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The Pharma Innovation

ISSN (E): 2277- 7695
ISSN (P): 2349-8242
NAAS Rating: 5.03
TPI 2019; 8(12): 170-174

www.thepharmajournal.com
Received: 25-10-2019
Accepted: 27-11-2019

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Genotype x environment interaction and stability analysis of broccoli for growth and yield components

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Abstract
The present investigation was conducted to study stability of 13 genotype of broccoli for growth and yield traits. The analysis of variance for stability showed that mean squares due to environment (linear) components revealed significant difference among the genotypes for all the traits studied indicating that variability among environments was large enough for a proper estimation of 'bi' values. The significance of mean squares due to genotype x environment (linear) components was noticed for plant height, curd length, curd weight/plant and curd yield. Among the genotypes used in the study, Green Magic exhibited highest curd yield and was found to be stable over the different environments, which could be used in the breeding programme for the development of high yielding stable broccoli genotypes over environments for future use.

Keywords: Broccoli, regression, g x e interaction, stability analysis

Introduction
Broccoli belongs to family Brassicacea and includes a number of cole vegetable crops; which includes Cabbage, Cauliflower, and Chinese cabbage, Broccoli, Brussels sprouts and Kohlrabi. It is well known that, broccoli has enormous nutritional and medicinal values due to its high contents of vitamins (A, B1, B2, B5, B6 and E), minerals (Ca, Mg, Zn, and Fe) and antioxidant substances which prevent the formation of cancer causing agents (Beecher, 1994) [2]. Consuming more than one serving of broccoli a week reduces the risk of prostate cancer by up to 45%. Broccoli is an important winter season vegetable crop which resembles cauliflower. Broccoli is an Italian word derived from 'Brachium' meaning an 'arm of the branch'. Broccoli is grown for its immature heads which are consumed as salad in curry and soup. It is cherished for its delicious taste, flavour and nutritive value which has been reported to prevent cancer (Michaud *et al*., 2002) [6]. Although broccoli is most nutritive crop yet its cultivation is restricted to some pockets around metropolitan cities only.
Varietal adaptability to environmental fluctuations is critical for the stabilization of crop production both over regions and years. Adaptability is the ability of a genotype to produce a relatively narrow range of phenotypes in different environments. Thus, stability reflects the suitability of a variety for general cultivation over a wide range of environments. The wide variation in climatic conditions from season to season and region to region implies that, no two growing conditions are similar. They may therefore perform differently depending on where they are grown. Farmers need to be provided with genotypes that can perform predictably well over a wide range of environmental conditions. This would offer an opportunity for predictable yields and therefore contribute to a more stability. Therefore, present investigation was designed with the objective to estimate G x E interaction and to identify stable genotype of broccoli for yield and yield related components over different locations.

Materials and Methods
An experiment was carried out in thirteen genotypes of broccoli (Punjab broccoli 1, Palam samridhi, Palam Kanchan, Palam vichithra, CITH 1 and CITH 2, Lucky, Fiesta, Dynasty, SSB06, A1, Green magic, Punjab hybrid. The investigation was carried out at ooty during the period of February to May 2018 and September to January 2019. The genotypes were transplanted in three locations (Ooty, Coonoor, Kothagiri) with a spacing of 45 x 45 cm and Randomized Block Design (RBD) was adopted with three replications. Recommended crop production and protection practices were followed to bring a healthy plant stand.

Five plants in each genotypes of three replications were randomly chosen to record the observations on plant height (cm), curd length (cm), curd width (cm), curd weight per plant (g), curd yield(t/ha) and ascorbic acid (mg/100g). Genotypes were assessed for their stability of performance over environments in accordance with method described by Eberhart and Russel (1966) [5].

Result and Discussion

Genotype x environment interaction is of major importance to the plant breeders in developing improved varieties and in choosing the suitable genotypes to be grown in a specific area. Selection of genotype that interact less with the environment in which they are to be grown are known to reduce genotype and environment interaction to a considerable extent (Allard and Bradshaw, 1964) [1]. The term adaptability as related to crop plants applies not only to the ability of plants to survive but also to maintain stability in yield levels under varying environments. Eberhart and Russell (1966) [5]. defined a stable genotype as one which produces high mean yield, depicts regression coefficients (bi) around unity and non-significant deviations from regression (S^2di). The results of analysis of variance for six growth and yield related traits in genotypes of broccoli are summarized in Table-1. Analysis of variance revealed significant difference among the genotypes for all the traits studied. The partitioning of mean squares (environments + genotype x environments) revealed that significant difference among the genotypes for all the traits studied except for ascorbic acid. The mean squares due to environment (linear) components revealed significant difference among the genotypes for all the traits. The significance of mean squares due to genotype x environment (linear) components for plant height, curd length, curd weight/plant,days to curd initiation and curd yield suggested that the genotypes were diverse for their regression response to change with the environmental fluctuations. Significant mean squares due to pooled deviation was observed for all the characters studied suggesting that the deviation from linear regression also contributed substantially towards the differences in stability of genotypes. Thus, both linear (predictable) and non-linear (un-predictable) components significantly contributed to genotype x environment interactions.

According to Eberhart and Russell (1966) [5]. model, an ideal genotype is defined as the one, which is having high mean performance with regression coefficient around unity (bi=1) with non-significant deviation from regression coefficient (is close to zero). The linear regression is considered as a measure of response of a particular genotype to changing environments. If regression coefficient (bi) is greater than unity, the genotype is said to be highly sensitive to environmental changes and adapted to favourable environments. If regression coefficient (bi) is equal to unity, it indicates average sensitivity to environmental changes and coefficient is less than unity ($bi \leq 1$), indicates less sensitivity to environmental changes and if genotype shows a higher mean value, then the genotype was adapted to widely differing environment conditions. If the mean is low, the genotype is considered to be poorly adapted to all environments S^2di.

The mean values for growth and yield related components, regression coefficient (bi) and deviation from regression (S^2di) of broccoli genotypes were presented in Table 2 to 7**.**

Genotypes Palam Vichithra and CITH 2 were found to be stable with respect to plant height as indicated by their low mean values ((50.58cm and 48.27cm), near unity regression coefficient (bi=1.47 and 1.29) and non-significant deviation of regression coefficient from zero (S^2di= -0.19 and -0.52). The genotypes SSBO6, A1, lucky and dynasty have recorded the highest plant height (66.60cm ,63.30cm, 63.89cm, 63.37cm) but was unpredictable due to significant deviation from regression (S^2di= 6.37**,12.46**,3.61**,3.42**). So, these genotypes may be further tested under different locations to identify a suitable environment for their adaptability in respect of plant height. Such varied responsiveness of genotypes to changing environments for plant height was also reported earlier by Pan *et al*. (2007) [7]. and Singh *et al*. (2007) [8].

In case of curd length, all the genotypes exhibited non-significant deviation from regression (S^2di) indicating that their performance can be predicted. Among the genotypes studied, the genotypes Green magic, Punjab hybrid was ideally stable as it expressed high mean (22.21cm, 20.31cm), regression coefficient near to unity (bi=0.99, 0.84) and non–significant deviation from regression (S^2di= 0.07 and -0.05) and hence suitable for different environments. Genotypes *viz*., Punjab broccoli 1, Palam Kanchan, CITH 2 and Fiesta registered moderate mean, regression coefficient more than 'unity' and non-significant deviation from regression and recommended for resource rich environments. Whereas, rest of the genotypes showed non-significant S^2di and bi values were average in performance. These genotypes were either poorly or well adapted to all the environments depending on the mean of the genotype.

The stability parameters for curd width revealed that all the thirteen genotypes expressed non-significant deviation from regression (S^2di) indicating that their performance can be predicted. The genotypes Green Magic, Punjab hybrid were found stable as they recorded high mean (24.97cm, 23.39cm) with regression coefficient (bi = 1.51, 1.08) near 'unity' and non–significant deviation from regression (S^2di = 0.03, -0.08). Remaining genotypes revealed non-significant S^2d_i and bi values exhibiting their average performance and hence they could be recommended for poorly or well adapted environments.

Regarding, curd weight/plant the mean square deviation from regression (S^2di) was significant for all thirteen genotypes making the prediction that the stability of the trait is difficult. The genotypes Green Magic, Punjab hybrid attained maximum curd weight but were unpredictable due to significant deviation from regression. Similar findings have also been reported by Chaubey *et al*. (2000) in cabbage where in the genotypes did not show uniform stability and linear pattern for all the characters.

For curd yield the mean square deviation from regression S^2d_i was significant in one genotype *viz.*, Punjab hybrid making it difficult to predict the stability of the trait for this genotype, however for the rest of the genotypes prediction of stability of the trait over environments would be precise and more reliable. The genotype Green Magic had maximum curd yield and was stable over different environments with high mean (27.33t/ha) with regression coefficient (bi = 2.07) more than 'unity' and non–significant deviation from regression (S^2di = 0.27). Whereas the rest of the genotypes showed non-significant S^2d_i and bi values around unity. And hence these genotypes are preferable in either poorly or well adapted to all the environments depending on their mean performance.

In case of ascorbic acid content (mg/100g) out of thirteen genotypes, twelve genotypes revealed non-significant deviation from regression (S^2di) indicating that their performance can be predicted. Among genotypes, Green Magic was considered as stable as it noted high mean (96.63mg/100g) with regression coefficient (bi= 0.87) near 'unity' and non-significant deviation from regression (S^2di = -0.96) revealing its adaptability over different environmental conditions. Genotypes *viz*., Punjab broccoli 1, Palam Kanchan, Palam Vichithra, CITH 1, A1 and Punjab hybrid were recommended for resource rich environments since they showed moderate mean, regression coefficient more than 'unity' and non-significant deviation from regression. The genotypes *viz*., Palam samridhi, CITH 2, lucky, Fiesta and SSBO6 which had expressed moderate mean with regression (bi) less than unity and non-significant deviation from regression (S^2d_i) and were inferred to be suitable for poor growing environments (marginal environments). Cheema *et al.*, (2013) [4]. reported ascorbic acid content in the range of 20.62 to 12.50mg/100g in 26 hybrids under study. Zahedi *et al.*, (2012) [9]. recorded a range of 23.57 to 31.62mg/100g in ten genotypes they evaluated.

Table 1: Analysis of variance for stability for different characters (Eberhart and Russel, 1966) [5].

source	df	P.H	C.L	C.W	C.W/P	Yt/ha	A.A
Varities	12	211.89**	42.06**	83.72**	112553.34**	164.82**	635.36**
ENV + GXE	65	5.15**	0.54**	0.34**	152.89**	1.21**	1.21
ENV(linear)	1	12.45**	28.60**	16.67**	4554.77**	5.76**	10.10*
GXE (linear)	12	4.39**	0.16**	0.14*	160.68**	0.58**	0.56
Pooleddev	52	5.18**	0.09	0.08	66.48**	1.27**	1.19
ERROR (pooled)	144	2.26	0.20	0.29	105.30	0.19	5.12

Significant at 5% level Significant at 1% level

P.H Plant height

C.L Curd lengthYt/ha Estimated yield t/ha

C.W Curd width A.A Ascorbic acid

C.W/P Curd weight/plant

Table 2: Stability parameters of Plant height

Genotypes	Mean	bi	S^2d_i
Punjab broccoli 1	60.57	2.68	10.05**
Palamsamridhi	54.46	4.02	8.79**
Palamkanchan	52.53	-0.05	1.32**
Palamvichithra	50.58	1.47	-0.19 ns
CITH 1	55.04	-1.86	6.97**
CITH 2	48.27	1.29	-0.52 ns
Lucky	63.89	2.52	3.61**
Fiesta	62.91	0.38	3.47**
Dynasty	63.37	2.29	3.42**
SSBO6	66.60	4.02	6.37**
A1	63.30	-0.19	12.46**
Green magic	52.84	-3.07*	0.74**
Punjab hybrid	58.04	-0.47	1.09**
SE	1.06		

Table 3: Stability parameters of Curd length

Genotypes	Mean	bi	S^2d_i
Punjab broccoli 1	12.01	1.20	0.09 ns
Palamsamridhi	14.27	0.89	-0.02 ns
Palamkanchan	14.69	1.61	0.18 ns
Palamvichithra	16.30	0.58*	-0.03 ns
CITH 1	14.91	0.94	0.06 ns
CITH 2	17.86	1.15	0.00 ns
Lucky	18.21	0.99	-0.02 ns
Fiesta	17.11	1.34	0.01 ns
Dynasty	17.80	0.89	-0.05 ns
SSBO6	16.16	0.88	0.00 ns
A1	17.32	0.67	0.01 ns
Green magic	22.21	0.99	0.07 ns
Punjab hybrid	20.31	0.84	-0.05 ns
SE	0.14		

Table 4: Stability parameters of Curd width

Genotypes	Mean	bi	S^2d_i
Punjab broccoli 1	11.16	0.70	0.00 ns
Palamsamridhi	15.87	0.72	-0.01 ns
Palamkanchan	15.20	1.16	-0.07 ns
Palamvichithra	17.29	1.06	-0.02 ns
CITH 1	15.92	0.48	-0.02 ns
CITH 2	18.99	0.94	0.03 ns
Lucky	21.18	1.40	-0.03 ns
Fiesta	19.88	0.46**	-0.09 ns
Dynasty	21.80	1.09	-0.02 ns
SSBO6	17.35	1.19	-0.04 ns
A1	17.84	1.22	0.04 ns
Green magic	24.97	1.51	0.03 ns
Punjab hybrid	23.39	1.08	-0.08 ns
SE	0.13		

Table 5: Stability parameters of Curd weight/plant

Genotypes	Mean	bi	S^2d_i
Punjab broccoli 1	225.20	0.51	-5.95**
Palamsamridhi	275.80	1.25	72.69**
Palamkanchan	303.15	1.53	27.89**
Palamvichithra	330.93	1.66	2.14**
CITH 1	312.38	1.96	45.35**
CITH 2	363.32	0.83	47.21**
Lucky	363.70	0.17	30.73**
Fiesta	347.83	0.72	-17.67**
Dynasty	534.17	-0.19*	22.44**
SSBO6	282.77	1.00	23.46**
A1	324.67	0.96	-6.78**
Green magic	691.87	2.06	110.90**
Punjab hybrid	585.62	0.55	55.48**
SE	3.8		

Table 6: Stability parameters of Estimated yield t/ha

Genotypes	Mean	bi	S^2d_i
Punjab broccoli 1	8.89	0.67	-0.03 ns
Palamsamridhi	10.89	0.73	0.26 ns
Palamkanchan	11.97	1.01	0.24 ns
Palamvichithra	13.07	0.99	0.27 ns
CITH 1	12.34	0.80	0.52 ns
CITH 2	14.45	0.54	0.20 ns
Lucky	14.36	0.33	0.03 ns
Fiesta	13.74	0.23	0.03 ns
Dynasty	21.10	0.06	0.03 ns
SSBO6	11.17	0.75	0.10 ns
A1	12.82	0.39	0.09 ns
Green magic	27.33	2.07	0.27 ns
Punjab hybrid	21.69	4.42	13.74**
SE	0.53		

Table 7: Stability parameters of Ascorbic acid

Genotypes	Mean	bi	S^2d_i
Punjab broccoli 1	73.68	1.10	-0.51 ns
Palamsamridhi	73.90	0.32	-0.16 ns
Palamkanchan	71.47	1.02	-1.03 ns
Palamvichithra	73.23	2.15	-1.17 ns
CITH 1	75.83	1.39	-1.00 ns
CITH 2	78.09	0.03	-0.21 ns
Lucky	90.32	0.74	-1.46 ns
Fiesta	92.88	0.92	-0.79 ns
Dynasty	94.69	0.77	0.88**
SSBO6	93.62	-0.64	-0.36 ns
A1	93.58	2.31	-0.38 ns
Green magic	96.63	0.87	-0.96 ns
Punjab hybrid	94.94	2.05	0.40 ns
SE	0.51		

Conclusion

The present study demonstrated the presence of GXE interaction among the genotypes of broccoli for growth and yield related traits. The genotype Green Magic was identified as widely adapted to all over environments for important yield components *viz.*, curd length, curd width, curd yield and vitamin C; genotypes Punjab hybrid for curd length and curd width. Among the genotypes used in the study, Green Magic exhibited highest curd yield and its component traits and it was found to be most stable over the different environments. Therefore, this genotype could be used in the breeding programme for developing of high yielding stable genotypes of broccoli over environments.

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