1 \times \bar{F}_1 + 1 \times \bar{F}_1 + 1 \times \bar{F}_2 + 1 \times \bar{F}_2)$$

$$[d] = \frac{1}{8}(0 + 0 + 0 + 0 + 1 \times \bar{F}_1 + 1 \times \bar{F}_1 + 1 \times 1/2 \bar{F}_2 + 1 \times 1/2 \bar{F}_2)$$

$$[h] = \frac{1}{8}(1 \times \bar{P}_3 + 1 \times \bar{P}_3 - 1 \times \bar{P}_2 - 1 \times \bar{P}_2 + 0 + 0 + 0 + 0)$$

$$e = \frac{1}{8}(1 \times \bar{P}_3 - 1 \times \bar{P}_3 + 1 \times \bar{P}_2 - 1 \times \bar{P}_2 + 1 \times \bar{F}_1 - 1 \times \bar{F}_1 + 1 \times \bar{F}_2 - 1 \times \bar{F}_2)$$

$$gd_1 = \frac{1}{8}(1 \times \bar{P}_3 - 1 \times \bar{P}_3 - 1 \times \bar{P}_2 + 1 \times \bar{P}_2 + 0 + 0 + 0 + 0)$$

$$gh_1 = \frac{1}{8}(0 + 0 + 0 + 0 + 1 \times \bar{F}_1 - 1 \times \bar{F}_1 + 1 \times 1/2 \bar{F}_2 - 1 \times 1/2 \bar{F}_2)$$

SE of \hat{m} , $[d]$, $[h]$, e , gd_1 and gh_1

$$= \sqrt{\frac{1}{64} [(SEP3)^2 + (SEP3)^2 + (SEP2)^2 + (SEP2)^2 + (SEP2)^2 + (SEF1)^2 + (SEF1)^2 + (SEF2)^2 + (SEF2)^2]}$$

2.2. Estimation of the mean values and standard errors

Mean: Data on individual plant basis were added together then divided by the total number of observations and the mean was obtained as follows:

$$\text{Mean} (\bar{X}) = \frac{\sum_{i=1}^n X_i}{n}$$

Where, X_i = individual reading recorded from each plant, $\sum X_i$ = total number of observations, n = number of observations, $i = 1, 2, 3, \dots, n$ and \sum = summation.

Standard error of mean (SE): If several samples are taken, the standard deviations of different samples will vary. These variations are measured by the standard error as follows:

$$SE = \sqrt{\frac{S^2}{n}}$$

Where, S^2 = variance and n = number of observations.

2.3. Estimation of \hat{m} , $[d]$, $[h]$, e , gd_1 and gh_1 and their standard errors

Estimation of \hat{m} , $[d]$, $[h]$, e , gd_1 and gh_1 and their standard errors by using their co-efficient were calculated as follows:

Table 1. The six-parameter G × E interaction model

Generation	Season	Mean	Variance	Wi= 1/variance	Full Model					
					\hat{m}	[d]	[h]	e ₁	gd ₁	gh ₁
P ₃	W				1	1	0	1	1	0
P ₃	S				1	1	0	-1	-1	0
P ₂	W				1	-1	0	1	-1	0
P ₂	S				1	-1	0	-1	1	0
F ₁	W				1	0	1	1	0	1
F ₁	S				1	0	1	-1	0	-1
F ₂	W				1	0	1/2	1	0	1/2
F ₂	S				1	0	1/2	-1	0	-1/2

Where, W= winter season, S= summer season, Wi= weight, \hat{m} = mid parent value, [d]= additive effects, [h]= dominance effects, e₁= differences between two environments, gd₁= measures the interaction between additive and environmental components, and gh₁= measures the interaction between dominance and environmental components.

Table 2. The parameters of the goodness of fit

Generation	Season	Observed (O _i)	Expected (E _i)	(O _i - E _i) ²	W _i	$\chi^2 = (O_i - E_i)^2 \times W_i$
P ₃	W					
P ₃	S					
P ₂	W					
P ₂	S					
F ₁	W					
F ₁	S					
F ₂	W					
F ₂	S					

$$\chi^2 = \sum (O_i - E_i)^2 \times W_i$$

Where, W = winter season, S = summer season, Wi= weight

2.4. Estimation of expected mean value

The expected mean value of all generations derived from the estimated values of \hat{m} , [d], [h], e₁, gd₁ and gh₁ were calculated as follows:

$$M = J^{-1} \times S$$

Where, M= estimate of the parameters, J= information matrix, J⁻¹= inverse of the information matrix and S= matrix of scores.

After perform the matrix, the expected mean of all generations are as follows:

$$\bar{P}_3 \text{ in } W = \hat{m} + [d] + e_1 + gd_1$$

$$\bar{P}_3 \text{ in } S = \hat{m} + [d] - e_1 - gd_1$$

$$\bar{P}_2 \text{ in } W = \hat{m} - [d] + e_1 - gd_1$$

$$\bar{P}_2 \text{ in } S = \hat{m} - [d] - e_1 + gd_1$$

$$\bar{F}_1 \text{ in } W = \hat{m} + [h] + e_1 + gh_1$$

$$\bar{F}_1 \text{ in } S = \hat{m} + [h] - e_1 - gh_1$$

$$\bar{F}_2 \text{ in } W = \hat{m} + 1/2 [h] + e_1 + 1/2 gh_1$$

$$\bar{F}_2 \text{ in } S = \hat{m} + 1/2 [h] - e_1 - 1/2 gh_1$$

In case of 4-parameter model for leaf length excluding [d] and gd₁ analysis was done. Regarding 5-parameter model for neck length excluding [d] and for number of leaves and bulb volume excluding gd₁ analyses were done.

2.5. Testing the goodness of fit using in 4, 5 and 6-parameter G × E interaction models

The goodness of fit was tested by using the Table 2. Where the calculated χ^2 values were compared with 2, 3 and 4 df depends on how many parameters used in the model. If the χ^2 value is significant, it indicates that the G × E interaction model is inadequate and the estimate of the model is biased to an unknown extent. A failure of this model may be attributed to one or more reasons given below (Singh and Pauer, 2005):

- The presence of epistasis, that is, the adequacy of the specification of genetic contribution,
- Unjustified reduction in the number of environmental parameters, that is, incomplete specification of the environmental contribution, and
- The presence of G × E interaction.

3. Results and Discussion

The simple additive-dominance model assumes that gene differences contribute independently from one another to variation in the phenotype. The additive-dominance model further assumes that gene differences and environmental differences also contribute independently of one another to variation in the phenotype. We must turn to consider the interaction of gene and environmental differences, how much interaction may arise and how it can be detected, measured and investigated. For the estimation of genotype × environment (G × E) interaction in the experiment different seasons in different years and locations are needed. Environmental differences arise due to

heterogeneity of the environment to which the individuals are distributed. This leads to the difference between both segregating and non-segregating individuals grown in the same experiment. Specification of the environmental contribution to the phenotype depends on the experimental design, this in turn determines the specification of $G \times E$ interaction.

Mean with standard error in different generations of each variety in two seasons were different for all the ten quantitative characters are presented in Table 3. The mean values show variations from generation to generation in both two varieties and seasons for each of the characters. The maximum mean values for all the characters were obtained for all the generations in winter season. The highest mean was observed in F_1 generation in winter season for all the characters. Parent P_3 in winter season performed better compared to F_2 with the maximum values of means for all the characters except bulb length. Similar trend was also observed regarding summer season. Comparatively the lowest mean values were recorded in F_2 generation in summer season for most of the characters.

The six-parameter \hat{m} , [d], [h], e_1 , gd_1 , gh_1 and their standard errors were estimated and their significant tests of each of the parameters for all the ten quantitative characters were done separately and are presented in Table 4. Table 4 shows that the values of each parameters for all the characters are significant except gd_1 for number of leaves, leaf length and bulb volume and also [d] for neck length and leaf length. Significant \hat{m} , [d], [h], e_1 , gd_1 and gh_1 values for bulb diameter, bulb length, neck diameter, plant height, bulb weight and bulb yield/plot indicated the presence of additive and dominance effects and also $G \times E$ interaction. Non-significant value of gd_1 for number of leaves, leaf length and bulb volume indicated the absence of additive \times environment interaction. Similar analysis in two varieties of *Nicotiana rustica* was done by Bucio Alanis (1966a) and reported that there was no evidence of $G \times E$ interaction as gd_1 found to be non-significant when compared with standard error although there were significant additive genetic [d] and environmental (e_1) effects noted for final plant height. Bucio Alanis (1966a) analyzed the data mean final height of two inbred lines P_1 and P_2 of *N. rustica* from the results of an experiment initiated in 1946 by Professor Mather and his colleagues. The experiment was conducted at the John Innes Institute in London from 1946 to 1948, and from 1950 to 1964 at the University of Birmingham and observed that two inbred lines show different responses to the changing environment, although an interpretation of the nature of the different responses ($G \times E$) is not obvious. Bucio Alanis (1966a) also concluded from generation mean analysis using the same data that genotype \times environmental interaction is linearly related to the environmental effect. On the basis of the $G \times E$ interaction analysis Bucio Alanis (1966a)

defining the best genotype as having (a) the highest performance over environments and (b) the highest stability of performance (lowest variance over the possible environments). Overall means 'm' had the highest magnitude than [d], [h], e_1 , gd_1 and gh_1 for all the characters in this investigation. Dominance effect [h] was also higher in magnitude than other parameters regarding all the characters. Environmental effect e_1 also exhibited higher magnitude than [d], gd_1 and gh_1 . The values of additive effect [d] for leaf length and neck length were found to be non-significant although gd_1 was significant for neck length. On the other hand, there was no evidence of additive \times environment interaction ' gd_1 ' for number of leaves, leaf length and bulb volume. The significant values of gd_1 indicated the evidence for additive \times environment interaction as well as significant values of gh_1 indicated the presence of dominant \times environment interaction.

As the values of [d] and gd_1 were found to be non-significant, so, 4-parameter model consisting of \hat{m} , [h], e_1 , and gh_1 was considered for leaf length only (Table 5). Five-parameter model consisting of \hat{m} , [d], [h], e_1 , and gh_1 was considered for number of leaves and bulb volume (Table 5). Another 5-parameter model consisting of \hat{m} , [h], e_1 , gd_1 and gh_1 was used for neck length (Table 5). Six-parameter model (Table 5) consisting of \hat{m} , [d], [h], e_1 , gd_1 and gh_1 was considered for the rest of six traits as all the parameters were found to be significant for these characters.

Chi-square (χ^2) testing of goodness of fit of model including four-parameter for one character, five-parameter for three characters and six-parameter for the rest six quantitative characters with two varieties of onion in two seasons were done separately and are shown in Table 5. This table showed that all of the four, five and six-parameter models were not adequate as indicated by their significant $\chi^2_{(4)}$, $\chi^2_{(3)}$ and $\chi^2_{(2)}$ values for all the characters except for neck length and bulb length. Similar trend of results in two and three parameters models were found by Azad (1991) in lentil. Researcher also reported that in case of 4-parameter model, the non-significant χ^2 values for all the six characters indicated the adequacy of $G \times E$ interaction model. Genetical approach of $G \times E$ interaction model based on first degree statistics was also explained by Mather and Jones (1958) and gave specifications of various phenotypes in terms of biometrical genetic parameters. Bucio Alanis (1966a) developed a biometrical genetic model to explain the $G \times E$ interaction and applied this model to *Nicotiana rustica* data on two inbred lines grown at two different locations over 16 years and observed the linear relationship between the environmental effect and $G \times E$ interaction. Bucio Alanis and Hill (1966b) extended of Bucio Alanis (1966a) model to include heterozygote and applied it to *N. rustica* data and again observed the similar result of Bucio Alanis

Table 3. Mean values with standard error (SE) and their weight (W_i) of four generations of ten bulb yield contributing traits in onion

Generations	Season	Mean \pm SE		W_i	Mean \pm SE		W_i
		Bulb diameter (cm)			Bulb length (cm)		
P ₃	W	4.3067 \pm 0.0287	20.2225	4.8783 \pm 0.0233	30.7031		
P ₃	S	3.5333 \pm 0.0172	56.0224	4.6333 \pm 0.0234	30.5158		
P ₂	W	4.1450 \pm 0.0227	32.2685	5.0133 \pm 0.0251	26.4620		
P ₂	S	3.0333 \pm 0.0169	58.2072	5.0667 \pm 0.0229	31.837		
F ₁	W	4.7117 \pm 0.0293	19.3949	6.0033 \pm 0.0273	22.3564		
F ₁	S	3.4333 \pm 0.0207	38.9864	5.4167 \pm 0.0347	13.8408		
F ₂	W	3.9867 \pm 0.0340	11.5500	5.0133 \pm 0.1139	1.0280		
F ₂	S	2.6367 \pm 0.0412	9.8348	4.3667 \pm 0.0550	5.5072		
		Neck diameter (cm)		Neck length (cm)			
P ₃	W	0.8367 \pm 0.0100	164.2036	1.8667 \pm 0.0171	57.1102		
P ₃	S	0.7333 \pm 0.0116	124.6883	1.4500 \pm 0.0140	85.5432		
P ₂	W	0.9117 \pm 0.0109	139.8601	1.7200 \pm 0.0109	64.3915		
P ₂	S	0.5700 \pm 0.0073	265.2520	1.5183 \pm 0.0191	45.7457		
F ₁	W	1.1083 \pm 0.0139	86.0585	2.000 \pm 0.0165	61.4628		
F ₁	S	0.8633 \pm 0.0110	137.3626	1.6000 \pm 0.0249	26.8168		
F ₂	W	0.8987 \pm 0.0194	15.4108	1.2080 \pm 0.0351	10.8260		
F ₂	S	0.7667 \pm 0.0153	70.8215	1.5667 \pm 0.0572	5.1245		
		Plant height (cm)		Number of leaves			
P ₃	W	47.2167 \pm 0.0792	2.6596	5.8333 \pm 0.1041	1.5391		
P ₃	S	35.5000 \pm 0.0770	2.8095	5.700 \pm 0.1017	1.6121		
P ₂	W	42.3333 \pm 0.0614	4.4250	5.6667 \pm 0.0812	2.5286		
P ₂	S	31.8833 \pm 0.1065	1.4683	5.1500 \pm 0.0884	2.1338		
F ₁	W	47.4667 \pm 0.0805	2.5727	6.3000 \pm 0.1147	1.2661		
F ₁	S	35.8667 \pm 0.1268	1.0363	5.8000 \pm 0.0974	1.7560		
F ₂	W	42.3733 \pm 0.3071	0.1413	5.6400 \pm 0.1180	0.9576		
F ₂	S	30.2667 \pm 0.4522	0.0813	5.0000 \pm 0.1188	1.1800		
		Leaf length (cm)		Bulb weight (gm)			
P ₃	W	36.3333 \pm 0.1227	1.1063	30.6667 \pm 0.0999	1.6698		
P ₃	S	23.6333 \pm 0.1188	1.1816	20.1667 \pm 0.1191	1.3308		
P ₂	W	35.5000 \pm 0.0905	2.0345	29.2167 \pm 0.1092	1.3987		
P ₂	S	19.9167 \pm 0.1172	1.2144	18.4000 \pm 0.1145	1.2716		
F ₁	W	37.3333 \pm 0.1133	1.2107	31.0833 \pm 0.1122	1.3234		
F ₁	S	25.3333 \pm 0.1132	1.3015	20.7500 \pm 0.1026	1.5839		
F ₂	W	33.8533 \pm 0.3875	0.0888	27.9733 \pm 0.3013	0.1468		
F ₂	S	24.0333 \pm 0.2820	0.2063	18.3333 \pm 0.2466	0.2774		
		Bulb yield plot ⁻¹		Bulb volume (cm ³)			
P ₃	W	7.6333 \pm 0.0263	24.0500	17.0000 \pm 0.1438	1.6110		
P ₃	S	5.0333 \pm 0.0344	14.0706	14.6667 \pm 0.3333	0.6000		
P ₂	W	7.3400 \pm 0.0289	19.9045	16.3333 \pm 0.1541	1.4030		
P ₂	S	4.2660 \pm 0.0251	26.4201	13.400 \pm 0.2350	1.2069		
F ₁	W	7.7100 \pm 0.0271	22.5648	21.3333 \pm 0.1465	1.5536		
F ₁	S	5.2133 \pm 0.0351	13.5648	15.6667 \pm 0.2108	1.5000		
F ₂	W	6.9733 \pm 0.0390	8.7819	16.0000 \pm 0.4180	0.1908		
F ₂	S	4.6267 \pm 0.0612	4.4571	13.6667 \pm 0.3737	0.4773		

W = winter season, S = summer season

Table 4. Estimated values of \hat{m} , [d], [h], e, gd_1 and gh_1 and their standard error from 6-parameter model of ten bulb yield contributing traits in onion

Characters	\hat{m}	[d]	[h]	e ₁	gd_1	gh_1	Standard error
Bulb diameter	3.7233*	0.0827*	1.4321*	0.5642*	-0.0423*	0.2442*	0.0097
Bulb length	5.0490*	-0.0710*	2.0138*	0.1782*	0.0373*	0.1137*	0.0178
Neck diameter	0.8361*	0.0110*	0.3505*	0.1028*	-0.0298*	0.0389*	0.0046
Neck length	1.6162*	0.0098 ^{NS}	0.6234*	0.0825*	0.0269*	0.0276*	0.0101
Plant height	39.1133*	1.0625*	14.9567*	5.7342*	0.15833*	2.2066*	0.0740
Number of leaves	5.6363*	0.0896*	2.1775*	0.2238*	-0.0479 ^{NS}	0.1025*	0.0367
Leaf length	29.4921*	0.0544 ^{NS}	1.2061*	0.7749*	0.0487 ^{NS}	0.4082*	0.0693
Bulb weight	24.5738*	0.4021*	9.3733*	5.1613*	0.8359*	1.8942*	0.0591
Bulb yield plot ⁻¹	6.0996*	0.1325*	2.3404*	1.3146*	0.7072*	0.4588*	0.0128
Bulb volume	16.0083*	0.2417*	6.4792*	1.6583*	-0.075 ^{NS}	0.8542*	0.0961

* and NS indicate significant and non-significant, respectively.

Table 5. Chi-square (χ^2) values following 6, 5, and 4-parameter models of ten bulb yield contributing traits in onion

Bulb diameter (cm)											
Generations	Mean	\hat{m}	d	h	e	gd	gh	Expected mean	Wi	$(O_i - E_i)^2$	$W_i \times (O_i - E_i)^2$
P ₃	4.3067	1	1	0	1	1	0	4.2788	20.2225	0.0008	0.0158
P ₃	3.5333	1	1	0	-1	-1	0	3.4933	56.0224	0.0016	0.0894
P ₂	4.1450	1	-1	0	1	-1	0	4.1275	32.2685	0.0003	0.0099
P ₂	3.0333	1	-1	0	-1	1	0	2.9948	58.2072	0.0015	0.0864
F ₁	4.7117	1	0	1	1	0	1	4.5896	19.3949	0.0149	0.2890
F ₁	3.4333	1	0	1	-1	0	-1	3.3501	38.9864	0.0069	0.2701
F ₂	3.9867	1	0	½	1	0	½	4.3964	11.5500	0.1678	1.9384
F ₂	2.6367	1	0	½	-1	0	-½	3.2971	9.8348	0.4361	4.2887
$\sum \chi^2_{(2)} = 6.9876^*$											
Bulb length (cm)											
Generations	Mean	\hat{m}	d	h	e	gd	gh	Expected mean	Wi	$(O_i - E_i)^2$	$W_i \times (O_i - E_i)^2$
P ₃	4.8783	1	1	0	1	1	0	4.8746	30.7031	1.4255	0.0004
P ₃	4.6333	1	1	0	-1	-1	0	4.6025	30.5157	0.00095	0.0291
P ₂	5.0133	1	-1	0	1	-1	0	5.0089	26.4620	1.9279	0.0005
P ₂	5.0667	1	-1	0	-1	1	0	5.0372	31.8370	0.00087	0.0277
F ₁	6.0033	1	0	1	1	0	1	5.9929	22.3564	0.00011	0.0024
F ₁	5.4167	1	0	1	-1	0	-1	5.2807	13.8408	0.0185	0.2558
F ₂	5.0133	1	0	½	1	0	½	5.4673	1.0280	0.2061	0.2119
F ₂	4.3667	1	0	½	-1	0	-½	5.0503	5.5072	0.4673	2.5735
$\sum \chi^2_{(2)} = 3.1013^{NS}$											
Neck diameter (cm)											
Generations	Mean	\hat{m}	d	h	e	gd	gh	Expected mean	Wi	$(O_i - E_i)^2$	$W_i \times (O_i - E_i)^2$
P ₃	0.8367	1	1	0	1	1	0	0.5543	164.2036	0.0797	13.0882
P ₃	0.7333	1	1	0	-1	-1	0	1.5665	124.6883	0.6942	86.5628
P ₂	0.9117	1	-1	0	1	-1	0	0.5628	139.8601	0.1217	17.0230
P ₂	0.5700	1	-1	0	-1	1	0	0.9735	265.252	0.1628	43.1862
F ₁	1.1083	1	0	1	1	0	1	1.1205	86.05852	0.0001	0.0128
F ₁	0.8633	1	0	1	-1	0	-1	0.7949	137.3626	0.0047	0.6431
F ₂	0.8987	1	0	½	1	0	½	0.8395	35.4107	0.0035	0.1238
F ₂	0.7667	1	0	½	-1	0	-½	1.0325	70.8215	0.0706	5.0033
$\sum \chi^2_{(2)} = 165.6432^{***}$											
Plant height (cm)											
Generations	Mean	\hat{m}	d	h	e	gd	gh	Expected mean	Wi	$(O_i - E_i)^2$	$W_i \times (O_i - E_i)^2$
P ₃	47.2167	1	1	0	1	1	0	48.7240	2.6596	2.2719	6.0424
P ₃	35.5000	1	1	0	-1	-1	0	45.7121	2.8095	104.287	292.9973
P ₂	42.3333	1	-1	0	1	-1	0	43.5870	4.4249	1.5718	6.9553
P ₂	31.8833	1	-1	0	-1	1	0	42.5989	1.4683	114.824	168.5940
F ₁	47.4667	1	0	1	1	0	1	47.3257	2.5727	0.0199	0.0512
F ₁	35.8667	1	0	1	-1	0	-1	42.9163	1.0363	49.6971	51.5011
F ₂	42.3733	1	0	½	1	0	½	46.7406	0.1413	19.0732	2.6958
F ₂	30.2667	1	0	½	-1	0	-½	43.5359	0.0815	176.073	14.3534
$\sum \chi^2_{(2)} = 543.1905^{***}$											
Bulb weight (g)											
Generations	Mean	\hat{m}	d	h	e	gd	gh	Expected mean	Wi	$(O_i - E_i)^2$	$W_i \times (O_i - E_i)^2$
P ₃	30.6667	1	1	0	1	1	0	30.4644	1.6698	0.0409	0.0683
P ₃	20.1667	1	1	0	-1	-1	0	20.2394	1.3308	0.0053	0.0070
P ₂	29.2167	1	-1	0	1	-1	0	29.5815	1.3987	0.1331	0.1862
P ₂	18.4000	1	-1	0	-1	1	0	17.8863	1.2716	0.2639	0.3356
F ₁	31.0833	1	0	1	1	0	1	31.1234	1.3234	0.0016	0.0021
F ₁	20.7500	1	0	1	-1	0	-1	20.5051	1.5839	0.0600	0.0950
F ₂	27.9733	1	0	½	1	0	½	30.5732	0.1468	6.7595	0.9923
F ₂	18.3333	1	0	½	-1	0	-½	25.2640	0.2740	48.0351	13.1616
$\sum \chi^2_{(2)} = 14.8481^{***}$											
Bulb yield plot ⁻¹											
Generations	Mean	\hat{m}	d	h	e	gd	gh	Expected mean	Wi	$(O_i - E_i)^2$	$W_i \times (O_i - E_i)^2$
P ₃	7.6333	1	1	0	1	1	0	8.6115	24.0500	0.9567	23.0096
P ₃	5.0333	1	1	0	-1	-1	0	4.9182	14.0710	0.0132	0.1864
P ₂	7.3400	1	-1	0	1	-1	0	2.9013	19.9045	19.7024	392.1654
P ₂	4.2666	1	-1	0	-1	1	0	0.3045	26.4201	15.6986	414.7591
F ₁	7.7100	1	0	1	1	0	1	7.7524	22.5648	0.0018	0.0407
F ₁	5.2133	1	0	1	-1	0	-1	5.3217	13.5648	0.0117	0.1592
F ₂	6.9733	1	0	½	1	0	½	6.7544	8.7819	0.0479	0.4209
F ₂	4.6267	1	0	½	-1	0	-½	3.9665	4.4571	0.4358	1.9424
$\sum \chi^2_{(2)} = 832.6837^{***}$											

Table 5. Chi-square (χ^2) values following 6, 5, and 4-parameter models of ten bulb yield contributing traits in onion (cont.)

Neck length (cm)										
Generations	Mean	\hat{m}	h	e	gd	gh	Expected mean	W_i	$(O_i - E_i)^2$	$W_i \times (O_i - E_i)^2$
P ₃	1.8667	1	0	1	1	0	1.8174	57.1102	0.0024	0.1387
P ₃	1.4500	1	0	-1	-1	0	1.4317	85.5432	0.0003	0.0285
P ₂	1.7200	1	0	1	-1	0	1.7115	64.3915	0.0001	0.0047
P ₂	1.5183	1	0	-1	1	0	1.5376	45.7457	0.0004	0.0170
F ₁	2.0000	1	1	1	0	1	1.9431	61.4628	0.0032	0.1991
F ₁	1.6000	1	1	-1	0	-1	1.6023	26.8168	0.0000	0.0001
F ₂	1.2080	1	½	1	0	½	1.8538	10.8260	0.4170	4.5145
F ₂	1.5667	1	½	-1	0	-½	1.5435	5.1245	0.0005	0.0028
$\sum \chi^2_{(3)} = 4.9054^{NS}$										
Number of leaves										
Generations	Mean	\hat{m}	d	h	e	gh	Expected mean	W_i	$(O_i - E_i)^2$	$W_i \times (O_i - E_i)^2$
P ₃	5.8333	1	1	0	1	0	-11.9707	1.5391	316.9833	487.8690
P ₃	5.7000	1	1	0	-1	0	23.1158	1.6121	303.3110	488.9677
P ₂	5.6667	1	-1	0	1	0	-11.9695	2.5286	311.0364	786.4868
P ₂	5.1500	1	-1	0	-1	0	23.1170	2.1338	322.8129	688.8182
F ₁	6.3000	1	0	1	1	1	-7.5799	1.2661	192.6514	243.9159
F ₁	5.8000	1	0	1	-1	-1	19.4376	1.756	185.9853	326.5902
F ₂	5.6400	1	0	½	1	½	-9.7750	0.9576	237.6222	227.5471
F ₂	5.0000	1	0	½	-1	-½	21.2770	1.1800	264.9416	312.6311
$\sum \chi^2_{(3)} = 3562.8260^{***}$										
Bulb volume (cm ³)										
Generations	Mean	\hat{m}	d	h	e	gh	Expected mean	W_i	$(O_i - E_i)^2$	$W_i \times (O_i - E_i)^2$
P ₃	17.0000	1	1	0	1	0	16.3607	1.6111	0.4087	0.6584
P ₃	14.6667	1	1	0	-1	0	16.4803	0.600	3.2892	1.9735
P ₂	16.3330	1	-1	0	1	0	14.7641	1.4032	2.4616	3.4542
P ₂	13.4000	1	-1	0	-1	0	14.8836	1.2069	2.2012	2.6566
F ₁	21.3333	1	0	1	1	1	21.1874	1.5536	0.0213	0.0331
F ₁	15.6670	1	0	1	-1	-1	15.3707	1.5000	0.0876	0.1314
F ₂	16.0000	1	0	½	1	½	18.3749	0.1908	5.6402	1.0761
F ₂	13.6667	1	0	½	-1	-½	15.5264	0.4773	3.4583	1.6506
$\sum \chi^2_{(3)} = 11.6339^{**}$										
Leaf length (cm)										
Generations	Mean	\hat{m}	h	e	gh	Expected mean	W_i	$(O_i - E_i)^2$	$W_i \times (O_i - E_i)^2$	
P ₃	36.3333	1	0	1	0	27.74277	1.1063	73.7973	81.6419	
P ₃	23.6333	1	0	-1	0	31.40086	1.1816	60.3345	71.2913	
P ₂	35.5000	1	0	1	0	27.74277	2.0345	60.1747	122.4253	
P ₂	19.9167	1	0	-1	0	31.40086	1.2144	131.8866	160.1631	
F ₁	37.3333	1	1	1	1	37.12479	1.2107	0.0435	0.0526	
F ₁	25.3333	1	1	-1	-1	25.13640	1.3015	0.0388	0.0505	
F ₂	33.8533	1	½	1	½	32.43378	0.0888	2.0151	0.1789	
F ₂	24.0333	1	½	-1	-½	28.26863	0.2063	17.9378	3.7006	
$\sum \chi^2_{(4)} = 439.5042^{***}$										

*, **, ***, and NS indicate significant at 5%, 1%, 0.1% level, and non-significant, respectively.

(1966a) that found earlier. Bucio Alanis et al. (1969) further extended this $G \times E$ interaction model to include F_2 and backcross generations in the analysis and predicted the relationship between potence, heterosis and additive environmental effects (Singh and Pawar, 2005). To determine the stability and adaptability performance of onion, statistical approach of $G \times E$ interaction model was also performed by Golani et al. (2005), Jokanovic et al. (2016), and Tahir et al. (2020). Results of the present investigation shows that out of the ten characters only for neck length and bulb length with the genetic and environmental effects, $G \times E$ interaction effect is also present due to adequate of $G \times E$ interaction model. So, in the future breeding experiments for the development of these two traits proper design and analysis needs to be done for consideration of $G \times E$ interaction. However, in other characters due to significant χ^2 values the

situation becoming more complex as $G \times E$ interaction model is inadequate to explain the genetic nature of these traits and hence for their genetic explanation need more generations as well as need to extend the $G \times E$ interaction model including other parameters like non-allelic interaction and linkage either individually or both at a time.

4. Conclusions

It is now recognized that $G \times E$ interaction is an important source of phenotypic variations. As under the control of gene, breeders are trying to produce and select suitable cultivars, which gave maximum economic yield over a range of environments with wider adaptabilities and stabilities. In the breeding program usually many potential genotypes are

evaluated in different environments before selecting certain desirable traits. In the present investigation, chi-square values for all the characters except bulb length and neck length are found to be significant which reveal that except additive genetic, dominance genetic and $G \times E$ interaction effects the other genetical effects may present in these traits that's why need to enlarge the $G \times E$ interaction model including linkage and non-allelic parameters either individually or both for getting the exact genetic information of these bulb yield contributing traits as well as stable onion genotypes over all the agro climatic regions.

Acknowledgements

Authors sincerely express their deep respect to Late Professor Dr. Md. Abdul Khaleque, Department of Botany, University of Rajshahi, Rajshah-6205, Bangladesh for the technical assistance during the experiment and analysis.

References

- Anonymous (1988). Production of Year Book. Food and Agricultural Organization of the United Nations, Rome, Italy. 42.
- Azad, A.K. (1991). Studies on variability and genotype-environment interaction based on space seedling as environment in Lentil (*Lens culinaris* Medic.). M.Sc. Thesis, Rajshahi University, Bangladesh.
- BBS (2019). Yearbook of Agricultural Statistics of Bangladesh-2019. <http://www.bbs.gov.bd/>. Accessed: 1 January 2021.
- Breese, E.L. (1969). The measurement and significance of genotype – environmental interactions in grasses. *Heredity*, 24:27-44.
- Brewster, J.L. (2008). Onions and other vegetable Alliums (2nd Edition). CAB International, Wallingford, Oxfordshire, OX10 8DE, UK. p. 1-413.
- Bucio Alanis, L. (1966a). Environmental and genotype-environmental components of variability: I. Inbred lines. *Heredity*, 21:387-397.
- Bucio Alanis, L., & Hill, J. (1966b). Environmental and genotype- environmental components of variability. II. Heterozygotes. *Heredity*, 21:399-405.
- Bucio Alanis, L., Perkins, J.M., & Jinks, J.L. (1969). Environmental and genotype-environmental components of variability. V. Segregating generations. *Heredity*, 24:115-127.
- Comstock, R.E., & Moll, R.H. (1963). Genotype – environment interaction. In: Statistical Genetics and Plant Breeding. W.D. Hanson and H.F. Robinson (ed.), *National Academy of Sciences and of the National Research Council*, 982:164-196.
- Eberhart, S.A., & Russell, W.A. (1966). Stability parameters for comparing varieties. *Crop Science*, 6:36-40.
- FAO (2019). Food and Agriculture Organization, Statistics Division (FAOSTAT). 2020. Retrieved 19 February 2021.
- Finlay, K.W., & Wilkinson, G.N. (1963). The analysis of adaptation on a plant breeding programme. *Australian Journal of Agricultural Research*, 14:742-754.
- Golani, I.J., Vaddoria, M.A., Mehta, D.R., Naliyadhara, M.V., & Dobariya, K.L. (2005). Genotype \times environment interaction and stability analysis in red onion (*Allium cepa* L.). *Indian Journal of Agricultural Research*, 39:307-309.
- Immer, F.R., Hayes, H.K., & Powers, L. (1934). Statistical determination of barley varietal adaptation. *Agronomy Journal*, 26:403-419.
- Jahromi, A.A., & Amirzadeh, S.R. (2015). Production potential of onion (*Allium cepa* L.) as influenced by different transplant ages. *Indian Journal of Fundamental and Applied Life Sciences*, 5:118-121.
- Jinks, J.L., & Mather, K. (1955). Stability in development of heterozygotes and homozygotes. *Proceedings of the Royal Society B: Biological Sciences*, 143:561-578.
- Jokanovic, M.B., Girek, Z., Ugrinovic, M., Sikora, V., Dalovic, I., & Zdravkovic, J. (2016). AMMI model in the analysis of genotype by environment interaction of conventionally and organically grown onion. *Genetika*, 48:1027-1038.
- Jones, H.A., & Mann, L.K. (1963). Onions and Their Allies. Leonard Hill (Books) Ltd. London.
- Mather, K. (1949). Biometrical Genetics (1st Edition). Methuen and Co. Ltd., London.
- Mather, K., & Jones, R.M. (1958). Interaction of genotype and environment in continuous variation. I Description. *Biometrics*, 14:343-359.
- Mila, F.A., & Parvin, M.T. (2019). Forecasting area, production and yield of onion in Bangladesh by using ARIMA model. *Asian Journal of Agricultural Extension, Economics & Sociology*, 37:1-12.
- Perkins, J.M., & Jinks, J.L. (1968). Environmental and genotype – environmental components of variability. III. Multiple lines and crosses. *Heredity*, 23:339-356.
- Sekara, A., Pokluda, R., Del Vacchio, L., Somma, S., & Caruso, G. (2017): Interactions among genotype, environment and agronomic practices on production and quality of storage onion (*Allium cepa* L.) – A review. *Horticultural Science - Prague*, 44:21-42.
- Singh, S., & Pawar, I.S. (2005). Theory and application of biometrical genetics (1st Edition). CBS Publishers & Distributors Pvt. Ltd., New Delhi-110002, India.
- Tahir, M., Aleem, S., Munawar, M., Parveen, N., Amin, E., Aslam, R., Saeed, A., & Najeebullah, M. (2020). GGE biplot an effective tool to study genotype and genotype \times environment interaction; a case study in onion (*Allium cepa* L.). *Pakistan Journal of Agricultural Sciences*, 57:1565-1571.
- Yates, F., & Cochran, W.G. (1938). The analysis of groups of experiment. *Journal of Agricultural Science*, 28:556-580.