GENOTYPE AND ENVIRONMENT INTERACTIONS IN YIELD CONTRIBUTING CHARACTERS OF MUSTARD (*Brassica rapa* L.)

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GENOTYPE AND ENVIRONMENT INTERACTIONS IN YIELD CONTRIBUTING CHARACTERS OF MUSTARD (*Brassica rapa* L.)

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CERTIFICATE

This is to certify that the thesis entitled ***'GENOTYPE AND ENVIRONMENT INTERACTIONS IN YIELD CONTRIBUTING CHARACTERS OF MUSTARD (Brassica rapa L.)'*** *submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of* ***Master of Science in Genetics and Plant Breeding****, embodies the result of a piece of bonafide research work carried out by* ***Susmita Mondal****, Registration number:* ***11-04368*** *under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.*

I further certify that any help or source of information, received during the course of this investigation has duly been acknowledged.

Dated: June, 2018
Dhaka, Bangladesh

Prof. Dr. Jamilur Rahman
Supervisor

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June, 2018 ***The Author***

SAU, Dhaka

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ABSRACT

The experiment was conducted in the experimental field of Sher-e-Bangla Agricultural University, Dhaka during October, 2017 to April, 2018. The objective of this study was to assess the genotype and environment interactions for yield and yield contributing characters of mustard varieties grown in Bangladesh through the AMMI (additive main effects and multiplicative interaction) model. The study comprised of eleven (11) mustard varieties of *Brassica rapa* released by BARI and BINA and three (3) environments laid out in randomized complete block (RCBD) design with three replications. The environments were three sowing times viz., optimum (Env-1), late (Env-2) and very late (Env-3) sowings of eleven mustard varieties. The results of combined analysis of variance (ANOVA) revealed significant differences between genotypes and environments as main effects. Genotype and environment interactions both linear and non-linear components were highly significant for most of the parameters except number of seeds per siliqua and hundred seed weight. The results also suggested that Env-3 was poor and Env-1 and Env-2 were found rich and favorable for mustard production. The IPCA1 (First Interaction Principal Component Axis) scores of a genotypes in the AMMI analysis used as an indication of the stability or adaptation over environments. The greater the IPCA1 scores indicated the better adaptation of a genotype to certain environments. Hence, considering the IPCA1 scores BARI Sharisha-9, BARI Sharisha-15, Maghi and Improved Tori were low yielding and unstable, while BARI Sharisha-6, BARI Sharisha-17 and BINA Sharisha-9 were shown high yielding but unstable genotypes. Again, Env-1 was found as rich environment where, BARI Sharisha-17, BINA Sharisha-9 were shown highly responsive to the environment (Env-1). BARI Sharisha-12 was found intermediate yielding and stable variety. As a whole, Sonali Sharisha-75 and BINA Sharisha-10 were found as high yielding and stable varieties and Env-1 and Env-2 were more favorable for the mustard production.

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List of Abbreviated Terms

Full Word	Abbreviation
Agro-Ecological Zone	AEZ
And others	*et al.*
Accessions	ACC
Bangladesh Agricultural Research Institute	BARI
Bangladesh Bureau of Statistics	BBS
Centimeter	cm
Co-efficient of Variation	CV
Etcetera	etc.
Figure	Fig.
Genotype	G
Genetic Advance	GA
Genotypic Co-efficient of Variation	GCV
Genotypic Variance	δ^2 g
Genotype-Environment Interaction	GEI
Heritability in broad sense	h^2b
Journal	j.
Kilogram	Kg
Meter	M
Mean Sum of Square	MSS
Millimeter	mm
Muriate of Potash	MP
Number	No.
Percent	%
Phenotypic Co-efficient of Variation	PCV
Phenotypic variance	δ^2p
Randomized Complete Block Design	RCBD
Replication	R
Research	Res.
Sher-e-Bangla Agricultural University	SAU

CHAPTER I

INTRODUCTION

Brassica rapa L. is commonly known as field mustard or rapeseed widely cultivated as oil seeds. It is the third most important oil crop in the world. In Bangladesh it occupies the first position in respect of cultivation area (78%) and oilseed production (38%) among all the oil crop (BBS, 2018).The main reason of its popularity in farmers lever because rapeseed has short duration life cycle (75-80 days) crop compared to other *Brassica* crop viz. *B. napus* and *B. juncea* (Islam *et al*., 2013). It has several medicinal values (Downey *et al*., 1990). It is a high energy food and a carrier for fat soluble vitamins (A, D, E, and K) in the body. The seeds of *Brassica rapa* L. contain 42% oil & 25% protein (Khaleque *et al*., 1985). During 2017-18, 760 thousand acres of land was under rapeseed cultivation which produced 352 thousand tons of seed and average yield was 463kg/acre in Bangladesh (BBS, 2018). In Bangladesh the edible oil consumption is increasing in every year. As per The Perspective Plan of Bangladesh (PPB) the demand for edible oil would be 24.91 lac MTs in 2021 as estimated (Quaiyum *et al*., 2015). Since the domestic production of edible oil is only 2.19 lac M.Tons on an average per annum, the country needs to import around 12.90 lac M. Tons of edible oil from outside indicating a big market and demands of edible oil in the country (Quaiyum *et al*., 2015). At present, on an average domestic production can only supply around 14.51% of current apparent consumption or around 8.79% of targeted requirement in 2021. The production of mustard seed and mustard oil in 2013 was 230 and 75 thousand tons respectively and 57 thousand ton of mustard oil was imported. So we need to develop high yielding and better-quality mustard variety to fulfill the requirement of edible oils of the country. In spite of its importance no major breakthrough has been made and limited numbers of improved varieties are being grown on the country.

Under this situation, new avenues of crop improvement require to be exploited. For achieving a substantial genetic improvement, a high knowledge of genotype-environment interactions of existing varieties and improved lines are essential to improve new varieties of mustard in the country. During the process of development of superior varieties, genotype x environmental interactions are of

major consequences to the breeder as these have masking effect on the performance of genotypes and the relative ranking of the genotypes do not remain same when tested over number of environments.

Stability is a genetic character (Perkins and Jinks, 1968) and it is possible to breed lines or variety having stability in yield and yield components. Stability of a promising line or a variety is most important for its adaptation and spread among the growers' level. Selection of better plant type either from local or exotic genotypes can be of immense value to the breeder. Keeping this view in mind, eleven (11) popular mustard varieties released by BARI and BINA were collected and their genotype-environment interaction was assessed in this study using AMMI (additive main effects and multiplicative interaction) model.

To assess the nature and magnitude of multiplicative GEI the Additive Mean and Multiplicative Interaction (AMMI) model i.e. yield vs. PC1 (yield vs. Principle component 1) is most suitable as it captures maximum genotypic sensitivity in different environments and necessitates the avoidance or exploitation of GEI to harvest genetic gains rather than to ignore it. Eberhart and Russell (1966) model for stability emphasized the need of considering both linear (bi) and non-linear (S^2di) components of genotype x environment interaction in judging the phenotypic stability of a genotype. They considered that the most desirable variety is one which has high mean yield (μ), unit regression coefficient (bi= 1.00) and least deviation (S^2di= 0) from regression.

Yield stability over it range of environmental conditions is of great concern to plant breeders. Farmers are more interested in the cultivars that produce consistent yields tinder their growing conditions and breeders want to meet these needs (Mulema *et al.*, 2008). The reactions of crop varieties to the ever changing environments are complex. Variation in locations, seasons, involving physical, edaphic and biotic factors is important for adaptation of crop plants. In Bangladesh, edaphic variations over locations, temperature and rainfall differences greatly contribute for adaptation of different crops. Due to ever increasing food demands, improved varieties well adapted to changing conditions is the need of the day and plant breeders are faced with the task of developing varieties for either closely defined environment or wide range of environments.

Research investigations on phenotypic stability by many workers provided fundamental knowledge on adaptation in plants. But there are gaps between laboratory and field studies. Acharya and Sharma (1985) reported that stability analysis under simulated environments cannot be substituted for several sites. Wide adaptability and stability are important consideration to plant breeders in the cultivar selection programme. Yield of a crop cultivar is an important criterion in evaluating stability. Stability parameters can be used for varietal evaluation to lower risk, and to raise profit for the grower to account for variability in the yield over sites and to transfer technology to other environments without extensive experimentation at specific sites (Miah, 1980)

Stability of varieties can be measured by determining interaction of varieties with locations and seasons. Uni location trials can serve the purpose provided different environments are created by planting experimental materials (Luthra *et al*., 1974 and Tehlan. 1973). Genotypes x environment interactions are nearly universal during the field testing phases. Such interactions confound the selection of superior cultivar by altering their relative productivities in different environments. Therefore, conceiving the above idea the present investigation was undertaken with the following objectives:

- Finding out the stable mustard varieties under different sowing times environments,
- Comparing the average performance of the varieties in different sowing times environments and
- Identifying the suitable sowing times for specific mustard variety.

CHAPTER II

REVIEW OF LITERATURE

Brassica species has received much attention by a large number of researchers on various aspects of its production and utilization. Brassicaceae species is the most important oil crop in Bangladesh and many other countries of the world. Many studies on the genotype and environment interactions have been carried out in many countries of the world. The review of literature concerning the studies presented under the following heads:

2.1 Importance of genotype and environment interactions in plant breeding

2.2 *Brassica* and genotype x environment interactions

2.3 Methods for estimation of genotype x environment interactions and their application

2.1 Importance of genotype and environment interactions in plant breeding

The phenotype is that which reflects genetic as well as non-genetic influences on development. However, the phenotypic response to a change in environment is not always the same for all the genotypes. The inter-play of effects of the genetic and non-genetic factors on development is measured as the genotype-environment interaction. These interactions constitute an important limiting factor in the estimation of variance components and the efficacy of a selection programme. Detection and estimation of the magnitude of genotype-environment interaction is, therefore, important for obtaining an unbiased estimate of genetic variances. Little is known concerning the environmental factors which contribute to such interactions. Even if such information was available the possibilities of materially reducing such interactions under field conditions appear somewhat questionable. It is, therefore, vital that the statistical methods used to design and analyze data from crop cultivar breeding and evaluation programme should be as accurate, efficient and informative as possible (Smith *et al.* 2005). This emphasized that the accurate assessment of the yield performance of new genotypes, across a range of environments, is crucial for plant breeding programmes. Hence, multi-environment yield trials (MEYTs or MET) are used in the final selection cycles to

identify superior genotypes in plant breeding programs and also helpful to avoid type II error i.e., probability of releasing an inferior genotype, otherwise farmers have to pay yield plenty which causes greater losses than accrued on the proper evaluating of genotypes for commercial use of crop cultivars (Cullis *et al.* 1996). This task is not generally easy due to the frequent presence of genotype by environmental interactions (GEI).

GEI refers to inconsistent phenotypic performance of genotypes across environments. When it is associated with a significant genotypic rank change over environments, it potentially presents limitations on selection and recommendation of varieties for target set of environments (Navabi *et al.* 2006) as it attenuates the association between phenotype and genotype, reducing genetic progress in plant breeding programs. Means across environments are adequate indicators only in the absence of GEI. If it is present, the use of means across environments ignores the fact that genotypes differ in relative performance over environments (Voltas *et al.* 2002).

A significant GEI may be either (i) a non-crossover type where the ranking of genotypes remains constant across environments and the interactions is significant because of changes in the magnitude of the response, or (ii) a crossover type whereas significant change in rank occurs from one environment to another. When selecting genotypes across a number of environments, plant breeders look for a non-crossover type of GEI or preferably the absence of a GEI for general adaptation (Matus *et al.* 2003), and a crossover type of GEI for specific adaptation. The recommendations of cultivar for commercialization as well as evaluation of germplasm in advanced stage for adaptation and performance stability are also essential breeding objectives. Consequently, selection based on multiple traits is an inevitable issue for all breeders (Yan and Fregeau 2008). In these situations the yield potential of recommended cultivar(s) is predicted only on genotypic and environmental means alone, and is main cause for the failure of formal breeding to serve small resource-poor farmers in marginal fragile environments (Ceccarelli *et al* 1996). There is a need to collect, analyze, and interpret morpho-physiological and environmental variables for studying their relationships with genotype performance and understanding the causes of the observed G x E (Westcott 1986).

Simmonds (1981) observed genotype x environment (GE) interactions as a component of historically rising crop yields. For various cereals (both temperate and tropical), past selection has seemingly evoked responsive varieties, and GE effects constitute about one third of the total estimated yield increase due to G + E + GE. Historically, responses have been largely due to unconscious selection, but GE effects could be deliberately manipulated by breeding if it were desirable to do so, for example, to produce varieties adapted to low-input agriculture (already an object of breeding research in a few crops). Kang and Miller (1984) reported that genotype x environment interactions were almost universally encountered in replicated trials conducted in different environments during varietal evaluation phases of a breeding programme. These interactions affect relative ranking of genotypes and thereby hinder selection of superior genotypes based on their mean performance.

Information on stability performance of genotypes can facilitate selection of stable and consistent performing genotypes across environments. In confirmation of their previous work, Kang and Miller (1984) evaluated three methods of portioning GE interactions into stability variance components assignable to each cultivar in sugarcane cultivar tests. They noted that covariance of fertility and cultural practices at different locations remove heterogeneity variances (non-additive) from the GE interactions and partition the remainder of variance assignable to each cultivar.

McIntosh (1983) cited the insufficient detail for complete field experiments conducted at two or more locations or years. Therefore, he based his work on combined analyses. These included: tabulating, finding source of variation, degrees of freedom and F ratios for one factor, and split plot experiment combined over locations and/ or years and F test for fixed and random models. The test of main effect of locations, or years may be of interest to researcher, but they may not have the statistical skills to identify all sources of variations and derived their expected mean square (EMS). It is important to completely define the statistical model, even if a researcher is not interested in testing the main effects of years or locations.

2.2 *Brassica* and genotype x environment interactions

Till date most of the *B. juncea* types grown in the world were of conventional mustard quality as they contained high levels of glucosinolates in the meal and high levels of erucic acid in the oil fraction. During the past two to three decades, significant attempts have been made to introduce canola quality traits into *B. juncea* in an effort to change its seed quality while retaining its agronomic benefits. The first significant achievement in this direction was the development of low erucic acid *B. juncea* (Kirk and Oram, 1981). The next breakthrough occurred with the development of a low glucosinolate form of *B. juncea* (Love *et al* 1990) following interspecific hybridization between *B. rapa* and *B. juncea*.

Gunasekera *et al.* (2006) studied seven cultivars of canola in three regions, during two consecutive years, within three cropping intervals, under Mediterranean climate of the southwest of Australia. The results showed that grain yield vary significantly among different locations, cultivation time, and genotypes. The grain yield of early cropping in all locations was more than that of late cropping. Based on biplot grain yield, the studied environments were divided into three groups with high, intermediate and low yield. The genotypes specifically adaptable to certain regions were identified.

Brar *et al* (2007) studied twenty-eight genotypes of Indian mustard grown in four diverse environments to study genotype environment (G x E) interaction and phenotypic stability for grain yield and its components. Sufficient G x E interaction was exhibited by the genotypes for all the characters except percent oil content. However, characters differed with respect to the contribution of linear and non-linear components of G x E interaction. Three genotypes exhibited stability for seed yield and yield contributing characters. These genotypes can be utilized in future breeding programmes to develop high yielding strains having wider adaptability.

Jeromela *et al.* (2008) carried out experiments using eight registered cultivars of rapeseed developed at European breeding stations and 11 experimental lines developed in the Institute of Field and Vegetable Crops, Novi Sad, Serbia. The objective of the study was to identify genotypes with most stable oil yield by using

combination of three parameters: ecovalence (wi), regression coefficient (bi) and deviations mean square (S^2di) (first model) and AMMI model analysis (second model). Average oil yield of experimental genotypes was higher compared to registered genotypes. According to the first model, seven experimental lines and two registered varieties were estimated as stable and wide adaptable genotypes. A complete positive and highly significant correlation was estimated between wi and S^2di that implies that both of these parameters could be used independently. According to the AMMI models, in the environmental conditions of Northern Serbia, two genotypes were most stable and with high average oil yield. Such genotypes can be implemented in future breeding programs and recommended for growing in South Eastern Europe.

Brar *et al.* (2010) in which six genotypes of rocket salad were grown at six locations during *rabi* (post-rainy) season of 2008-09. Data recorded on seed yield were subjected to GGE biplotanalyses, which revealed that total sums of squares of variation were 78.73% for environments (E), 7.67% for genotypes (G) and 13.60% for genotype by environment interactions (GE). It was demonstrated that with GGE biplot analyses we identify genotypes having high seed yield and stable performance across all the environments.

Chauhan *et al.* (2010) conducted experiment to assess the genotype by environment interaction effects and stability parameters for oil and seed meal quality, seed yield and its contributing characters of 25 Indian mustard [*Brassica juncea* (L.) Czern & Coss] varieties. Pooled analysis of variance indicated highly significant differences for genotypes (G), environments (E) and G × E interaction for oil, protein, glucosinolates, fatty acid profile, seed yield and contributing characters. The environment (linear) was highly significant for all the characters, while the linear component of genotype × environment interaction was highly significant for protein content only. Pooled deviation differed significantly for linoleic, linolenic, erucic acid, glucosinolates, days to maturity, 1000-seed weight and seeds/siliqua, suggesting the genotypes had varying level of stability over the cropping seasons for these characters. Stability parameters indicated that oil and protein content were fairly stable across environments in 14 and 11 varieties, respectively. Only 3 varieties were stable for maximum of 6 quality characters.

Three varieties showed stab le performance for seed yield over environments. Two varieties showed relatively stable maturity duration and 1000-seed weight, respectively over the environments.

Yadava *et al.* (2010) studied stability of improved and high-yielding varieties of Indian mustard (*Brassica juncea* L. Czern & coss.). Analysis of variance on 14 characters was carried out individually as well as pooled over the years and locations. Genotype × environment interaction was significant for days to maturity, plant height, point to first branch, primary branches/plant, secondary branches/plant, point to first siliqua and 1000-seed weight along with seed yield/plant. G × E (linear) was also significant for all these 8 traits and days to 50% flowering, indicating substantial amount of predictable G × E interaction. Thirty genotypes were tested for 3 stability parameters, viz mean, bi and $\check{S}^2$ di. Out of all the genotypes, four were identified to be high yielding and stable. Two were having superior performance for seed yield/plant but were found to be suitable for cultivation under rainfed (poor) environments. One was superior to the population mean for seed yield/plant and was found to be suitable for cultivation under irrigated (favourable) environment. Four genotypes were identified which may be included in any breeding programme to develop high-yielding stable genotypes over the environments. Direct selection in the segregating generations of such parents for 1000-seed weight, point to first branch along with simultaneous selection for secondary branches per plant, siliqua length and total number of siliquae per plant will be responsive for improvement of seed yield per plant.

Dar *et al.* (2011) evaluated ten genotypes of brown sarson over three locations for analysis of stability parameters with respect to seed yield per plant and oil content. Significant differences were observed for seed yield per plant and oil content among genotypes. G x E interaction (linear) was significant suggesting that performance of genotypes across environments could be predicted with greater precision. Statistical analysis was carried out as per Eberhart and Russell (1966) model. Joint regression analysis indicated that varieties and environments differed significantly for seed yield per plant and oil content. Variance due to environment + (variety x environment) component was significant for seed yield per plant.

Partitioning of this variability indicated divergent linear response to the environmental changes.

Escobar *et al.* (2011) conducted two experiments in canola to assess the nature and magnitude of GEI and division of mega-environments by SREG (Sites Regression) based models. The G × E interaction was significant for seed yield in many locations in one cropping season. Most of the analyzed seed yield variation was due to environment and G × E effects. Principal components (PC1 and PC2) of the Sites Regression (SREG) model, with five and eight environments, accumulated 74.5% and 61.1% of the total variation, respectively. Two mega-environments were formed; the first being the Chillán environment while the second included the remaining environments. Six of the evaluated cultivars, all hybrids except one, were superior. The mean vs. stability analysis indicated that the one hybrid had the highest yield and was the most stable cultivar across all environments. Although the information is for only one year, results could change with data from several years of experimentation. Hence, the study was carried out in many locations in order to provide validity to the results.

Francisco *et al.* (2011) studied twelve varieties of *B. rapa* at three locations in North western Spain over two years. Varieties were transplanted in a randomized complete block design with three replications. Several agronomic and morphological data were recorded. The Sites Regression method (SREG) was used to study the fresh production of these varieties and the stability of the genotypes. Each environment was defined as the combination of a year and a location resulting in six different environments under study. Principal components (PC) analysis was made on residuals of an additive model with locations as the only main effects. A two-dimensional biplot called GGE biplot (G plus GE interaction) of the two first PCs was plotted. Genotypes and locations were displayed in the same plot. The analysis of variance for SREG showed that turnip greens fresh matter and turnip tops fresh production were significantly affected by E, which explained 44% and 40% of the total variation, respectively; while GGE accounted for 46% and 58% of total sum of squares. Genotype main effects (G) accounted for the 69% and 64% of the GGE variation of turnip greens fresh matter and turnip tops fresh production, respectively. Therefore, the variation due to G was larger

than due to the GE interaction, but GE interaction was significant, meaning that differences among genotypes vary across environments. Varieties evaluated in this work displayed enough variability to identify appropriate and stable varieties for turnip greens and/or turnip tops fresh production.

Jeromela *et al.* (2011) conducted study to assess genotype by environment interaction for seed yield per plant in rapeseed cultivars grown in Northern Serbia by the AMMI (additive main effects and multiplicative interaction) model. The study comprised 19 rapeseed genotypes, analyzed in seven years through field trials arranged in a randomized complete block design, with three replicates. Seed yield per plant of the tested cultivars varied from 1.82 to 19.47 g throughout the seven seasons, with an average of 7.41 g. In the variance analysis, 72.49% of the total yield variation was explained by environment, 7.71% by differences between genotypes, and 19.09% by genotype by environment interaction. On the biplot, cultivars with high yield genetic potential had positive correlation with the seasons with optimal growing conditions, while the cultivars with lower yield potential were correlated to the years with unfavorable conditions. Seed yield per plant was highly influenced by environmental factors, which indicates the adaptability of specific genotypes to specific seasons.

Shojaei *et al.* (2011) studied the interaction of genotype and environment in canola crop. Ten genotypes of canola were studied under normal conditions of irrigation in four locations using randomized complete block design with three replications. Using GGE biplot method, grain yield was investigated for each cultivar. According to analysis of variance, there was significant difference among the regions. Based on the average yield and genotype stability, four genotypes were found the best cultivars. However, GGE biplot analysis indicated that three genotypes were better than the rest of the genotypes based on yield potential coupled with stability performance. Based on stability analysis four locations were divided into three mega-environments.

Yarnia *et al.* (2011) conducted study to evaluate the effect of drought stress on seed yield of some winter rapeseed cultivars and to study relevant drought tolerance indices, along with identifying resistant cultivars to drought stress, at Islamic Azad University of Tabriz research field. Three drought stress levels were

considered as the main factor levels, while seven winter rapeseed cultivars were arranged to sub plots. The quantitative drought tolerance indices were, tolerance index (TOL), mean productivity (MP), stress susceptibility index (SSI), stress tolerance index (STI), geometric mean productivity (GMP), yield index (YI), yield stability index (YSI), and percentage of yield reduction (% reduction). Multiplicative analysis showed that STI and GMP were two superior indices for identifying drought resistant cultivars.

Zhang *et al.* (2011) investigated genotype × environment (G×E) interaction and defined specific and general adaptation of canola to southwestern Australia wheat belt. The performance of 18 cultivars across 28 locations in 2008 and 2009 using National Varieties Trial data was evaluated. Finaly-Wilkson, AMMI and GGE Biplot analysis were used to visualize G×E interactions and determine the best performing cultivar for each environment. G×E interaction for seed yield was highly significant ($P < 0.001$), and accounted for more variance than that attributed to genotypes alone, suggesting that canola genotypes responded differently to variable environments. Three mega environments were identified and characterized by different climates. The results confirm the importance of matching phenology to growing season length, highlighting the need for specifically adapted cultivars even over relatively limited geographic scales, as defined by southwestern Australia.

Brar *et al.* (2012) conducted experiment in which twenty three genotypes of safflower were grown at 14 diverse locations covering vast area of India. The total sums of squares were 75.58% for environment, 6.53% for genotype, and 17.89% for the interaction for seed yield per hectare. Some genotypes which exhibited consistency for yield over all sites were identified while some genotypes which were most unstable performer across the locations because of their extreme adaptability to some specific locations were identified. Biplot analysis showed that some genotypes had additive gene(s) for increasing yield potentials and can prove better donor for developing genotypes having wider adaptability for high yield in safflower.

Chauhan *et al.* (2013) investigated the stability of oil, protein and glucosinolates, erucic, ecosenoic, oleic, linoleic, linolenic, palmitic and stearic acid along with

seed yield of 25 Indian mustard (*Brassica juncea* L.) genotypes using AMMI (additive main effect and multiplicative interaction) and bi-plot analyses based on double centred principal component analysis (PCA). Combined analysis of variance showed highly significant (P<0.01) difference between the genotypes, locations and G×E interaction, suggesting differential response of genotypes across growing environments, which could be attributed to differential ranking of genotypes. PCA 1 and PCA 2 axes were significant (P< 0.01) and captured the largest portion of the variation of the G×E interaction for all the characters, indicating that AMMI 2 model was the best for the data set, therefore, a bi-plot of PCA 1 and PCA 2 was constructed to identify the most stable genotypes for different quality characters. AMMI‟s stability parameter- ASV (AMMI stability value) has been calculated for each genotype. Higher ASV reflected variable response to different environment and lower ASV reflects stability across the environments. AMMI analysis revealed that IPCA1 and IPCA2 captured almost 100% of the interaction sum of squares and were also significant (P < 0.01) for all the characters investigated, suggesting that the AMMI model with two principal components was the best predictive model. Considering results from AMMI and bi-plot analyses, five genotypes were most stable for oil, protein, glucosinolates content, fatty acid profile and seed yield.

Wani *et al.* (2013) conducted experiments over two years to assess the stability on yield and its attributes along with oil content of twelve genotypes of Indian mustard (*Brassica juncea* L. Czern and Coss) at two locations with two different dates of sowing creating eight artificial environments. Variance due to G x E interaction was significant for all the characters except for days to 50% flowering, while G x E (linear) was found to be significant for number of secondary branches per plant, number of siliquae per plant, siliqua length, seed yield per plot and 1000 seed weight. Three genotypes were recommended for general cultivation and their utilization in future breeding programme. Under favourable environments, four genotypes were recommended for general cultivation. On the contrary, one genotype were recommended for poor/unfavourable environmental conditions.

Wilkes *et al.* (2013) conducted two experiments in north-western New South Wales, Australia to determine the effect of genotype (G), growing site (S) and year

(Y) on the suitability of Indian mustard (*Brassica juncea*) as a biodiesel feedstock. The first experiment analyzed the effect of growing environment on six mustard genotypes while the second experiment analyzed the effect of sowing of same genotypes across two seasons. The results demonstrate that late sowing forced maturity of the seed and decreased the yield whilst early sowing resulted in economically viable seed yields. The oil content of the seed ranged from 34 to 39.8% and the main fatty acids present in the oil were oleic (C18:1) and linoleic acid (C18:2) in both experiments. The main factor that impacted on the fatty acid profile in a single season was the seed genotype while in the second experiment the growing year and interactions between year and the other parameters had a major impact on the fatty acid profile. The main fatty acids affected by the growing year were oleic, linoleic and erucic (C22:1). Oleic and linoleic acids were inversely correlated with erucic acid content which tended to be higher in cooler growing conditions. Two genotypes were processed into biodiesel and assessed for quality. The fuel met most requirements except for oxidation stability and kinematic viscosity. The relatively high concentration of polyunsaturated fatty acids was deemed to be responsible for the poor oxidation stability and higher amounts of erucic acid and glycerol would contribute to poor kinematic viscosity values. The mustard genotypes analyzed may prove to be both a viable break crop as well as providing a good feedstock for the establishment of a biodiesel industry in this area.

2.3 Methods for estimation of genotype x environment interactions and their application

Different organisms achieve stability or buffering through different genetic mechanism. Among the genetic mechanisms of phenotypic stability and adaptation, ploidy level and genome composition, maintenance of high degree of heterozygosity, selection history, release of cryptic genetic variability, nature of environment in which selection is made and association of plant type for specific adaptation has been investigated. Allard and Bradshaw (1964) revealed that a variety can achieve stability of performance by individual buffering and by populational buffering which can be measured in terms of G x E interaction.

Increased concern with the importance of homeostasis in living organisms has stimulated plant breeder's awareness for the need to develop well buffered cultivars. This has led to a greater emphasis on phenotypic stability in breeding programmes. Several methods have been proposed for an estimation and partitioning of G x E interaction in quite different ways depending on how the scientists look at the problem and a still increasing number of stability parameters has been developed. This leads many workers to wonder which stability statistics, would be used for their particular problem.

For comparing varietal performance in several environments for several years, various workers viz. Immer *et al.* (1934), Salmon (1951), Horner and Frey (1957) and Sandison and Bartlett (1958) have discussed some of the methods and problems, but were unable to pin point the genotype which were stable in productivity, owing to the change in ranks at different locations. The idea of breaking down interaction into several parts is entirely missing in the various component approaches.

Eberhart and Russell (1966) in their model for stability emphasized the need of considering both linear (bi) and non-linear (S^2di) components of genotype x environment interaction in judging the phenotypic stability of a genotype. They considered that the most desirable variety is one which has high mean yield (μ), unit regression coefficient (bi= 1.00) and least deviation (S^2di= 0) from regression. Fisher and Mackenzie (1923) were first to apply both singular value decomposition (SVD) and ANOVA, separately to the same dataset, a potato (*Solanum tuberosum* L.) yield trial. But Kempton (1984) was the first publication in the agricultural literature that substantially accelerated interest, and it used both AMMI and GGE. Zobel *et al* (1988) built on that work, further popularizing AMMI. About a decade later, several papers popularized GGE, beginning with Yan *et al*. (2000).

At present, AMMI and GGE are among the foremost statistical methods for analyzing yield-trial data. The MEYT allow the investigation of varietal yield performance across a range of geographic locations and years. The earlier statistical methods were focused on Analysis of Variance (ANOVA) techniques (Yate and Cochran 1938) that partitions total variance into sources to genotypes,

environments (location/year combination), genotype by environment interactions (GEI) and within trial error variance. ANOVA being an additive model that describes the main effects of genotypes and environments effectively and determines if GEI is a significant source of variation, but it does not provide insight into the genotypes or environments that give rise to the interactions (Samonte *et al* 2005) and this may hinder varietal selection and recommendation decisions (Kempton 1984). Thus, the equivalence of GEI and non-additive in linear statistical models is rather restrictive. But Generalized Linear Bilinear Models (GLBM) is best solution to resolve the magnitude, causes and exploitation of multiplicative interactions of GEI (Cornelius and Seyedsadr 1997).

The Additive Main effects and Multiplicative Interactions (AMMI) model and the Genotype main effects and Genotype × Environment interactions effects (GGE) model (fitted to residuals after removal of environment main effects) have been the two most commonly used models for the biplot analysis. Above these, two modeling are based on the fixed models in this environmental and genotypic main effects are fixed but recently mixed models have been used in Factorial Analysis (FA) which is capable to resolve non-additively in fine way (Yang 2007).

An understanding of environmental and genotypic causes of GEI is important at all stages of plant breeding, including ideotype design, parent selection, selection based on traits and selection based on yield (Jackson *et al* 1996, Yan and Hunt 1998). Understanding the causes of GE interactions can be used to establish breeding objectives, identify ideal conditions, and formulate recommendations for areas of optimal cultivar adaptation.

Numerous methods have been used in the search for an understanding of the causes of GXE interactions (Van *et al* 1996). These methods can be categorized into two major strategies. The first strategy involves factorial regression analysis of the GE matrix (i.e., the yield matrix after the environment and genotype main effects are removed) against environmental factors, genotypic traits, or combinations thereof (Baril *et al* 1995). The second strategy involves correlation or regression analysis which relates the genotypic and environmental scores derived from principal component analysis of the GE interactions matrix to genotypic and environmental covariates. Frensham *et al* (1998) and Vargas *et*

al(1999), used methods that belong to the first category. Frensham *et al* (1998), when analyzing 10 years of oat (*Avena sativa* L.) evaluation data in Australia, incorporated several genotypic covariates into a mixed model. They indicated that plant type (plant height, kernel type) by environment interactions explained 50% of the observed GE interactions.

Gabriel 1971 provided graphical presentation of interactions patterns called biplot technique, which allowed the response of each variety in each environment predicted by these models to be directly identified. It provided a useful tool for data analysis and allowed visual appraisal of the structure of large data matrices. The second strategy is associated with the use of the AMMI model in MET data analysis, which partitions the GE interactions matrix into individual genotypic and environmental scores. The first example was provided by Zobel *et al* (1988), who attributed the GE interactions of a soybean [*Glycine max* (L.) Merr.].

The term GXE interactions commonly refer to yield variation that cannot be explained by the genotype main effect (G) and the environment main effect (E). For cultivar evaluation, however, both G and GE must be considered simultaneously. Using a Sites Regression model (SREG) as devised by Cornellius *et al* (1996), Yan *et al* (2000) combined G and GE, denoted as G + GE or GGE referred to biplot based on singular value decomposition (SVD) of environment-centered or within environment as „GGE Biplot" as these biplot display both G and GE, which are the two sources of variation that are relevant to cultivar evaluation (Kang 1988, 1993, Gauch and Zobel 1996, Yan and Kang 2003, Yan *et al* 2007) and repartitioned this into non-crossover GE interactions and crossover GE interactions based on the Shifted Multiplicative Models (SHMM) for non-additive variances (Seyedsadr and Cornellius 1992).

Understanding the causes of non-crossover and crossover GE interactions would help develop an understanding of the genotypic characteristics that contribute to a superior cultivar, and the environmental factors that can be manipulated to facilitate selection for such cultivars. The method is based on the fact that although the quantitative traits are obtained from the combined effect of genotype (G), environment (E) and genotype × environment interactions (G x E). The GGE

biplot analysis only considers the effects of G×E and G to be relevant in the evaluation of cultivars (Miranda *et al* 2009).

Blanche & Myers (2006) used the GGE Biplot method to identify test locations that optimize genotype selection on the basis of their discriminating ability and representativeness. Kang *et al* (2006) also used GGE Biplot methods and concluded that the analysis helped identify cultivars that were adapted across locations, or whose stability was influenced by a linear effect of an environmental index. The GGE biplot methodology drew the attention of many plant breeders and other researchers for two reasons. Firstly, it explicitly and necessarily requires that genotype (G) and (GE) interaction, i.e., GGE, be regarded as integral parts in cultivar evaluation and plant breeding. Second, it presents GGE using the biplot technique (Gabriel, 1971) in a way that many important questions, such as the 'which-won-where' pattern, mean performance and stability of genotypes, discriminating ability and representativeness of environments, etc., can be addressed graphically.

CHAPTER III

MATERIALS AND METHODS

The experiment was conducted to study the genotype and environment interactions in yield and its contributing characteristics of eleven (11) mustard varieties in Bangladesh with three sowing time environments viz., Evn-1 (optimum), Evn-2 (late) and Evn-3 (very late). The details of the materials and methods i.e. description of the experimental site, soil and climatic condition of the experimental plot, materials used, experimental design, data collection and procedure of data analysis that used or followed in this experiment has been presented below under the following points:

3.1 Description of the experimental site

3.1.1 Experimental period

The field experiment was conducted during the period of October, 2017 to April, 2018.

3.1.2 Location of the experiment

The present research work was conducted in the experimental area of Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka. The location of the site is 23074'N latitude and 90035'E longitude with an elevation of 8.2 meter from sea level. Location of the experimental site presented in Appendix I.

3.1.3 Climatic condition

The geographical location of the experimental site was under the subtropical climate and its climatic conditions is characterized by three distinct seasons, namely winter season from the month of November to February and the pre-monsoon period or hot season from the month of March to April and monsoon period from the month of May to October (Edris *et al*., 1979). Details of the meteorological data of air temperature, relative humidity, rainfall and sunshine hour during the period of the experiment was collected from the Weather Station

of Bangladesh, Sher-e-Bangla Nagar, Dhaka and details has been presented in Appendix II.

3.1.4 Soil characteristics of the experimental plot

The soil belonged to "The Modhupur Tract", AEZ-28 (FAO, 1988). Top soil was silt clay in texture, olive-gray with common fine to medium distinct dark yellowish brown mottles. Soil pH was 5.6 and had organic carbon 0.45%. The experimental area was flat having available irrigation and drainage system and above flood level. The selected plot was medium high land. The details have been presented in Appendix III.

3.2 Experimental details

3.2.1 Planting materials

In this experiment eleven (11) mustard genotypes (Table 1) were used as experimental materials which were collected from Bangladesh Agricultural Research Institute (BARI).The purity and germination percentage were assessed as 94% and 91% respectively of the plant materials.

Table 1. Name and sources of mustard varieties the used in the present study

Genotype	Name	Source
V1	BARI Sharisha-6	BARI, Gazipur
V2	BARI Sharisha-9	BARI, Gazipur
V3	BARI Sharisha-12	BARI, Gazipur
V4	BARI Sharisha-14	BARI, Gazipur
V5	BARI Sharisha-15	BARI, Gazipur
V6	Sonali Shaisha-75 (SS-75)	BARI, Gazipur
V7	BARI Sharisha-17	BARI, Gazipur
V8	Maghi	Local, Manikgonj
V9	Improved Tori	BARI, Gazipur
V10	BINA Sharisha 10	BINA, Mymensingh
V11	BINA Sharisha 9	BINA, Mymensingh

3.2.2 Experimental design and layout

The experiment was laid out in randomized complete block design (RCBD) with 3 replications. The field was divided into 9 blocks. The individual block size was 1m × 3m, plant to plant distance was 3-5 cm and row to row distance was 30 cm. The genotypes were distributed to each row in each block randomly. Experimental field is presented in Plate 1.For studying the GXE interactions we used three environments e.g. Evn-1, Evn-2 and Env-3 of three sowing times. The Env-1 was sowing of the eleven mustard varieties on 1 November, 2017, the Env-2 was second sowing of the mustard varieties on 10 November, 2017 and Env-3 was third sowing of the mustard varieties on 20 November, 2017. The detail layout the experiment of GXE interaction with eleven mustard varieties with three environments in three replications has been depicted in the plate 1.

3.3. Growing of crops

3.3.1 Preparation of the main field

The selected field for growing mustard was first opened with power tiller and was exposed to the sun for a week. Then the land was prepared to obtain good tilth by several ploughing, cross ploughing and laddering. Subsequent operations were done with harrow, spade and hammer. Weeds and stubbles were removed; larger clods were broken into small particles and finally attained into a desirable tilth to ensure proper growing conditions. The plot was partitioned into the unit blocks according to the experimental design as mentioned earlier. Recommended doses of well decomposed cow dung, manure and chemical fertilizers were applied and mixed well with the soil each blocks. Proper irrigation and drainage channels were also prepared around the blocks. Each unit block was prepared keeping 5 cm height from the drains. The bed soil was made friable and the surface of the bed was leveled.

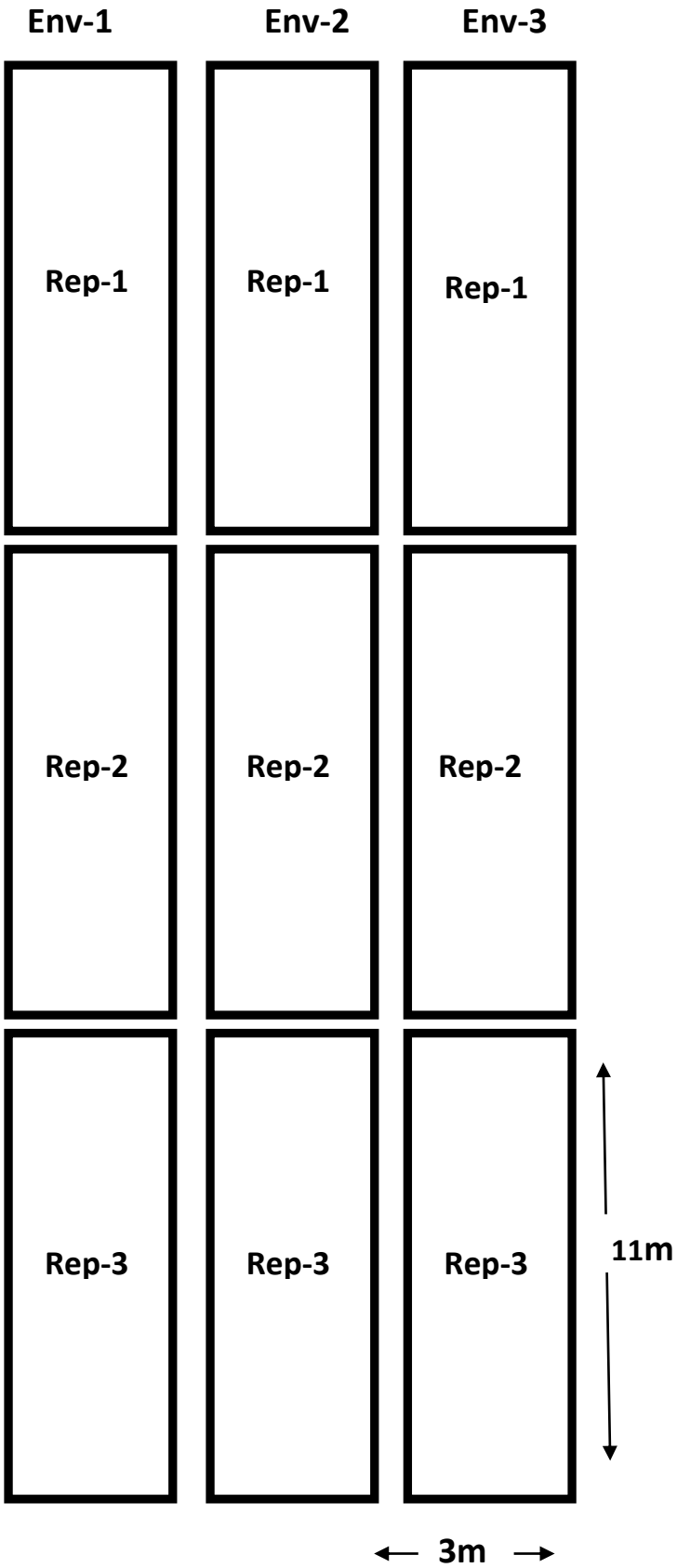


Plate 1. Experimental layout of showing eleven mustard varieties in three environments (e.g. Env-1, Env-2, Env-3) in three replications

Fig 1. Experimental field at Sher-e-Bangla Agricultural University

3.3.2 Application of manure and fertilizers

Organic and inorganic fertilizer viz. cow dung, urea, TSP and MP fertilizers are required for mustard cultivation. The field was fertilized as the rate shown in Table 2. The area was fertilized with 10 to cow dung per ha. The entire amount of cow dung was applied seven days before sowing. Half amount of urea, total TSP, MP, Gypsum and Boron were applied during final land preparation and incorporated into the soil. The rest amount of urea was applied as top dressing after 25 days of sowing (DAS) for each of the environments.

3.3.3 Sowing of seeds in the field

The mustard seeds were sowed in lines each having a line to line distance of 30 cm under direct seeding in the well prepared plot on three different times and three replications for every sowing. First sowing (Env-1) was done on 1 November, 2017, second sowing (Env-2) was done on 10 November, 2017 and third sowing (Env-3) was done on 20 November.

3.3.4 Post care

When the seedlings started to emerge in the beds it was always kept under careful observation. After emergence of seedlings, various intercultural operations were accomplished for better growth and development of the mustard seedlings.

3.3.4.1 Irrigation and drainage

Irrigation was given with cane after sowing of seeds to bring proper moisture condition of the soil to ensure uniform germination of the seeds. A good drainage system was maintained for immediate release of rainwater from the experiment plot during the growing period. Slide irrigation was also given after the top dressing of urea at 25 DAS.

3.3.4.2 Thinning

The seedling were first thinned from all of the plots at 10 Days after Sowing (DAS) 2nd thinning was carried out after seven days of 1^{st} thinning for maintaining proper plant population in the experimental plots.

3.3.4.3 Weeding

Weeding were done to keep the plots free from weeds, easy aeration of soil and to conserve soil moisture, which ultimately ensured better growth and development. The newly emerged weeds were uprooted carefully after complete emergence of mustard seedlings and whenever necessary. Breaking the crust of the soil, when needed was done through mulching.

3.3.4.4 Plant Protection

After 50 days of planting, first spray of chloropyriphose was done against sucking pest such as and aphids.

3.4 Harvesting

.The crop was harvested in different dates according to maturity. Harvesting was started when the 80% of the crop showed maturity symptoms like straw color of siliqua, leaves, stem and desirable seed color in the matured siliqua, the crop was

assessed to attain maturity. For harvesting 5 plants was selected randomly from each of the replication of every environment. The plants were harvested by uprooting and then tagged properly.

Table 2. Dose and method of application of fertilizers in mustard field

Sl No.	Fertilizer	Doses	Application Procedure
01	Cow dung	10 ton/ha	as basal
02	Urea	270 kg/ha	50% basal and 50% at 25 DAS
03	TSP	170 kg/ha	as basal
04	MP	100 kg/ha	as basal
05	Gypsum	150 kg/ha	as basal
06	Zinc oxide	5 kg/ha	as basal
07	Boron	3 kg/ha	as basal

3.5 Data recording

3.5.1 Plant height excluding root (cm)

Plant height was measured in centimeter (cm) from the base of the plants to the tip of the longest inflorescence at each of the five randomly selected plants from every environment.

3.5.2 Number of Primary Branch

The total number of branches arisen from the main stem of a plant was counted as the number of primary branches per plant.

3.5.3 Number of Secondary Branch

The total number of branches arisen from the primary branch of a plant was counted as the number of secondary branches per plant.

3.5.4 Number of Siliqua per Plant

Total number of siliquae of each plant was counted and considers as the number of siliquae per plant.

3.5.5 Length of Siliqua (cm)

This measurement was taken in centimeter (cm) from the base to the tip of a siliqua of the five representative siliquae for every replication from every environment.

3.5.6 Number of Seeds/Siliqua

Well filled seeds were counted from five siliquae which was considered as the number of seeds per siliqua.

3.5.7 Thousand Seed Weight

Weight in grams of randomly counted thousand seeds of each entry was recorded.

3.5.8 First flowering date

Days to first flowering were recorded from sowing date to the date of first flowering of every replication from Env-1, Env-2 and Env-3.

3.5.9 50% Flowering Date

Days to 50% flowering were recorded from sowing date to the date of 50% flowering of every replication from Env-1, Env-2 and Env-3.

3.5.10 Date of Maturity

The data were recorded from the date of sowing to siliquae maturity at 80% plants of every replication from Env-1, Env-2 and Env-3.

3.5.11Yield per plant

All the seeds produced by a representative plant was weighed in g and considered as the seed yield per plant.

3.6 Statistical analysis

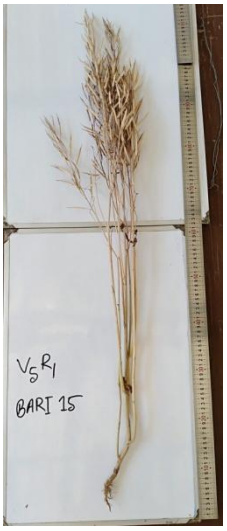
The data on growth parameters and other plant were statistically analyzed following standard procedure followed by Kulsum *et al*. (2013). ANOVA was

BARI Sharisha-6

BARI Sharisha-9

BARI Sharisha-12

BARI Sharisha-14



BARI Sharisha-15

Sonali Sharisha-75

BARI Sharisha-17

Maghi

Improved Tori

BINA Sharisha-10

BINA Sharisha-9

Plate 2. Matured harvested Plants of eleven verities used in experiments

used and the GEI was estimated by the AMMI model (Zobel *et al*., 1988). In this model the contribution of each genotype and each environment to the GEI is assessed by use of the IPCA1 (Zobel *et al*., 1988). The stability parameters, regression coefficient (bi) and deviation from regression (S^2di) were estimated according to Eberhart and Russell (1966). Significance of differences among bi value and unity was tested by t test, between S^2di and zero by F test (Eberhart and Russell, 1966). All the data were subjected using statistical analysis package software Cropstat version 7.2 (AMMI, SSA and ANOVA models) after Zobel *et al*. (1988).

3.6.1 AMMI model of stability analysis

The AMMI model has been extensively applied in the statistical analysis of multi-environment cultivar trials (Kempton, 1984; Gauch and Zobel, 1989, 1997; Crossa *et al*., 1990). According to Oliveira *et al*. (2010) the AMMI analysis according to Zobel *et al*. (1988) combines in a single model additive components for the main effects of genotype (gi) and environments (ej), and multiplicative components for the effect of GE interaction (geij). The model that describes the mean of genotype I in environment j is given by:

$$\bar{Y}ij = \mu + gi + aj + \sum_{k=1}^{n} \lambda_k \gamma_{ik} \alpha_{jk} + r_{ij} + \varepsilon_{ij}$$

Where:

$\bar{Y}ij$ is the average yield of ith genotype in jth environment, and is the overall mean yield

Gi is the effects of genotype i;

Aj is the effect of environment j;

γ_k is the kth singular value of the original matrix interactions (GE);

γ_{ik} is the the element corresponding to the i^{th} genotype in the k^{th} singular vector of the GE matrix column;

α_{ik} is the element corresponding to the jth environment in the k^{th} singular vector of the GE matrix row;

r_{ij} is the noise associated with the expression ge_{jk} not explained by the retained principal components;

n is the number of axes or principal components retained to describe the GE interaction pattern;

εij is the average experiment error associated with observation, assumed to be independent ε~N (0, σ2).

For the GE interaction, the biplot is interpreted by observing the magnitude and sign of the acores of genotypes and environments, for the axis (axes) of interaction. Tus, low acores (close to zero) represent genotypes and environments are little involved in the interaction and characterized as stable. In an AMMI2 biplot, the points of stable genotypes and environments.

3.6.2 Eberhart and Russel's method of stability analysis

The statistical approach suggested by Eberhart and Russell (1966) was followed for genotype environment interaction and estimation of stability parameters. According to them, a stable genotype may be considered as one having high mean, average linear regression as close to zero. According to Panwar *et al*.(1995), during data analysis, different sowing dates are considered as separate environment. Therefore, results of three environments were considered for data analysis.

Luthra *et al*. (1974) rcommended Eerhart and Russell's model for stability analysis condidering its simplicity. Everhart and Russell(1966) used the following models to study the stability of genotypes under different environments.

Yij= μ + bilj +δij+ eij(i=1,2,...g andj = l,2 ... e)

Where Yij is the mean for the genotypes i at location j; μ is the general mean for genotype i; bi is the regression coefficient for the ith genotype at a given location index, which measures the response of a given genotype to varying location; Ij is

the environmental index, which is defined as the mean deviation from regression for the ith genotype at the jth location; and eij is the mean for experimental error.

Yij= μ + bilj +δij+ eij(i=1,2,...g andj = l,2 ... e)

Where Yij is the mean for the genotypes i at location j; μ is the general mean for genotype i; bi is the regression coefficient for the ith genotype at a given location index, which measures the response of a given genotype to varying location; Ij is the environmental index, which is defined as the mean deviation from regression for the ith genotype at the jth location; and eij is the mean for experimental error.

$Bi= \sum Y_{ij}I_j / \sum I_j^2$

Where ∑YijIj is the sum of products and ∑Ij2 is the sum of squares

Mean square deviations S_{di}^2 is the linear regression,

$$S_{di}^2 = [\frac{\sum j \hat{\delta}_{ij}^2}{b-2}] - S_e^2/n$$

Where S= no. of environments, S^2e=is the estimate of the pooled error, and

$$\hat{\delta}_{ij}^2 = \left[\sum y_{ij} - \frac{y_j^2}{b}\right] - (jy_{ij}Ej)^2/E_j^2$$

The model provides a means of partitioning the GE interaction of each genotype into two parts:

(i) The variation due to the response of genotype to varying environmental indices (sums of square due to regression), and

(ii) The unexplainable deviation from regression on the environmental indices.

Further, they define that the stable variety will ve one with bi=1.0 and s2di=0; and the null hypothesis

H0: μ1=μ2=….=μm

Can be tested by the F-test

$F \cong M_G/M_d$

With Homogeneous deviation means squares, being Md the pooled deviations.

The hypothesis that there are no genetics differences among phenotypes for there regression on the environmental index

Ho:

Can be tested by the F-test

$F \cong M_{EI}/M_d$

The deviation from regression for each genotype can be further tested by

$F \cong [(\sum j \hat{\delta}\_ij\text{^}2)/(b-2)]/$ Pooled error

Thus, in this approach one can see that two measures of sensitivity of the genotype to changes on environment are worked out:

The linear sensitivity measure in terms of the regression coefficient, bi, of the ith genotype to the environmental change, and

The non linear sensitivity measure in terms of the deviation from regression mean square

The individual genotypic response i.e. regression coefficient (bi) was tested by t-test using the standard error of the corresponding bi value against the hypothesis. The individual deviation from linear regression tested by F- test using pooled error and S2 di did not significantly from zero in most of the genotypes.

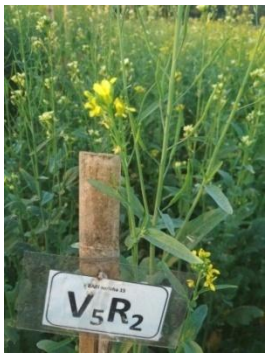
Plate 3. The experimental field showing seedlings in three environments

BARI Sharisha-6

BARI Sharisha-9

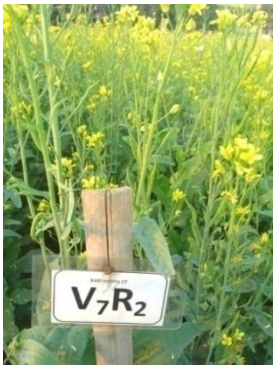
BARI Sharisha-12

BARI Sharisha-14



BARI Sharisha-15

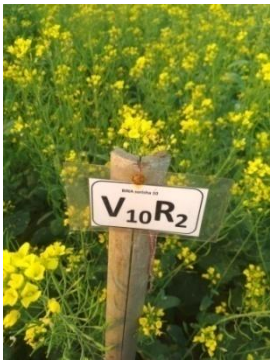
Sonali Sharisha-75



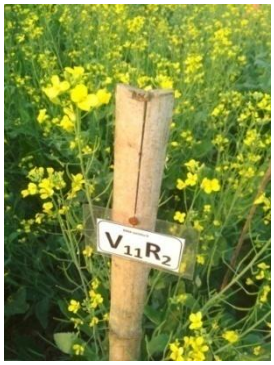
BARI Sharisha-17

Maghi

Improved Tori



BINA Sharisha-10



BINA Sharisha-9

Plate 4. Eleven genotypes using in G x E interaction of mustard

CHAPTER IV

RESULT AND DISCUSSION

In the present investigation the data was collected from eleven diverse *Brassica rapa* verities cultivated in three environments on eleven traits related to vegetative, reproductive and yield parameters emphasizing growth and yield. The data were subjected to biometrical analysis and results obtained are presented below under the following headings:

4.1 Combined analysis of variance (ANOVA) according to the best AMMI model

4.2 Stability analysis for different characters of eleven genotypes of Mustard

4.3 Interaction Biplot of AMMI Model

4.1 Combined analysis of variance (ANOVA) according to the best AMMI model

Results of combined analysis of variance for eleven characters viz. days to first flowering, days to 50% flowering, plant height excluding rood(cm), number of primary branches per plant, number of secondary branches per plant, number of siliqua per plant, length of siliqua, number of seed per siliqua, thousand seed weight and yield per plant are presented in Table 4. The mean sum of squares for the genotypes were highly significant for all the characters except length of siliqua and thousand seed weight which reveals the presence of genetic variability in the material under investigation for all the characters studied. The G (genotype) x E (environment) interactions both nonlinear and linear was significant for maximum of the characters except number of primary branch, number of secondary branch, length of siliqua and thousand seed weight when tested against pooled error, suggesting the data might be extended for stability analysis. Highly significant mean sum of squares due to environments (linear) indicated the difference between the environments.

Table 3. Full joint combined analysis of variance including the partitioning of G xE interaction of eleven varietiesof Mustard

Source of variation	df	Mean Sum of squares										
		PH	**NPB**	**NSB**	**DFF**	**DHF**	**DM**	**NSP**	**LS**	**NSS**	**TSW**	**TYP**
Genotype (G)	10	203.98**	3.93**	6.35**	25.86**	55.25**	52.19**	2439.67**	1.44	69.33**	0.89	15.51**
Environment (E)	2	4.41*	0.15	0.02	11.64**	11.04**	111.55**	910.58**	0.06	18.24**	0.04	0.06
Interaction (G x E)	20	26.85**	0.07	0.14	1.57	0.77	1.68	102.75**	0.00	1.33	0.04	0.03
AMMI Component 1	11	567.69	10.72	17.36**	70.60	150.69	142.34**	6663.78	3.92	189.08	2.47**	42.31
AMMI Component 2	9	61.70	0.00	0.07**	5.10	0.00	0.07*	39.76	0.00	0.00	0.08**	0.00
AMMI Component 3	7	13.37	0.00	0.04**	0.31	0.00	0.02	1.28	0.00	0.00	0.04**	0.00
G x E (Linear)	10	30.43**	0.16	0.19	5.09**	3.18**	24.30**	376.70**	0.01	5.94**	0.05	0.05
Polled deviation	10	24.16**	0.01	0.09	0.38	0.57	1.37	10.91**	0.00	0.36	0.04	0.02
Polled error	60	22.89	0.21	0.24	1.32	1.93	4.59	222.40	0.00	5.45	0.03	0.17

** Significant at 1% level of significance

* Significant at 5% level of significance

PH =Plant height, NPB = Number of Primary Branch, NSB= Number Secondary Branch, DFF= Days to First Flowering, DHF= Days to 50% Flowering, DM= Days to Maturity, NSP = Number of Siliquae per Plant, LS = Length of Siliquae, NSS = Number of Seeds per Plant, TSW= Thousand seed weight, TYP = Total Yield per Plant

4.2 Stability analysis for different characters of eleven genotypes of Mustard

Eberhart and Russell (1966) emphasized the need of both linear (bi) and non-linear (S^2di) components of genotype x environment interactions in judging the phenotypic stability of genotype. In this model regression coefficient (bi) is considered as parameter of response and deviation from regression (S2di) as the parameter of stability. Relatively lower value of bi, say around 1 will mean less responsive to the environmental change and therefore, more adaptive. If, however, b is negative, the genotype may be grown only in poor environment. Deviation from regression (S^2di), if significant, the performances of a genotype for a given environment may be predicted. Therefore, a genotype whose performance for a given environment can be predicted i.e., S^2di is around 0 will said to be stable genotype

Results of stability and response of the genotypes under different environments according to Eberhart and Russel are discussed character-wise as follows: Stability parameter i.e., regression coefficient (bi) and deviation from regression (S^2di) for days to first flowering, days to 50% flowering, plant height excluding rood(cm), number of primary branches per plant, number of secondary branches per plant, number of siliqua per plant, length of siliqua, number of seed per siliqua, thousand seed weight and yield per plant of the individual genotypes are presented under the following heads.

4.2.1 Days to first flowering

Mean performance of the promising genotypes, their response and stability parameters phenotypic indices (Pi), regression coefficient (bi) and deviation from regression (S^2di) for days to first flowering are presented in Table 4.

Among the genotypes Sonali Sharisha-75 and BARI Sharisha-15 took minimum and maximum days for first flowering, respectively. The environmental mean and genotypic mean ranged from 27.70 to 27.73 and 22.67 to 31.22 respectively.

Four genotypes i.e. BARI Sharisha-14, Sonali Sharisha-75, Maghi and Improved Tori showed negative phenotypic index, which represents those genotypes were desirable for early first flowering. While the other seven genotypes i.e., BARI

Sharisha-6, BARI Sharisha-9, BARI Sharisha-12, BARI Sharisha-15, BARI Sharisha-17, BINA Sharisha 10 and BINA Sharisha 9 had positive phenotypic index for days to first flowering this represents the undesirability of those genotypes for early first flowering or desirability of those genotypes for late first flowering.

Again positive and negative environmental index (Ij) reflects the rich or favorable and poor or unfavorable environment for early first flowering. Thus the Env-2 and Env-3 was poor environments for early first flowering and rich environments for late first flowering. Env-1 was rich environment for early first flowering and poor environments for late first flowering in mustard production. Genotypes having negative bi value may be grown in poor environments (Muradunnabi, 2010). In that sense, BARI Sharisha-9, Maghi, Improved Tori and BINA Sharisha 9 was found adaptive for poor environment.

The regression coefficient (bi) values of these genotypes ranged from 0.05 to 3.29. These differences in bi values indicated that all the genotypes responded differently to different environments. Considering the mean, bi and S^2di, it was evident that all the genotypes showed different response of adaptability under different environmental conditions. There is no genotype exhibited comparatively lower first flowering day, as their bi~1 and S2di~0 indicated that the genotypes were stable across the environment. The cultivars which has significant deviation mean square (S2di), implying that these cultivars have unstable performance across the testing environment (Worku and Zelleke, 2009).

Table 4. Stability analysis for days to first flowering of eleven (11) varieties of Mustard in three environments (Env) evaluated during rabi season of 2017-18

Code	Genotype Name	Environments				Pi	bi	S^2di
		Env-1	Env-2	Env-3	Overall Mean			
G1	BARI Sharisha-6	30.67	29.67	29.33	29.89	1.2727	2.07	-0.30
G2	BARI Sharisha-9	32.67	30.67	30.00	31.11	2.4950	-0.47	30.75
G3	BARI Sharisha-12	32.33	29.67	29.33	30.44	1.8283	0.05	7.83
G4	BARI Sharisha-14	30.67	26.67	25.67	27.67	-0.9495	2.23	19.76
G5	BARI Sharisha-15	33.67	30.67	29.33	31.22	2.6061	3.29	-0.18
G6	SS-75	22.67	22.67	22.67	22.67	-5.9495	2.19	12.74
G7	BARI Sharisha-17	32.33	29.67	28.33	30.11	1.4950	2.82	25.67
G8	Maghi	26.33	26.00	25.67	26.00	-2.6162	-0.93	0.00
G9	Improved Tori	26.67	24.00	23.33	24.67	-3.9495	-0.24	-0.15
G10	BINA Sharisha 10	28.67	31.00	31.00	30.22	1.6061	0.43	5.78
G11	BINA Sharisha 9	30.33	32.00	30.00	30.78	2.1616	-0.42	7.13
	E. Mean	**29.73**	**28.42**	**27.70**	**28.62**			
	E. Index (Ij)	**1.1111**	**-0.1919**	**-0.9192**				
	CV%	**3.46**	**4.21**	**4.38**				
	LSD (0.05)	**3.03**	**3.53**	**3.58**				

4.2.2 Days to 50% flowering

Mean performance of the promising genotypes, their response and stability parameters phenotypic indices (Pi), regression coefficient (bi) and deviation from regression (S^2di) for days to 50% flowering are presented in Table 5.

Among the genotypes Maghi and BARI Sharisha-17 took minimum and maximum days for 50% flowering, respectively. The environmental mean and genotypic mean ranged from 29.44 to 40.78 and 34.94 to 36.91 respectively.

Six genotypes i.e. BARI Sharisha-14, Sonali Sharisha-75, Maghi, Improved Tori, BINA Sharisha 10, BINA Sharisha 9 showed negative phenotypic index, which represents those genotypes were desirable for early 50% flowering. While the other five genotypes i.e., BARI Sharisha-6, BARI Sharisha-9, BARI Sharisha-12, BARI Sharisha-15, BARI Sharisha-17, had positive phenotypic index for days to 50% flowering this represents the undesirability of those genotypes for early 50% flowering or desirability of those genotypes for late 50% flowering.

Again positive and negative environmental index (Ij) reflects the rich or favorable and poor or unfavorable environment for early 50% flowering. Thus the Env-2 and Env-3 was poor environments for early 50% flowering and rich environments for late 50% flowering. Env-1 was rich environment for early 50% flowering and poor environments for late 50% flowering in mustard production. Genotypes having negative bi value may be grown in poor environments (Muradunnabi, 2010). In that sense BINA Sharisha-9 was found adaptive for poor environment.

The regression coefficient (bi) values of these genotypes ranged from 0.37 to 1.81. These differences in bi values indicated that all the genotypes responded differently to different environments. Considering the mean, bi and S^2di, it was evident that all the genotypes showed different response of adaptability under different environmental conditions. The genotypes BARI Sharisha-14 and BARI Sharisha-15 exhibited comparatively lower 50% flowering day, as their bi~1 and S^2di~0 indicated that the genotypes were stable across the environment.

Table 5. Stability analysis for days to 50% flowering of eleven (11) varieties of Mustard in three environments (Env) evaluated during rabi season of 2017-18

Code	Genotype Name	Environments				Pi	Bi	S^2di
		Env-1	Env-2	Env-3	Overall Mean			
G1	BARI Sharisha-6	41.33	39.67	40.33	40.44	4.6263	1.63	12.78
G2	BARI Sharisha-9	40.67	39.67	37.67	39.33	3.5152	1.81	19.42
G3	BARI Sharisha-12	40.67	39.33	38.00	39.33	3.5152	1.41	3.90
G4	BARI Sharisha-14	35.67	33.67	33.00	34.11	-1.7071	1.44	-0.47
G5	BARI Sharisha-15	42.00	40.33	37.00	39.78	3.9596	1.33	2.02
G6	SS-75	34.67	31.67	32.33	32.89	-2.9293	0.57	12.05
G7	BARI Sharisha-17	40.67	40.67	41.00	40.78	4.9596	1.26	17.20
G8	Maghi	30.67	29.00	28.67	29.44	-6.3737	1.36	8.59
G9	Improved Tori	31.33	30.67	30.00	30.67	-5.1515	0.47	6.44
G10	BINA Sharisha 10	32.67	30.67	31.00	31.44	-4.3737	0.09	15.93
G11	BINA Sharisha 9	35.67	36.33	35.33	35.78	-0.0404	-0.37	7.02
	E. Mean	**36.91**	**35.61**	**34.94**	**35.82**			
	E. Index (Ij)	**1.0909**	**-0.2121**	**-0.8788**				
	CV%	**2.40**	**3.13**	**5.55**				
	LSD (0.05)	**2.62**	**3.28**	**5.71**				

4.2.3 Plant Height excluding root (cm)

Mean performance of the promising genotypes, their response and stability parameters phenotypic indices (Pi), regression coefficient (bi) and deviation from regression (S^2di) for plant height excluding root are presented in Table 6.

Among the genotypes Sonali Sharisha-75 and BARI Sharisha-6 took minimum and maximum days for plant height, respectively. The environmental mean and genotypic mean ranged from 101.67 to 102.92 and 93.14 to 118.39 respectively.

Six genotypes i.e. BARI Sharisha-12, BARI Sharisha-14, Sonali Sharisha-75, Maghi, Improved Tori, BINA Sharisha 9 showed negative phenotypic index, which represents those genotypes were desirable for short plant height. While the other five genotypes i.e., BARI Sharisha-6, BARI Sharisha-9, BARI Sharisha-15, Sonali Sharisha-75, BARI Sharisha-17, BINA Sharisha 10 had positive phenotypic index for days to plant height this represents the undesirability of those genotypes for early plant height or desirability of those genotypes for long plant height.

Again positive and negative environmental index (Ij) reflects the rich or favorable and poor or unfavorable environment for early plant height. Thus the Env-2 and Env-3 was poor environments for early plant height and rich environments for late plant height. Env-1 was rich environment for early plant height and poor environments for late plant height in mustard production. Genotypes having negative bi value may be grown in poor environments (Muradunnabi, 2010). In that sense, BARI Sharisha-14, BARI Sharisha-17, Maghi, BINA Sharisha 10, BINA Sharisha 9 was found adaptive for poor environment.

The regression coefficient (bi) values of these genotypes ranged from 0.224 to 4.449. These differences in bi values indicated that all the genotypes responded differently to different environments. Considering the mean, bi and S^2di, it was evident that all the genotypes showed different response of adaptability under different environmental conditions. The genotypes BARI Sharisha-15 exhibited comparatively lower plant height, as their bi~1 and S^2di~0 indicated that the genotypes were stable across the environment. The genotype BARI Sharisha-6 had

Table 6. Stability analysis for plant height of eleven (11) varieties of Mustard in three environments (Env) evaluated during rabi season of 2017-18

Code	Genotype Name	Environments				Pi	bi	S^2di
		Env-1	Env-2	Env-3	Overall Mean			
G1	BARI Sharisha-6	114.80	124.40	115.97	118.39	16.04	4.449	25.58
G2	BARI Sharisha-9	99.60	112.60	109.77	107.32	9.0198	6.09	49.59
G3	BARI Sharisha-12	103.10	86.57	100.00	96.56	-5.7947	2.904	-1.17
G4	BARI Sharisha-14	90.50	94.67	97.87	94.34	-8.0058	-0.224	25.29
G5	BARI Sharisha-15	101.63	106.47	107.40	105.17	2.8164	1.658	95.68
G6	SS-75	96.07	91.03	92.33	93.14	-9.2058	0.428	187.47
G7	BARI Sharisha-17	118.83	111.33	108.33	112.83	10.4831	-0.831	89.35
G8	Maghi	96.97	92.08	93.33	94.13	-8.2236	-2.571	431.70
G9	Improved Tori	101.27	101.33	103.27	101.96	-0.3947	2.399	159.85
G10	BINA Sharisha 10	106.13	106.17	101.60	104.63	2.2831	-1.768	113.34
G11	BINA Sharisha 9	89.48	100.47	102.20	97.38	-4.9681	-1.534	-7.02
	E. Mean	**101.67**	**102.46**	**102.92**	**102.35**			
	E. Index (Ij)	**-0.6794**	**0.1146**	**0.5649**				
	CV%	**1.35**	**6.09**	**5.12**				
	LSD (0.05)	**4.04**	**18.41**	**15.55**				

bi value significantly different from the unity with insignificant S^2di value indicating high responsiveness of the genotype but suitable for Env-2 and Env-3.

4.2.4 Number of primary branch

Mean performance of the promising genotypes, their response and stability parameters phenotypic indices (Pi), regression coefficient (bi) and deviation from regression (S^2di) for number of primary branch are presented in Table 5.

Among the genotypes BARI Sharisha-9 and BARI Sharisha-6 took minimum and maximum number of primary branch, respectively. The environmental mean and genotypic mean ranged from 5.94 to 6.15 and 4.23 to 7.87 respectively.

Six genotypes i.e. BARI Sharisha-9, BARI Sharisha-12, BARI Sharisha-14, BARI Sharisha-15, Maghi, Improved Tori showed negative phenotypic index, which represents those genotypes were desirable for short number of primary branch. While the other five genotypes i.e., BARI Sharisha-6, Sonali Sharisha-75, BARI Sharisha-17, BINA Sharisha 10, BINA Sharisha 9 had positive phenotypic index for number of primary branch this represents the undesirability of those genotypes for early number of primary branch or desirability of those genotypes for long number of primary branch.

Again positive and negative environmental index (Ij) reflects the rich or favorable and poor or unfavorable environment for early number of primary branch. Thus the Env-1 was poor environments for early number of primary branch and rich environments for late number of primary branch. Env-2 and Env-3 was rich environment for early number of primary branch and poor environments for late number of primary branch in mustard production. Genotypes having negative bi value may be grown in poor environments (Muradunnabi, 2010). In that sense, BARI Sharisha-6, BARI Sharisha-9 and BARI Sharisha-12 was found adaptive for poor environment.

The regression coefficient (bi) values of these genotypes ranged from 1.12 to 5.81. These differences in bi values indicated that all the genotypes responded differently to different environments. Considering the mean, bi and S^2di, it was evident that all the genotypes showed different response of adaptability under

Table 7. Stability analysis for number of primary branches of eleven (11) varieties of Mustard in three environments (Env) evaluated during rabi season of 2017-18

Code	Genotype Name	Environments				Pi	Bi	S^2di
		Env-1	Env-2	Env-3	Overall Mean			
G1	BARI Sharisha-6	7.67	7.87	8.07	7.87	1.8500	-5.17	1.27
G2	BARI Sharisha-9	4.03	4.26	4.39	4.23	-1.7889	-5.19	-0.14
G3	BARI Sharisha-12	5.83	5.90	5.80	5.84	-0.1722	-5.61	1.65
G4	BARI Sharisha-14	4.81	4.50	4.66	4.66	-1.3589	2.57	-0.15
G5	BARI Sharisha-15	5.98	4.75	4.92	5.22	-0.7989	2.85	3.17
G6	SS-75	7.10	7.00	6.73	6.94	0.9278	4.81	0.71
G7	BARI Sharisha-17	6.70	6.57	6.57	6.61	0.5944	1.28	0.05
G8	Maghi	5.98	5.57	5.38	5.64	-0.3722	1.12	0.02
G9	Improved Tori	5.81	5.28	5.01	5.37	-0.6478	2.98	-0.08
G10	BINA Sharisha 10	6.40	6.30	6.30	6.33	0.3167	5.56	-0.12
G11	BINA Sharisha 9	7.33	7.57	7.50	7.47	1.4500	5.81	0.14
	E. Mean	**6.15**	**5.96**	**5.94**	**6.02**			
	E. Index (Ij)	**0.1336**	**-0.0558**	**-0.0779**				
	CV%	**12.45**	**3.46**	**1.45**				
	LSD (0.05)	**2.26**	**0.61**	**0.25**				

different environmental conditions. The genotypes BARI Sharisha-14, BARI Sharisha-17, Maghi, Improved Tori, BINA Sharisha 10, BINA Sharisha 9 exhibited comparatively lower number of primary branch, as their bi~1 and S^2di~0 indicated that the genotypes were stable across the environment.

4.2.5 Number of secondary branch

Mean performance of the promising genotypes, their response and stability parameters phenotypic indices (Pi), regression coefficient (bi) and deviation from regression (S^2di) for number of secondary branch are presented in Table 8.

Among the genotypes BARI Sharisha-15 and BINA Sharish-10 took minimum and maximum number of secondary branch, respectively. The environmental mean and genotypic mean ranged from 3.41 to 3.48 and 1.36 to 5.36 respectively.

Six genotypes i.e. BARI Sharisha-6, BARI Sharisha-9, BARI Sharisha-12, BARI Sharisha-14, BARI Sharisha-15, BARI Sharisha-17 showed negative phenotypic index, which represents those genotypes were desirable for short number of secondary branch. While the other five genotypes i.e., Sonali Sharisha-75, Maghi, Improved Tori, BINA Sharisha 10, BINA Sharisha 9 had positive phenotypic index for number of secondary branch this represents the undesirability of those genotypes for early number of secondary branch or desirability of those genotypes for long number of secondary branch.

Again positive and negative environmental index (Ij) reflects the rich or favorable and poor or unfavorable environment for early number of secondary branch. Thus the Env-2 and Env-3 was poor environments for early number of secondary branch and rich environments for late number of secondary branch. Env-1 was rich environment for early number of secondary branch and poor environments for late number of secondary branch in mustard production. Genotypes having negative bi value may be grown in poor environments (Muradunnabi, 2010). In that sense, Improved Tori was found adaptive for poor environment.

The regression coefficient (bi) values of these genotypes ranged from 0.02 to 1.89. These differences in bi values indicated that all the genotypes responded differently to different environments. Considering the mean, bi and S^2di, it was

Table 8. Stability analysis for number of secondary branches of eleven (11) varieties of Mustard in three environments (Env) evaluated during rabi season of 2017-18

Code	Genotype Name	Environments				Pi	bi	S^2di
		Env-1	Env-2	Env-3	Overall Mean			
G1	BARI Sharisha-6	2.33	2.83	2.47	2.54	-0.9141	1.42	0.68
G2	BARI Sharisha-9	1.17	1.77	1.33	1.42	-2.0364	1.11	4.37
G3	BARI Sharisha-12	3.53	2.73	3.77	3.34	-0.1141	0.82	1.82
G4	BARI Sharisha-14	2.43	2.50	2.53	2.49	-0.9697	1.37	0.54
G5	BARI Sharisha-15	1.17	1.47	1.43	1.36	-2.1030	0.98	8.49
G6	SS-75	6.40	5.20	5.07	5.56	2.0970	1.89	2.70
G7	BARI Sharisha-17	2.70	3.17	3.37	3.08	-0.3808	0.73	0.38
G8	Maghi	4.50	5.27	4.97	4.91	1.4525	1.29	0.84
G9	Improved Tori	4.07	4.00	4.17	4.08	0.6192	-0.02	0.13
G10	BINA Sharisha 10	5.53	5.17	5.37	5.36	1.8970	0.82	-0.06
G11	BINA Sharisha 9	3.67	4.20	3.87	3.91	0.4525	0.58	1.24
	E. Mean	**3.41**	**3.48**	**3.48**	**3.46**			
	E. Index (Ij)	**-0.0495**	**0.0232**	**0.0263**				
	CV%	**13.09**	**13.77**	**15.26**				
	LSD (0.05)	**1.32**	**1.41**	**1.57**				

evident that all the genotypes showed different response of adaptability under different environmental conditions. The genotypes BARI Sharisha-12, BARI Sharisha-15, Sonali Sharisha-75, BINA Sharisha 10 exhibited comparatively lower number of secondary branch, as their bi~1 and S^2di~0 indicated that the genotypes were stable across the environment.

4.2.6 Days to maturity

Mean performance of the promising genotypes, their response and stability parameters phenotypic indices (Pi), regression coefficient (bi) and deviation from regression (S^2di) for days to maturity are presented in Table 9.

Among the genotypes BINA Sharisha-10 and BARI Sharisha-17 took minimum and maximum days to maturity, respectively. The environmental mean and genotypic mean ranged from 94.36 to 100.67 and 91.33 to 104.89 respectively.

Six genotypes i.e. BARI Sharisha-14, Sonali Sharisha-75, Maghi, Improved Tori, BINA Sharisha 10, BINA Sharisha 9showed negative phenotypic index, which represents those genotypes were desirable for short days to maturity. While the other five genotypes i.e., BARI Sharisha-6, BARI Sharisha-9, BARI Sharisha-12, BARI Sharisha-15, BARI Sharisha-17 had positive phenotypic index for days to maturity this represents the undesirability of those genotypes for early maturity or desirability of those genotypes for late maturity.

Again positive and negative environmental index (Ij) reflects the rich or favorable and poor or unfavorable environment for early maturity. Thus the Env-2 and Env-3 was poor environments for early days to maturity and rich environments for late days to maturity. Env-1 was rich environment for early days to maturity and poor environments for late days to maturity in mustard production. Genotypes having negative bi value may be grown in poor environments (Muradunnabi, 2010). In that sense, BARI Sharisha-15, Sonali Sharisha-75, BARI Sharisha-17, Maghi, BINA Sharisha 9 was found adaptive for poor environment.

The regression coefficient (bi) values of these genotypes ranged from 0.26 to 2.17. These differences in bi values indicated that all the genotypes responded

Table 9. Stability analysis for days to maturity of eleven (11) varieties of Mustard in three environments (Env) evaluated during rabi season of 2017-18

Code	Genotype Name	Environments				Pi	bi	S^2di
		Env-1	Env-2	Env-3	Overall Mean			
G1	BARI Sharisha-6	103.00	99.33	97.33	99.89	2.6364	0.83	34.51
G2	BARI Sharisha-9	103.67	100.67	97.67	100.67	3.4141	1.26	7.07
G3	BARI Sharisha-12	103.67	99.33	101.67	101.56	4.3030	-0.26	-1.41
G4	BARI Sharisha-14	98.67	95.67	93.33	95.89	-1.3636	0.71	39.37
G5	BARI Sharisha-15	101.33	98.67	93.67	97.89	0.6364	1.09	0.68
G6	SS-75	96.67	92.00	92.33	93.67	-3.5859	0.06	14.60
G7	BARI Sharisha-17	110.67	103.67	100.33	104.89	7.6364	1.28	42.93
G8	Maghi	99.67	95.00	92.00	95.56	-1.6970	2.17	116.50
G9	Improved Tori	99.33	96.33	92.67	96.11	-1.1414	1.15	6.32
G10	BINA Sharisha 10	95.67	92.33	89.00	92.33	-4.9192	1.30	5.93
G11	BINA Sharisha 9	95.00	91.00	88.00	91.33	-5.9192	1.41	19.47
	E. Mean	**100.67**	**96.73**	**94.36**	**97.25**			
	E. Index (Ij)	**3.4141**	**-0.5253**	**-2.8889**				
	CV%	**0.89**	**2.60**	**2.73**				
	LSD (0.05)	**2.65**	**7.43**	**7.60**				

differently to different environments. Considering the mean, bi and S^2di, it was evident that all the genotypes showed different response of adaptability under different environmental conditions. The genotypes BARI Sharisha-9, BARI Sharisha-14, BARI Sharisha-15, BARI Sharisha-17, Improved Tori, BINA Sharisha-10 exhibited comparatively lower days to maturity, as their bi~1 and S^2di~0 indicated that the genotypes were stable across the environment.

4.2.7 Number of siliqua per plant

Mean performance of the promising genotypes, their response and stability parameters phenotypic indices (Pi), regression coefficient (bi) and deviation from regression (S^2di) for number of siliqua per plant are presented in Table 10.

Among the genotypes BARI Sharisha-9 and BINA Sharisha-9 took minimum and maximum number of siliqua per plant, respectively. The environmental mean and genotypic mean ranged from 92.82 to 108.70 and 66.00 to 127.89 respectively.

Seven genotypes i.e. BARI Sharisha-9, BARI Sharisha-12, BARI Sharisha-14, BARI Sharisha-15, BARI Sharisha-17, Maghi, Improved Tori showed negative phenotypic index, which represents those genotypes were desirable for short number of siliqua per plant. While the other four genotypes i.e., BARI Sharisha-6, Sonali Sharisha-75, BINA Sharisha 10, BINA Sharisha 9 had positive phenotypic index for number of siliqua per plant this represents the undesirability of those genotypes for early number of siliqua per plant or desirability of those genotypes for long number of siliqua per plant.

Again positive and negative environmental index (Ij) reflects the rich or favorable and poor or unfavorable environment for early number of siliqua per plant. Thus the Env-2 and Env-3 was poor environments for early number of siliqua per plant and rich environments for late number of siliqua per plant. Env-1 was rich environment for early number of siliqua per plant and poor environments for late number of siliqua per plant in mustard production. Genotypes having negative bi value may be grown in poor environments (Muradunnabi, 2010). In that sense,

Table 10. Stability analysis for number of siliqua per plant of eleven (11) varieties of Mustard in three environments (Env) evaluated during rabi season of 2017-18

Code	Genotype Name	Environments				Pi	bi	S2di
		Env-1	Env-2	Env-3	Overall Mean			
G1	BARI Sharisha-6	166.67	169.33	160.67	165.56	67.3636	8.52	3316.21
G2	BARI Sharisha-9	74.00	60.00	64.00	66.00	-32.1919	5.44	3777.25
G3	BARI Sharisha-12	106.67	83.33	88.00	92.67	-5.5253	9.39	585.12
G4	BARI Sharisha-14	77.67	63.67	65.00	68.78	-29.4141	0.54	-98.76
G5	BARI Sharisha-15	90.67	69.67	70.33	76.89	-21.3030	-5.87	-73.83
G6	SS-75	110.67	111.00	106.00	109.22	11.0303	-3.21	1334.64
G7	BARI Sharisha-17	95.67	91.33	94.33	93.78	-4.4141	-0.78	61.09
G8	Maghi	119.67	75.33	76.00	90.33	-7.8586	-1.06	-54.67
G9	Improved Tori	113.67	75.33	73.67	87.56	-10.6364	1.18	450.62
G10	BINA Sharisha 10	120.67	89.67	94.00	101.44	3.2525	0.76	1616.58
G11	BINA Sharisha 9	119.67	135.00	129.00	127.89	29.6970	-3.93	1791.34
	E. Mean	**108.70**	**93.06**	**92.82**	**98.19**			
	E. Index (Ij)	**10.5051**	**-5.1313**	**-5.3737**				
	CV%	**23.14**	**5.28**	**3.48**				
	LSD (0.05)	**74.18**	**14.49**	**9.53**				

BARI Sharisha-15, Sonali Sharisha-75, BARI Sharisha-17, Maghi, BINA Sharisha 9 was found adaptive for poor environment.

The regression coefficient (bi) values of these genotypes ranged from 0.54 to 9.39. These differences in bi values indicated that all the genotypes responded differently to different environments. Considering the mean, bi and S^2di, it was evident that all the genotypes showed different response of adaptability under different environmental conditions. The genotypes Sonali Sharisha-75, Maghi, Improved Tori, BINA Sharisha-10 exhibited comparatively lower number of siliqua per plant, as their bi~1 and S^2di~0 indicated that the genotypes were stable across the environment. The genotype BARI Sharisha-12 had bi value significantly different from the unity with insignificant S^2di value indicating high responsiveness of the genotype but suitable for Env-1.

4.2.8 Length of siliqua

Mean performance of the promising genotypes, their response and stability parameters phenotypic indices (Pi), regression coefficient (bi) and deviation from regression (S^2di) for length of siliqua are presented in Table 11.

Among the genotypes Sonali Sharisha-75 and BINA Sharisha-9 took minimum and maximum length of siliqua, respectively. The environmental mean and genotypic mean ranged from 4.34 to 4.48 and 3.44 to 5.94 respectively.

Six genotypes i.e. BARI Sharish-9, BARI Sharish-14, Sonali Sharish-75, Maghi, Improved Tori, BINA Sharisha-10 showed negative phenotypic index, which represents those genotypes were desirable for short length of siliqua. While the other five genotypes i.e., BARI Sharisha-6, BARI Sharisha-12, BARI Sharisha-15, BARI Sharisha-17, BINA Sharisha-9 had positive phenotypic index for length of siliqua this represents the undesirability of those genotypes for early length of siliqua or desirability of those genotypes for long length of siliqua.

Again positive and negative environmental index (Ij) reflects the rich or favorable and poor or unfavorable environment for early length of siliqua. Thus the Env-2 was poor environments for early length of siliqua and rich environments for late length of siliqua. Env-1 and Env-3 was rich environment for early length of siliqua

Table 11. Stability analysis for length of siliqua of eleven (11) varieties of Mustardin three environments (Env) evaluated during rabi season of 2017-18

Code	Genotype Name	Environments				Pi	Bi	S2di
		Env-1	Env-2	Env-3	Overall Mean			
G1	BARI Sharisha-6	4.72	4.60	4.74	4.69	0.2636	-1.77	0.18
G2	BARI Sharisha-9	4.22	4.10	4.24	4.19	-0.2364	-2.93	0.22
G3	BARI Sharisha-12	4.47	4.35	4.49	4.44	0.0136	-5.32	0.11
G4	BARI Sharisha-14	3.97	3.85	3.99	3.94	-0.4864	-4.46	0.68
G5	BARI Sharisha-15	5.22	5.10	5.24	5.19	0.7636	-0.15	0.16
G6	SS-75	3.47	3.35	3.49	3.44	-0.9864	1.49	0.41
G7	BARI Sharisha-17	4.72	4.60	4.74	4.69	0.2636	-0.05	0.44
G8	Maghi	4.22	4.10	4.24	4.19	-0.2364	-1.22	0.04
G9	Improved Tori	3.82	3.70	3.84	3.79	-0.6364	7.22	-0.03
G10	BINA Sharisha 10	4.22	4.10	4.24	4.19	-0.2364	8.08	0.08
G11	BINA Sharisha 9	5.97	5.85	5.99	5.94	1.5136	10.11	-0.04
	E. Mean	**4.45**	**4.34**	**4.48**	**4.42**			
	E. Index (Ij)	**0.0289**	**-0.0844**	**0.0556**				
	CV%	**3.46**	**2.87**	**3.11**				
	LSD (0.05)	**1.87**	**0.89**	**1.36**				

and poor environments for late length of siliqua in mustard production. Genotypes having negative bi value may be grown in poor environments (Muradunnabi, 2010). In that sense, BARI Sharisha-6, BARI Sharisha-9, BARI Sharisha-12, BARI Sharisha-14, BARI Sharisha-15, BARI Sharisha-17, Maghi, Improved Tori, BINA Sharisha-10 was found adaptive for poor environment.

The regression coefficient (bi) values of these genotypes ranged from 0.15 to 10.11. These differences in bi values indicated that all the genotypes responded differently to different environments. Considering the mean, bi and S^2di, it was evident that all the genotypes showed different response of adaptability under different environmental conditions. The genotypes BARI Sharisha-6, BARI Sharisha-12, BARI Sharisha-15, Maghi, BINA Sharisha-10, exhibited comparatively lower length of siliqua, as their bi~1 and S^2di~0 indicated that the genotypes were stable across the environment. The genotype BINA Sharisha-9 had bi value significantly different from the unity with insignificant S^2di value indicating high responsiveness of the genotype but suitable for Env-1 and Env-3

4.2.9 Number of seeds per siliqua

Mean performance of the promising genotypes, their response and stability parameters phenotypic indices (Pi), regression coefficient (bi) and deviation from regression (S^2di) for number of seeds per siliqua are presented in Table 12.

Among the genotypes BARI Sharisha-9 and BARI Sharisha-6 took minimum and maximum number of seeds per siliqua, respectively. The environmental mean and genotypic mean ranged from 15.95 to 18.24 and 12.38 to 26.44 respectively.

Four genotypes i.e. BARI Sharisha-14, Maghi, Improved Tori, BINA Sharisha-10 showed negative phenotypic index, which represents those genotypes were desirable for short number of seeds per siliqua. While the other seven genotypes i.e., BARI Sharisha-6, BARI Sharisha-9, BARI Sharisha-12, BARI Sharisha-15, Sonali Sharisha-75, BARI Sharisha-17, BINA Sharisha-9 had positive phenotypic index for number of seeds per siliqua this represents the undesirability of those

Table 12. Stability analysis for number of seeds per siliqua of eleven (11) varieties of Mustard in three environments (Env) evaluated during rabi season of 2017-18

Code	Genotype Name	Environments				Pi	Bi	S^2di
		Env-1	Env-2	Env-3	Overall Mean			
G1	BARI Sharisha-6	29.33	24.00	26.00	26.44	9.6905	10.18	124.45
G2	BARI Sharisha-9	12.70	12.30	12.13	12.38	-4.3762	8.17	23.47
G3	BARI Sharisha-12	14.67	13.50	13.57	13.91	-2.8428	8.33	73.78
G4	BARI Sharisha-14	17.53	12.50	12.35	14.13	-2.6273	-0.53	-1.90
G5	BARI Sharisha-15	15.97	12.80	12.73	13.83	-2.9206	4.84	87.22
G6	SS-75	25.00	20.33	20.67	22.00	5.2461	0.48	32.61
G7	BARI Sharisha-17	19.67	16.77	17.00	17.81	1.0572	3.57	18.95
G8	Maghi	13.67	13.23	13.33	13.41	-3.3428	1.44	18.42
G9	Improved Tori	13.10	13.20	13.00	13.10	-3.6539	-10.05	0.18
G10	BINA Sharisha 10	15.00	13.83	14.67	14.50	-2.2539	-6.24	-1.09
G11	BINA Sharisha 9	24.00	23.00	21.33	22.78	6.0238	-9.19	-1.90
	E. Mean	**18.24**	**15.95**	**16.07**	**16.75**			
	E. Index (Ij)	**1.4855**	**-0.8024**	**-0.6830**				
	CV%	**20.46**	**6.38**	**7.32**				
	LSD (0.05)	**11.00**	**3.00**	**3.47**				

genotypes for early number of seeds per siliqua or desirability of those genotypes for long number of seeds per siliqua.

Again positive and negative environmental index (Ij) reflects the rich or favorable and poor or unfavorable environment for early number of seeds per siliqua. Thus the Env-2 and Env-3 was poor environments for early number of seeds per siliqua and rich environments for late number of seeds per siliqua. Env-1 was rich environment for early number of seeds per siliqua and poor environments for late number of seeds per siliqua in mustard production. Genotypes having negative bi value may be grown in poor environments (Muradunnabi, 2010). In that sense BARI Sharisha-14, Improved Tori, BINA Sharisha 10, BINA Sharisha-9 was found adaptive for poor environment.

The regression coefficient (bi) values of these genotypes ranged from 1.44 to 10.18. These differences in bi values indicated that all the genotypes responded differently to different environments. Considering the mean, bi and S^2di, it was evident that all the genotypes showed different response of adaptability under different environmental conditions. The genotypes Improved Tori exhibited comparatively lower number of seeds per siliqua, as their bi~1 and S^2di~0 indicated that the genotypes were stable across the environment.

4.2.10 Thousand seed weight

Mean performance of the promising genotypes, their response and stability parameters phenotypic indices (Pi), regression coefficient (bi) and deviation from regression (S2di) for thousand seed weight are presented in Table 13.

Among the genotypes BARI Sharisha-12 and BINA Sharisha-10 took minimum and maximum thousand seed weight, respectively. The environmental mean and genotypic mean ranged from 3.19 to 3.30 and 2.63 to 4.15 respectively.

Five genotypes i.e. BARI Sharisha-9, BARI Sharisha-12, BARI Sharisha-14, BARI Sharisha-15, Sonali Sharisha-75showed negative phenotypic index, which represents those genotypes were desirable for short thousand seed weight. While the other six genotypes i.e., BARI Sharisha-6, BARI Sharisha-9, BARI Sharisha-12,

Table 13. Stability analysis for thousand seed weight of eleven (11) varieties of Mustard in three environments (Env) evaluated during rabi season of 2017-18

Code	Genotype Name	Environments				Pi	Bi	S2di
		Env-1	Env-2	Env-3	Overall Mean			
G1	BARI Sharisha-6	3.62	3.34	3.43	3.46	0.2052	0.46	0.45
G2	BARI Sharisha-9	3.12	3.29	3.27	3.23	-0.0304	0.30	0.11
G3	BARI Sharisha-12	2.37	2.80	2.73	2.63	-0.6260	0.39	0.30
G4	BARI Sharisha-14	2.60	2.77	2.69	2.68	-0.5726	1.24	0.17
G5	BARI Sharisha-15	2.88	2.68	2.61	2.72	-0.5360	0.08	0.30
G6	SS-75	2.52	2.65	2.60	2.59	-0.6693	2.07	0.28
G7	BARI Sharisha-17	4.54	3.79	3.60	3.98	0.7185	2.74	-0.01
G8	Maghi	3.54	3.50	3.32	3.45	0.1985	1.11	1.39
G9	Improved Tori	3.35	3.63	3.02	3.33	0.0774	0.63	0.51
G10	BINA Sharisha 10	4.22	4.07	4.17	4.15	0.8940	0.98	0.43
G11	BINA Sharisha 9	3.53	3.59	3.68	3.60	0.3407	1.00	0.24
	E. Mean	**3.30**	**3.28**	**3.19**	**3.26**			
	E. Index (Ij)	**0.0408**	**0.0247**	**-0.0656**				
	CV%	**2.57**	**7.68**	**5.72**				
	LSD (0.05)	**0.25**	**0.74**	**0.54**				

BARI Sharisha-14, BARI Sharisha-15, Sonali Sharisha-75, BARI Sharisha-17, Maghi, Improved Tori, BINA Sharisha-10, BINA Sharisha-9had positive phenotypic index for thousand seed weight this represents the undesirability of those genotypes for early thousand seed weight or desirability of those genotypes for long thousand seed weight.

Again positive and negative environmental index (Ij) reflects the rich or favorable and poor or unfavorable environment for early thousand seed weight. Thus the Env-3 was poor environments for early thousand seed weight and rich environments for late thousand seed weight. Env-1 and Env-2 was rich environment for early thousand seed weight and poor environments for late thousand seed weight in mustard production. Genotypes having negative bi value may be grown in poor environments (Muradunnabi, 2010).The regression coefficient (bi) values of these genotypes ranged from 0.08 to 2.74. These differences in bi values indicated that all the genotypes responded differently to different environments. Considering the mean, bi and S^2di, it was evident that all the genotypes showed different response of adaptability under different environmental conditions. The genotypes BARI Sharisha-14, Maghi, BINA Sharisha-10 and BINA Sharisha-9 exhibited comparatively lower thousand seed weight, as their bi~1 and S^2di~0 indicated that the genotypes were stable across the environment. The genotype BARI Sharisha-17 had bi value significantly different from the unity with insignificant S^2di value indicating high responsiveness of the genotype but suitable for Env-1 and Env-2.

4.2.11 Yield per plant

Mean performance of the promising genotypes, their response and stability parameters phenotypic indices (Pi), regression coefficient (bi) and deviation from regression (S^2di) for yield per plant are presented in Table 14.

Among the genotypes BARI Sharisha-9 and BARI Sharisha-6 took minimum and maximum yield per plant, respectively. The environmental mean and genotypic mean ranged from 5.86 to 5.98 and 2.69 to 9.77 respectively.

Table 14. Stability analysis for yield per plant of eleven (11) varieties of Mustard in three environments (Env) evaluated during rabi season of 2017-18

Code	Genotype Name	Environments				Pi	Bi	S^2di
		Env-1	Env-2	Env-3	Overall Mean			
G1	BARI Sharisha-6	9.63	10.03	9.77	9.81	3.9098	-7.99	10.77
G2	BARI Sharisha-9	2.62	2.83	2.61	2.69	-3.2124	-9.63	8.26
G3	BARI Sharisha-12	5.92	6.00	5.60	5.84	-0.0602	-10.19	5.43
G4	BARI Sharisha-14	3.36	3.47	3.38	3.40	-2.4991	3.07	0.04
G5	BARI Sharisha-15	3.80	4.03	3.87	3.90	-2.0013	2.51	14.42
G6	SS-75	8.15	7.53	7.72	7.80	1.8998	7.20	5.58
G7	BARI Sharisha-17	7.16	7.15	7.38	7.23	1.3276	1.29	1.34
G8	Maghi	4.82	5.33	4.82	4.99	-0.9102	1.51	0.31
G9	Improved Tori	4.23	4.30	4.10	4.21	-1.6902	4.83	-0.04
G10	BINA Sharisha 10	6.50	6.60	6.81	6.64	0.7365	9.49	1.13
G11	BINA Sharisha 9	8.25	8.55	8.40	8.40	2.4998	8.92	0.91
	E. Mean	**5.86**	**5.98**	**5.86**	**5.90**			
	E. Index (Ij)	**-0.0419**	**0.0835**	**-0.0416**				
	CV%	**4.60**	**8.36**	**7.47**				
	LSD (0.05)	**0.80**	**1.47**	**1.29**				

Six genotypes i.e. BARI Sharisha-9, BARI Sharisha-12, BARI Sharisha-14, BARI Sharisha-15, Maghi, Improved Tori showed negative phenotypic index, which represents those genotypes were desirable for low yield per plant. While the other five genotypes i.e., BARI Sharisha-6, Sonali Sharisha-75, BARI Sharisha-17, BINA Sharisha 10, BINA Sharisha-9 had positive phenotypic index for yield per plant this represents the undesirability of those genotypes for low yield per plant or desirability of those genotypes for high yield per plant.

Again positive and negative environmental index (Ij) reflects the rich or favorable and poor or unfavorable environment for low yield per plant. Thus the Env-1 and Env-3 was poor environments for low yield per plant and rich environments for late yield per plant. Env-2 was rich environment for low yield per plant and poor environments for high yield per plant in mustard production. Genotypes having negative bi value may be grown in poor environments (Muradunnabi, 2010). In that sense, BARI Sharisha-6, BARI Sharisha-9 and BARI Sharisha-12 was found adaptive for poor environment.

The regression coefficient (bi) values of these genotypes ranged from 1.29 to 10.19. These differences in bi values indicated that all the genotypes responded differently to different environments. Considering the mean, bi and S^2di, it was evident that all the genotypes showed different response of adaptability under different environmental conditions. The genotypes BARI Sharisha-14, Maghi exhibited comparatively lower yield per plant, as their bi~1 and S^2di~0 indicated that the genotypes were stable across the environment. The genotype BARI Sharisha-12 had bi value significantly different from the unity with insignificant S^2di value indicating high responsiveness of the genotype but suitable for Env-2.

4.3 Interaction Biplot of AMMI Model

The AMMI biplot prodive a visual expression of the relationship between the First Interaction Principal Component Axis (IPCA1) or AMMI component 1 and Mean of genotype and environment (Figure 2) with the biplot up to 100% of the treatment sum of squares. Consequently, biplots generated using genotypic and environmental scores of the AMMI 1 components can help breeders have an overall picture of the behavior of the genotypes, the environments and G x E

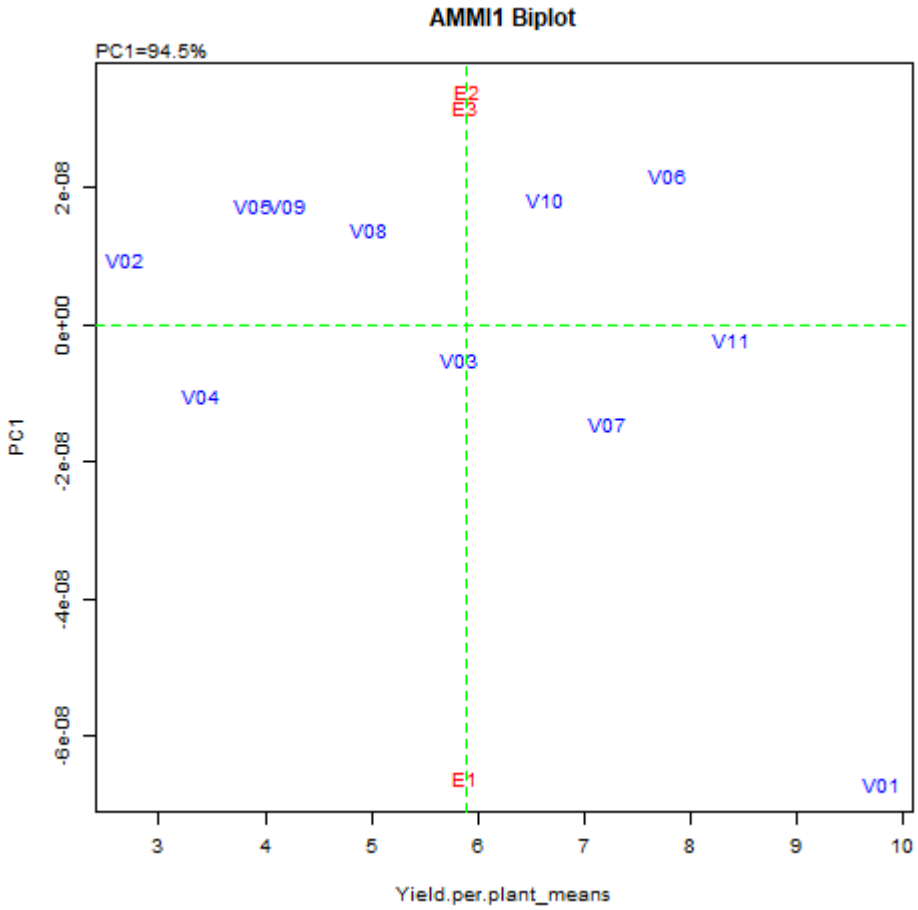


Figure 2. Interaction biplot of AMMI1 where IPCA1 score (y-axis) plotted against mean yield (x-axis) for eleven genotypes of mustard

(Manrique and Hermann, 2002; Kaya *et al.*, 2002; Tarakanovas and Ruzgas, 2006). The first interaction principal components axis (AMMI components 1) was highly significant and explained the interaction pattern better than other interaction axis. Balestre *et al.* (2009) found that the GGE biplot method to be superior to the AMMI 1 graph, due to more retention of GE and G+GE in the graph analysis.

In Figure 2 the IPCA1 scores for both the genotypes and the environments were plotted against the mean yield for the genotypes and the environments, respectively. By plotting both the genotypes and the environments on the same graph, the associations between the genotypes and the environments can be seen clearly. The IPCA scores of a genotypes in the AMMI analysis are an indication of the stability or adaptation over environments. The greater the IPCA scores, negative or positive (as it is a relative value), the more specific adaptation of a genotype to certain environments. The more the IPCA scores approximate to zero, the more stable or adaptation of the genotype in over all environments sampled.

Considering only the IPCA 1 scores BARI Sharisha-9 (V2), BARI Sharisha-15 (V5), Maghi (V8), Improved Tori (V9) were low yielding and unstable (Figure 2). BARI Sharisha-6 (V1), BARI Sharisha-17 (V7), BINA Sharisha-9 (V11) is the high yielding and unstable genotype according to figure 2. We also fond Env-1 as rich environment where, BARI Sharisha-17 (V7), BINA Sharisha-9 (V11)were found highly responsive to rich environment (Env-1) in figure-2. BARI Sharisha-12 (V3) was found intermediate yielder and stable. We find Sonali Sharisha-75 (V6), BINA Sharisha 10 (V10) high yielding stable genotype according to figure 2.

Since IPCA 2 scores also play a significant role in explaining the GEI the IPCA 1 scores were plotted against the IPCA2 scores to further explore adaptation (Figure 3). According to figure 3 BARI Sharisha-6 (V1), BARI Sharisha-14 (V4), BARI Sharisha-15 (V5) was outliner (unstable) followed by Sonali Sharisha-75 (V6), BARI Sharisha-17 (V7), Maghi (V8) and unstable bur to a lesser extent. BARI Sharisha-9 (V2), BARI Sharisha-12 (V3), BINA Sharisha 9 (V11) showed more stability when plotting the IPCA1 and IPCA2 scores where BINA Sharisha 9 (V11) was highly stable.

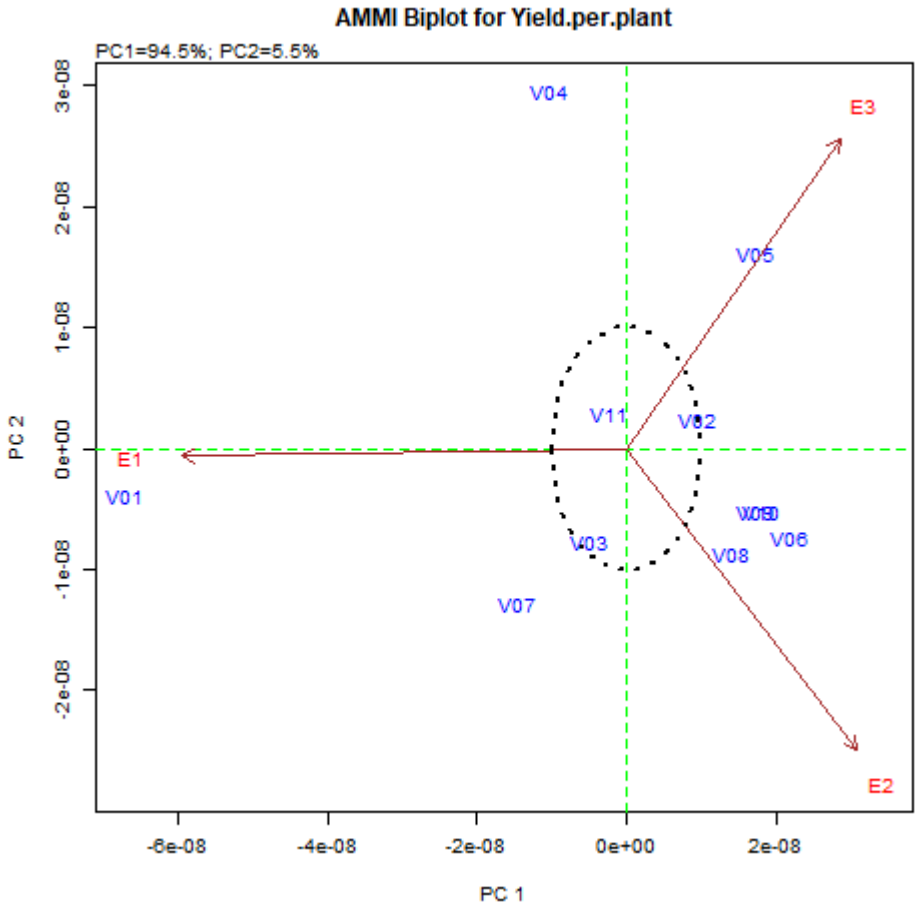


Figure 3. Interaction biplot of AMMI2 where IPCA2 score (Y-axis) plotted against IPCA1 score (X-axis) for eleven varietiesof mustard

CHAPTER V

SUMMARY AND CONCLUSION

The experiment was conducted at the experimental field of Sher-e-Bangla Agricultural University during rabi season 2017-2018 with eleven varieties of mustard of different collected from BARI and BINA to assess the GXE interactions with three (3) sowing time environments, Evn-1 (early sowing), Env-2 (Mid sowing) and Env-3 (late sowing) source. The experiment was laid out in Randomized Complete Block Design (ROD) with three replications in three different environments. The three environments was created by different sowing time viz. optimum sowing time (Env-1), late sowing time (Env-2) and very late sowing time (Env-3) The objectives of the experiment were to find best genotype or genotypes with high mean yield and good adaptation to different environments. Data were collected on days to first flowering, days to 50% flowering, plant height excluding root (cm), number of primary branches per plant, number of secondary branches per plant number of siliqua per plant, length of siliqua (cm), number of seeds per siliqua, thousand seed weight and yield per plant.

The analysis of variance (ANOVA) was used and the GE interaction was estimated by the AMMI model (Zohel *el at*. 1988). The stability parameters, regression coefficient (bi) and deviation from regression (S^2di) were estimated according to Eberhart and Russel (1996). Significance of differences among bi value and unity was tested by t-test, between S^2di and zero by F-test.

In combined analysis of variance (ANOVA) according to the best AMMI model. The mean sum of squares for the genotypes were highly significant for all the characters except length of siliqua and thousand seed weight and the mean sum of squares for environment and interactions were also significant for most of the characters.

According to Eherhart and Russel (1966) model regression coefficient (bi) is considered as parameter of response and deviation from regression (S^2di) as the parameter of stability. Relatively lower value of bi, say around 1 will mean less responsive to the environmental change and therefore, more adaptive. If however, bi is negative, the genotype may be grown only in poor environment. Deviation from regression (S^2di), if significantly different from zero, will invalidate the linear prediction. If S^2di is non-significant, the performances of a genotype for a

given environment may be predicted. Therefore, a genotype whose performance for a given environment can be predicted i.e., $S^2di \sim 0$ is said to be stable genotype. The genotypes which have bi value significantly different from the unity with insignificant S^2di value indicating high responsiveness of the genotype suitable for rich environment.

Considering the mean, bi and S^2di, it was evident that all the genotypes showed different response of adaptability under different environmental conditions. The genotypes Sonali Sharisha-75, Improved Tori, Maghi exhibited comparatively lower days to first flowering and were found stable across the environments. Sonali Sharisha-75, Improved Tori, BINA Sharisha-10 exhibited comparatively lower days to 50% flowering and were found stable where Sonali Sharisha-75 showed high responsiveness to rich environments. BARI Sharisha-6, BARI Sharisha-17, BARI Sharisha-9, BARI Sharisha-15exhibited comparatively higher plant height and were found stable. The genotypes BARI Sharisha-6, BINA Sharisha-9exhibited comparatively higher number of primary branches per plant and were found stable across the environments where BARI Sharisha-6 showed high responsiveness to rich environments. Sonali Sharisha-75, Maghi exhibited comparatively higher number of secondary branches per plant and were found stable where Sonali Sharisha-75 showed high responsiveness to rich environments. BINA Sharisha-9, BINA Sharisha-10, BARI Sharisha-14 exhibited comparatively minimum days to maturity and were found stable where BINA Sharisha-9 showed high responsiveness to rich environments.

BARI Sharisha-6, BINA Sharisha-9, BINA Sharisha-10 exhibited comparatively higher numbers of siliqua per plant and found stable where BINA Sharisha-9 showed high responsiveness to rich environments. BARI Sharisha-15, BINA Sharisha-9 exhibited comparatively higher length of siliqua and found stable where BARI Sharisha-15 showed high responsiveness to rich environments. BARI Sharisha-6, BINA Sharisha-9 exhibited comparatively higher number of siliqua per plant and found stable. BARI Sharisha-6, BINA Sharisha-10 exhibited comparatively higher number of seeds per siliqua and found stable. BARI Sharisha-6, BINA Sharisha-9 exhibited comparatively higher individual fruit weight (g) and found stable where BINA Sharisha-9 showed high responsiveness to rich environments.

Considering only the IPCA 1 scores BARI Sharisha-9 (V2), BARI Sharisha-15 (V5), Maghi (V8), Improved Tori (V9) were low yielding and unstable (Figure 2). BARI Sharisha-6 (V1), BARI Sharisha-17 (V7), BINA Sharisha-9 (V11) is the high yielding and unstable genotype according to figure 2. We also fond Env-1 as rich environment where, BARI Sharisha-17 (V7), BINA Sharisha-9 (V11)were found highly responsive to rich environment (Env-1) in figure-2. BARI Sharisha-12 (V3) was found intermediate yielder and stable. We find Sonali Sharisha-75 (V6), BINA Sharisha 10 (V10) high yielding stable genotype according to figure 2.

Since IPCA 2 scores play a significant role in explaining the GEI the IPCA 1 scores were plotted against the IPCA2 scores to further explore adaptation (Figure 3). According to figure 3 BARI Sharisha-6 (V1), BARI Sharisha-14 (V4), BARI Sharisha-15 (V5) was outliner (unstable) followed by Sonali Sharisha-75 (V6), BARI Sharisha-17 (V7), Maghi (V8) and unstable bur to a lesser extent. BARI Sharisha-9 (V2), BARI Sharisha-12 (V3), BINA Sharisha 9 (V11) showed more stability when plotting the IPCA1 and IPCA2 scores where BINA Sharisha 9 (V11) was highly stable.We found Sonali Sharisha-75 and BINA Sharisha-1 and high yielding and highly stable verities. The Env-1 was more favorable for the mustard production.

Recommendation:

The GXE interactions study of eleven mustard varieties in three sowing times Env-1 (optimum sowing time), Env-2 (late sowing time) and Env-3 (very late sowing time) suggested that BARI Sharisha-9, BARI Sharisha-15, Maghi and Improved Tori varieties responded highly to the different sowing times. BARI Sharisha-12was found intermediate yielding and stable variety. While, Sonali Sharisha-75 and BINA Sharisha-10 were found as high yielding and stable verities so these varieties would be suggested for different sowing. The yield performance of all the varieties was good in Env-1 (sowing on 1st November). Therefore, the results suggest that the favorable sowing time of mustard cultivation is in 1st week November to get the potential yield of the varieties.

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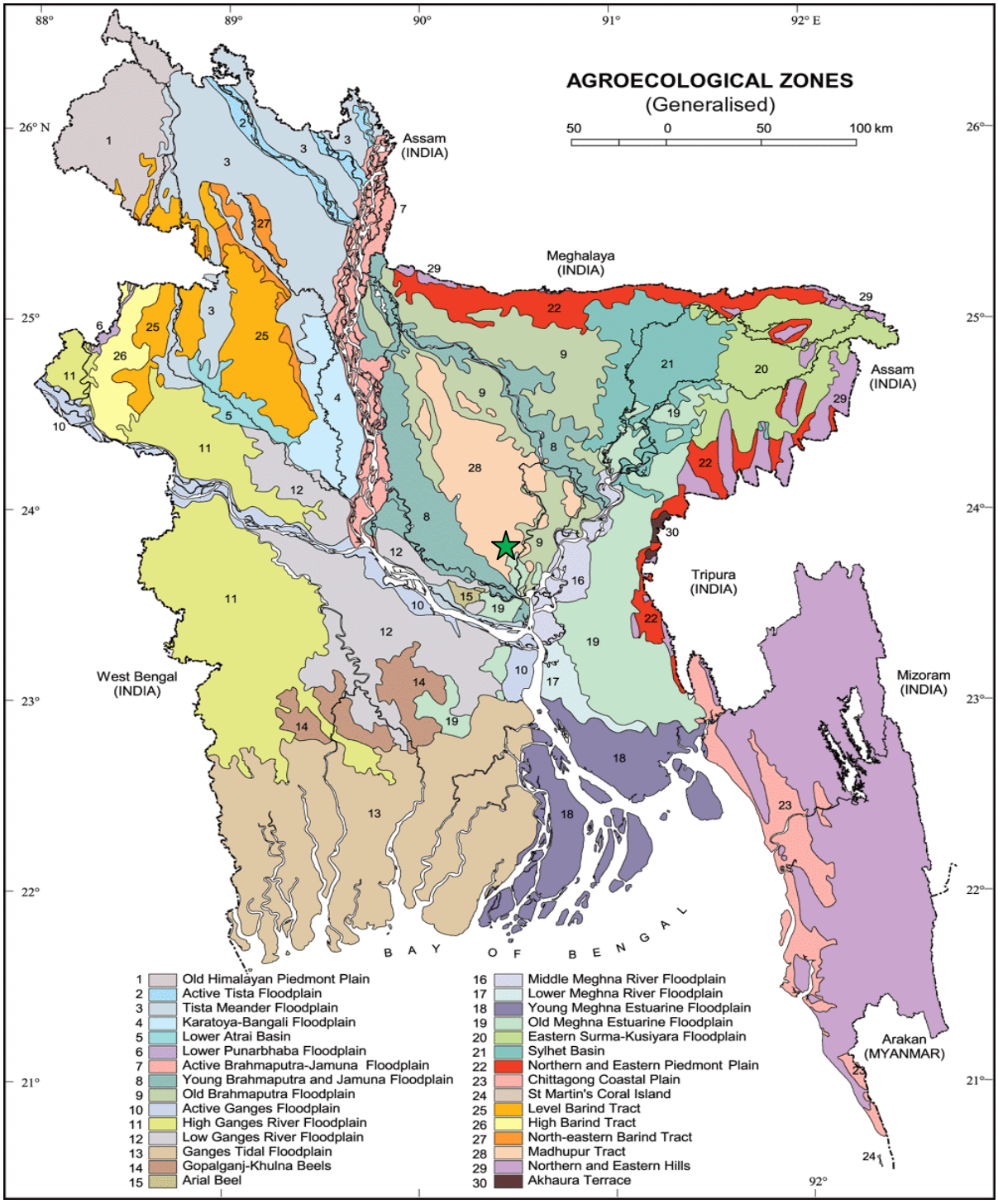
Apendices

Appendix I. Map showing the experimental site under the study



★ The experimental site under the study

Appendix II: Morphological, Physical and chemical characteristics of initial soil (0-15 cm depth) of the experimental site

A. Morphological characteristics of the experimental field

Morphological features	Characteristics
Location	:Sher-e-Bangla Agricultural University Research Farm, Dhaka
AEZ	: AEZ-28, Modhupur Tract
General Soil Type	: Deep Red Brown Terrace Soil
Land type	: High land
Soil series	: Tejgaon
Topography	: Fairly leveled

B. Physical composition of the soil

Soil separates	**%**	**Methods employed**
Sand	26	Hydrometer method (Day, 1915)
Silt	45	Do
Clay	29	Do
Texture class	Silty loam	Do

C. Chemical composition of the soil

Sl. No.	**Soil characteristics**	**Analytical data**	**Methods employed**
1	Organic carbon (%)	0.45	Walkley and Black, 1947
2	Total N (%)	0.03	Bremner and Mulvaney, 1965
3	Total S (ppm)	225.00	Bardsley and Lanester, 1965
4	Total P (ppm)	840.00	Olsen and Sommers, 1982
5	Available N (kg/ha)	54.00	Bremner, 1965
6	Available P (ppm)	20.54	Olsen and Dean, 1965
7	Exchangeable K (me/100 g soil)	0.10	Pratt, 1965
8	Available S (ppm)	16.00	Hunter, 1984
9	pH (1:2.5 soil to water)	5.6	Jackson, 1958
10	CEC	11.23	Chapman, 1965

Source: Soil Resource and Development Institute (SRDI), Farmgate, Dhaka

Appendix III. Monthly average temperature, relative humidity and total rainfall and sunshine of the experimental site during the period from November, 2017 to February, 2018.

Month	Air temperature (°c)		Relative humidity (%)	Rainfall (mm) (total)	Sunshine (hr)
	Maximum	Minimum			
November, 2017		18.0	77	227	**5.8**
December, 2017	32.4	16.3	69	0	**7.9**
January, 2018	29.1	13.0	79	0	**3.9**
February, 2018	**28.1**	**11.1**	**72**	**1**	**5.7**

Source: Bangladesh Meteorological Department (Climate & Weather Division), Agargoan, Dhaka – 1212

Appendix IV. Mean performance of mustard genotype trial at three environments during rabi 2017-18

Code	Genotype Name	Plant Height	No of prrimary branch	No of secondary branch	Days to first flower	Days to 50% flower	Days to maturity	No of siliqua/plant	length of siliqua	No of seeds/siliqua	thousand seed weight	Yield per plant
V1	BARI Sharisha-6	118.39	7.87	2.54	29.89	40.44	99.89	165.56	4.69	26.44	3.46	9.81
V2	BARI Sharisha-9	107.32	4.23	1.42	31.11	39.33	100.67	66.00	4.19	12.38	3.23	2.69
V3	BARI Sharisha-12	96.56	5.84	3.34	30.44	39.33	101.56	92.67	4.44	13.91	2.63	5.84
V4	BARI Sharisha-14	94.34	4.66	2.49	27.67	34.11	95.89	68.78	3.94	14.13	2.68	3.40
V5	BARI Sharisha-15	105.17	5.22	1.36	31.22	39.78	97.89	76.89	5.19	13.83	2.72	3.90
V6	SS-75	93.14	6.94	5.56	22.67	32.89	93.67	109.22	3.44	22.00	2.59	7.80
V7	BARI Sharisha-17	112.83	6.61	3.08	30.11	40.78	104.89	93.78	4.69	17.81	3.98	7.23
V8	Maghi	94.13	5.64	4.91	26.00	29.44	95.56	90.33	4.19	13.41	3.46	4.99
V9	Improved Tori	101.96	5.37	4.08	24.67	30.67	96.11	87.56	3.79	13.10	3.33	4.21
V10	BINA Sharisha 10	104.63	6.33	5.36	30.22	31.44	92.33	101.44	4.19	14.50	4.15	6.64
V11	BINA Sharisha 9	97.38	7.47	3.91	30.78	35.78	91.33	127.89	5.94	22.78	3.60	8.40
Grand mean		102.35	6.02	3.46	28.62	35.82	97.25	98.19	4.43	16.75	3.26	5.90

Appendix V. Mean data collected from the three replications from three environments

Rep	Env	Genotype	Plant Height	No of prrimary branch	No of secondary branch	**Days to first flower**	**Days to 50% flower**	**Days to maturity**	No of siliqua/plant	length of siliqua	No of seeds/siliqua	thousand seed weight	Yield per plant
R1	E1	V1	115.5	8	2	31	41	102	170	4.75	29	3.674	10
R1	E1	V2	99.8	4	1	33	41	103	80	4.25	14	3.179	2.5
R1	E1	V3	103.3	6	3.6	33	41	103	130	4.5	15	2.351	5.9699
R1	E1	V4	91	6	2	31	36	98	89	4	28	2.6512	3.09
R1	E1	V5	101.9	9	1	33	41	102	116	5.25	23	2.974	4
R1	E1	V6	96.7	8	6	22	34	96	107	3.5	29	2.554	8.152
R1	E1	V7	121.5	7	2	33	41	110	89	4.75	21	4.6391	7.1982
R1	E1	V8	97.4	7	5	26	30	99	181	4.25	14	3.5885	5
R1	E1	V9	101.3	7	4	27	31	98	177	3.85	14	3.4105	4.2
R1	E1	V10	106.9	7	5	29	32	95	165	4.25	12	4.277	6.7
R1	E1	V11	89.94	7.7	4	30	35	95	95	6	20	3.495	8
R2	E1	V1	112.4	7	2	30	42	105	155	4.25	32	3.5	9.5
R2	E1	V2	98.5	4.1	1.5	32	40	105	75	3.75	12	3.179	2.996
R2	E1	V3	102	5.85	3	31	40	105	100	4	14	2.4	5.8
R2	E1	V4	90	4.316	2.3	30	35	100	76	3.5	12.2	2.5	4
R2	E1	V5	102.5	4.572	1.3	35	44	100	82	4.75	12.5	2.68	3.6
R2	E1	V6	95.5	6.3	7	25	36	98	121	3	22	2.45	8.152
R2	E1	V7	115	6.2	3	31	40	112	104	4.25	20	4.34	7.27
R2	E1	V8	98	5.572	4	27	32	101	92	3.75	14	3.45	4.9
R2	E1	V9	100	5.322	4.2	26	32	102	86	3.35	12.5	3.23	4
R2	E1	V10	104.5	6.2	5.6	28	34	97	105	3.75	17	4.1	6.5

R2	E1	V11	90	6.9	3	31	37	95	125	5.5	27	3.6	8.55
R3	E1	V1	116.5	8	3	31	41	102	175	5.15	27	3.674	9.4
R3	E1	V2	100.5	4	1	33	41	103	67	4.65	12.1	3	2.37
R3	E1	V3	104	5.65	4	33	41	103	90	4.9	15	2.351	6
R3	E1	V4	90.5	4.116	3	31	36	98	68	4.4	12.4	2.6512	3
R3	E1	V5	100.5	4.372	1.2	33	41	102	74	5.65	12.4	2.974	3.8
R3	E1	V6	96	7	6.2	21	34	96	104	3.9	24	2.554	8.152
R3	E1	V7	120	6.9	3.1	33	41	110	94	5.15	18	4.6391	7
R3	E1	V8	95.5	5.372	4.5	26	30	99	86	4.65	13	3.5885	4.56
R3	E1	V9	102.5	5.122	4	27	31	98	78	4.25	12.8	3.4105	4.5
R3	E1	V10	107	6	6	29	32	95	92	4.65	16	4.277	6.3
R3	E1	V11	88.5	7.4	4	30	35	95	139	6.4	25	3.495	8.2
R1	E2	V1	126.6	7.5	2	30	39	98	162	4.72	26	3.264	9.2
R1	E2	V2	111.4	3.9	1.7	30	39	99	55	4.22	12.4	3.2	3
R1	E2	V3	85.7	5.45	2	30	39	97	81	4.47	13.5	2.945	5.5
R1	E2	V4	95	3.916	2.5	26	32	92	56	3.97	12.4	2.951	3.1
R1	E2	V5	109.7	4.172	1.7	30	39	100	62	5.22	12.9	2.722	4.2
R1	E2	V6	90	6.9	6	23	32	91	118	3.47	20	2.649	7.5
R1	E2	V7	103	6	3	30	39	103	88	4.72	16.5	3.4293	7.3
R1	E2	V8	93.12	5.172	5.7	25	28	94	71	4.22	13.5	3.445	5.3
R1	E2	V9	100	4.922	3.5	23	30	93	71	3.82	13.5	3.5	4.3
R1	E2	V10	103	5.8	5.4	30	30	95	86	4.22	13.5	4	7
R1	E2	V11	99	7.1	4.3	32	35	91	129	5.97	25	3.629	8.8
R2	E2	V1	120	7.8	3	29	41	102	168	4.37	24	3.5	10.3
R2	E2	V2	115	3.89	2	32	41	104	65	3.87	12.7	3.4775	3.5
R2	E2	V3	90	5.85	3	29	40	104	85	4.12	13	2.5	6.3

R2	E2	V4	98	4.316	2.1	28	37	103	66	3.62	12.5	2.4	3.5
R2	E2	V5	100	4.572	1.5	32	43	98	72	4.87	12.9	2.6	4.4
R2	E2	V6	89.1	6.9	5	22	33	94	115	3.12	20	2.64	7.8
R2	E2	V7	128	6.8	3.5	29	44	105	91	4.37	18	4.5	6.8
R2	E2	V8	90	5.572	5	25	31	97	75	3.87	13	3.6	4.8
R2	E2	V9	99	5.322	4	26	32	103	76	3.47	12.9	3.6	4.6
R2	E2	V10	109.5	6.2	5	32	32	91	90	3.87	13	4.2	6
R2	E2	V11	92	7.7	4	34	36	91	134	5.62	21	3.5	8.455
R3	E2	V1	126.6	8.3	3.5	30	39	98	178	4.72	22	3.264	10.6
R3	E2	V2	111.4	4.994	1.6	30	39	99	60	4.22	11.8	3.2	2
R3	E2	V3	84	6.4	3.2	30	39	97	84	4.47	14	2.945	6.2
R3	E2	V4	91	5.264	2.9	26	32	92	69	3.97	12.6	2.951	3.8
R3	E2	V5	109.7	5.517	1.2	30	39	98	75	5.22	12.6	2.722	3.5
R3	E2	V6	94	7.2	4.6	23	30	91	100	3.47	21	2.649	7.3
R3	E2	V7	103	6.9	3	30	39	103	95	4.72	15.8	3.4293	7.34
R3	E2	V8	93.12	5.977	5.1	28	28	94	80	4.22	13.2	3.445	5.9
R3	E2	V9	105	5.607	4.5	23	30	93	79	3.82	13.2	3.8	4
R3	E2	V10	106	6.9	5.1	31	30	91	93	4.22	15	4	6.8
R3	E2	V11	110.4	7.9	4.3	30	38	91	142	5.97	23	3.629	8.4
R1	E3	V1	110	8	3	29	39	94	158	4.25	25	3.4	9.4
R1	E3	V2	103	4.194	1.4	29	35	95	63	3.75	12.3	3.4	2.27
R1	E3	V3	90	5.6	3.1	29	39	100	91	4	13	2.6	5.5
R1	E3	V4	92	4.464	2.5	25	31	89	64	3.5	12.3	2.7	3.9
R1	E3	V5	103	4.717	1.6	29	35	93	68	4.75	13.1	2.588	3.8
R1	E3	V6	97	6.5	6	23	31	91	110	3	19	2.7	7.26
R1	E3	V7	110	6.5	4	29	40	99	93	4.25	16	3.5	7.1

R1	E3	V8	95	5.177	4.5	24	29	89	75	3.75	13.1	3.2	4.9
R1	E3	V9	101.3	4.807	4	22	28	89	72	3.35	13.1	3.015	3.9
R1	E3	V10	101.8	6.1	6	32	30	87	96	3.75	15	4.1	7
R1	E3	V11	102	7.3	4.8	31	33	88	128	5.5	20	3.913	8.1
R2	E3	V1	117.5	8	2	30	42	104	159	5.15	24	3.4	9.2
R2	E3	V2	110	4.394	1	32	43	103	63	4.65	12	3.25	3
R2	E3	V3	100	5.8	4	30	40	102	83	4.9	13.7	2.5	5.8
R2	E3	V4	102.3	4.664	2.4	27	33	102	64	4.4	12.34	2.6	3.23
R2	E3	V5	109.2	4.917	1.2	30	41	95	70	5.65	12.7	2.65	3.6
R2	E3	V6	91	6.8	5	22	35	95	103	3.9	23	2.5	8
R2	E3	V7	115	6.7	3.1	27	45	103	90	5.15	17	3.6	7.25
R2	E3	V8	98	5.377	5	26	28	98	73	4.65	13.7	3.27	5
R2	E3	V9	105.3	5.007	4.5	26	34	100	72	4.25	12.7	3.015	3.8
R2	E3	V10	100.5	6.3	5.1	30	32	93	88	4.65	14	4.4	7.1
R2	E3	V11	101.4	7.4	3.8	30	37	88	134	6.4	23	3.2	8.9
R3	E3	V1	120.4	8.2	2.4	29	40	94	165	4.83	29	3.5	10.7
R3	E3	V2	116.3	4.594	1.6	29	35	95	66	4.33	12.1	3.15	2.56
R3	E3	V3	110	6	4.2	29	35	103	90	4.58	14	3.082	5.5
R3	E3	V4	99.3	4.864	2.7	25	35	89	67	4.08	12.4	2.76	3
R3	E3	V5	110	5.117	1.5	29	35	93	73	5.33	12.4	2.588	4.2
R3	E3	V6	89	6.9	4.2	23	31	91	105	3.58	20	2.6	7.9
R3	E3	V7	100	6.5	3	29	38	99	100	4.83	18	3.7	7.8
R3	E3	V8	87	5.577	5.4	27	29	89	80	4.33	13.2	3.5	4.56
R3	E3	V9	103.2	5.207	4	22	28	89	77	3.93	13.2	3.015	4.6
R3	E3	V10	102.5	6.5	5	31	31	87	98	4.33	15	4	6.34
R3	E3	V11	103.2	7.8	3	29	36	88	125	6.08	21	3.913	8.2

Appendix VI. Honerable reaserch superviser and co superviser visiting my experimental plot.