Genotype × Environment Interaction in Yield Contributing Characters of Tomato (*Solanum lycopersicum* L.)

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CERTIFICATE

This is to certify that thesis entitled **"Genotype × Environment Interaction in Yield Contributing Characters of Tomato (*Solanum lycopersicum* 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 (MS) IN GENETICS AND PLANT BREEDING**, embodies the result of a piece of bona fide research work carried out by **Md. Rejaul Islam, Registration No.: 07-2395** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.

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

Dated: June, 2014
Dhaka, Bangladesh

(Prof. Dr. Mohammad Saiful Islam)
Supervisor

Dedicated to

My

Beloved Parents

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ABSTRACT

A field experiment was conducted at the farm of Horticulture, Sher-e-Bangla Agricultural University, Dhaka-1207,Bangladesh during the period from December 2012 to March 2013 to study the Genotype × Environment Interaction in Tomato (*Solanum lycopersicum* L.) by the Department of Genetics and Plant Breeding. Randomized Complete Block Design (RCBD) with three replications was followed in the experiment. The parental genotypes used in the study were G_1 (BD-7279), G_2 (BD-7281), G_3 (BD-7289), G_4 (BD-7759), G_5 (BD-7306), G_6 (BD-7292), G_7 (BARI Tomato-8), G_8 (BARI Tomato-9), G_9 (BARI Tomato-14) and G_{10} (BARI Tomato-15).Eight yield and yield contributing characters viz. days to first flowering, days to 50% flowering, days to maturity, plant height (cm), number of branches per plant, number of fruits per plant, fruit diameter (cm), fruit weight (g) were recorded. Analysis of variance for the genotypes and environments showed significant variation for all of the characters studied among the genotypes except fruit diameter which revealed the presence of considerable amount of genetic variability. Genotype x environment interactions was significant for all the traits which indicated that the genotypes responded well in environmental fluctuations (bi) and to their stability (S^2di).All the parameters influenced significantly by environment and also by different genotypes except fruit diameter. G × E interaction had significant influence on the parameters that were studied under the present experiment. The 5^{th} environment, Cow dung + Urea + TSP + MP were the best for all the characters studied. Environment, Env-4: Cow dung + TSP + MP was also good for most of the characters. It was followed by Env-1: Compost and Env-3: Manure (cow dung). Genotype BARI Tomato-9 showed stable performance respecting fruit weight/plant and similarly BARI Tomato-14 for Days to 50% flowering, BARI Tomato-9 and BARI Tomato-14 and BARI Tomato-15 for Number of fruits per plant and Fruit Diameter showed stable performance. **Based on the findings of the present investigation it can be concluded that** Genotype × environment interaction was present for the most of the characters. Environment × genotype was also significant for the most of the characters except fruit diameter. BARI Tomato-8, BARI Tomato-14 and BARI Tomato-15 were highly responsive i. e. suitable for rich environment in terms of yield per plant. BARI Tomato-9 showed stable performance considering fruit weight per plant.

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LIST OF ABBRIVIATIONS

BARI	=	Bangladesh Agricultural Research Institute
cm	=	Centimeter
^{0}C	=	Degree Centigrade
DAS	=	Days after sowing
DAT	=	Days after transplanting
et al.	=	and others *(at elli)*
Kg	=	Kilogram
Kg/ha	=	Kilogram/hectare
g	=	gram (s)
LSD	=	Least Significant Difference
MP	=	Muriate of Potash
m	=	Meter
P^H	=	Negative logarithm of Hydrogen ion.
RCBD	=	Randomized Complete Block Design
TSP	=	Triple Super Phosphate
t/ha	=	ton/hectare
TTA	=	Titratable acid
TSS	=	Total Soluble Solids
%	=	Percent

Chapter 1
Introduction

CHAPTER 1

INTRODUCTION

The cultivated tomato (*Solanum lycopersicum* L.) is the second most commonly consumed vegetable crop after potato (*Solanum tuberosum* L.) in the world and average yield of tomato is more than 4.7 million hectares (FAOSTAT, 2011).It is high nutritious and consumed as in fresh or processed form like as salads and cookies and it is also content of vitamins and minerals (Ram, 2005) due to adequate vitamin A and C, Calcium and Iron. At present new agriculture is trying to develop new identity of tomato productions require information regarding in various environment condition and magnitude of genetic variation. There is an important interaction of the available germplasm in multi-environmental conditions, which are important pre-requisites for systematic breeding programs.

There is a growing interest for improved tomato quality in the market place. In developed country markets, such as in European countries ones, there is a tendency to evolve from an agriculture focused on yield towards an agriculture focused on quality (Bouma *et al.*, 1998). In these areas, with high spending power, consumers demand products with higher internal quality which lead to the development of new higher quality products. This is especially true for 'functional foods' which offer an interesting growth opportunity for the food industry (Menrad *et al.*, 2003).

Recently, fruit quality has been the most important selection criterion for repeat buyers of tomato. Because of this, tomato breeders have placed significant efforts in improving tomato fruit quality traits, including lycopene content, TSS, vitamin C, and TTA content (Causse *et al.*, 2002, 2007; Chaib *et al.*, 2006). However, a tomato line with improved fruit quality in one location may not necessarily perform the same in another location; the phenomenon of performing differently by genotype in different locations results from G x E interactions. Environmental factors that may influence performance of a given genotype from location to location include soil, moisture, temperature, light intensity, humidity, rainfall, photoperiod, and cultural practices. These factors may play a role in gene regulation, which in turn can affect the expression of the genes controlling the trait of interest and ultimately result in different phenotypic expression among locations.

Tomato has moderate nutritional value, but it is consumed all year round. It is one of the most important sources of antioxidants, such as vitamin C or carotenoids, which are protective to degenerative diseases (Beecher, 1998 and Mayne, 1996). In this context, during the last decade there has been an increasing interest in the development cultivars with increased levels of L-ascorbic acid or the main carotenoids present in tomato: beta-carotene and lycopene. Cultivar such as 'Double Rich' has much vitamin C content or the 'high pigment' cultivars that are becoming popular in the processing tomato industry (Lenucci, 2007). Several mutations have been identified related to the carotenoid content in tomato, but important organoleptic or agricultural deficiencies have limited their use (Stevens and Rick, 1986 and Hanson, 2004) and it is necessary to survey new sources of variation.

Not only the environment plays an important role in the system, It has been suggested that the G x E interaction would be considerably high (Kuti and Konuru, 2005). Therefore more studies on the contribution of different environments, genotypes and their interactions to the expression of properties of functional value should be carried out in order to select elite genotypes with more precision that enhances the accumulation of favorable compounds. Information on the structure and nature of G x E interactions is particularly necessary to determine if it is possible to develop 'high functional value' cultivars with high environmental stability or specific cultivars for specific target environments.

In Bangladesh, tomato is the most important vegetable in all season, it is carrying a significant role among the other consuming vegetable. But its yield is not satisfactory enough in Bangladesh comparison with other tomato growing countries (Hossain *et al.*, 2004). Average yield of tomato in Bangladesh is very little; 7.51 t ha-1 (BBS, 2004). Performance of tomato production is decreasing and changing genotypic character due to the diverse environmental condition. The comparative performance of tomato genotypic character such as yield and other characteristic, which is influence yield, vary from an environment to another.

Multi-environment trials are conducted to evaluate yield stability performance of genetic materials under varying environmental conditions (Yanand Rajcan, 2002). It is largely depends on genotype and environmental interaction (Ahmad *et al.*, 1996). To developing genotype and phenotype interaction in various Tomatoes genotype is a major attention for a breeder. That interaction helps to select superior cultivars and their productiveness (Eagles and Frey, 1977) and it also evolve the adaptability of various crop varieties in different environmental condition (Morales *et al.*, 1991). According to gets a better genotype with high yielding capability and consistency, should be given to the importance of stable performance for the genotypes under different environments and their interactions which will help to develop a superior genotype character (Allard and Bradshow, 1964).

Objectives

The objectives of this study are:

(1) To identify genotype-environment interactions

(2) To assess the importance of the interaction for clinical practice and

(3) To determine if the interaction follows an additive or multiplicative model

Chapter 2
Review of literature

CHAPTER II
REVIEW OF LITERATURE

The tomato (*Solanum lycopersicum* L.), is an autogamous species with a narrow genetic base. The introduction of the species in Europe, from Mexico, was pivotal in the reduction of genetic variability, since in the European habitat tomatoes were generally cultivated in protected environments. This protected the wild forms, then allogamous, from the action of wind and insect pollinators, culminating in the maintenance of a germplasm adapted to autogamy only (Foolad, 2007). In this chapter an attempt has been made to briefly review some of the available works on tomato and few other crops having particular relevance to the present study.

2.1 Importance of tomato fruit morphology

Tomato fruits are important in marketing and processing industries in a variety of ways. Not only the host physiology change in tomato plants is crucial in tomato production, but also tomato fruit morphology is important. The guarantee of both characteristics will lead to a better tomato fruit production. Although tomato fruit quality has been studied in several aspects, the morphology of tomato fruits was relatively limited in knowledge. Our study mainly focuses on this part to fill the gap in terms of the morphology change in tomato fruits.

Great concerns about shape arise due to marketing since shape sorting of tomatoes is of great import to assess the sustainability for merchandized processing in terms of shape and size (Shi *et al.,* 2000). Breeding fresh market tomato cultivars that maintain a symmetrical and uniform shape with smooth blossom scars is of critical importance to the industry (Vavilav, 1951). Based on fruit morphology, consumers purchase tomato for specific purposes such as eating fresh and salads (grape, cherry tomato, tomatoes on the vine), for slicing to put onto hamburgers (beefsteak) or to use in sauces and stews (Roma tomatoes). In processing industry, elongated tomato fruit shape is desired due to the stability on the conveyer belt; better fit in cans than round tomatoes. As a result, the study of tomato fruit shape stability is important for the processing and fresh market industries, and even critical for tomato harvesting-related machine applications (Li *et al.*,2011).

2.2 Genotype- Environment interactions for yield related characters

What is not well understood is how the environment affects fruit shape and yield. For example, a tomato genotype may be classified to carry fruit in the round shape category. However, this variety may not yield exactly the same fruit shape and yield when grown in different environments. This is because different genotypes are expected to have different responses to environmental variation. It was once believed that a given trait was by genes (genotype, G) or exposure to environmental variation (environment, E); eventually the concept of a genotype by environment (G x E) interaction was developed (Baker, 1988).

The variant genotypic response to the environment factors such as temperature, soil type, nutrient level from different environments are a function of genotype x environment interactions. G x E interaction has been studied in many crops such as wheat (Taghouti *et al.*, 2010), rice (Shi *et al.*, 2000, Ahmed *et al.*, 2011) and soybean (Zhe *et al.*, 2010). Attempts have been made in tomatoes to evaluate genotypes for desired traits including yield, fruit weight (Ortiz *et al.*, 2007), aroma (Cebolla-Cornejo *et al.*, 2011) and quality (Panthee *et al.*, 2012) in diverse environments.

Suitable performance in diverse environments of certain genotypes with improved adaption to environment constraints has been suggested. Fruit shape traits, on the other hand, are rarely evaluated in diverse environments, except for peach and nectarines (Promchot *et al.*, 2008). Environmental factors are believed to affect tomato yield and quality (Ortiz *et al.*, 2007, Panthee *et al.*, 2012); grain shape of rice (Shi *et al.*, 2000). However, whether and how environmental conditions affect fruit shape, color and yield of tomato and many other crops is largely unknown. Although the fruit qualities have been studied a lot, few researches were carried to investigate the Genotype x Environment interaction on tomato fruit morphology. A major focus of my thesis project was the characterization of G x E interactions on tomato fruit shape, size, color and yield.

Tomato plant growth and fruits, in all aspects, have been evaluated in a lot of studies. However, the external factors such as grafting and genotype x environment interaction were relatively limited. For example, tomato rhizosphere, rich in microbes including both pathogens and beneficial contributors such as plant health promoting microbes and biocontrol agent aid in uptake nutrient will affect the host physiology and potentially, the biomass, leaf nutrient, fruit yield and shape. For example, a deficiency in calcium resulted in blossom end rot of tomato fruit in both yield and shape (Adams and Ho, 1993). Nutrient uptake such as phosphorous solubility or calcium increase either by microbes (Caballero-Mellado *et al.*, 2007) or by grafting (Leonardi and Giuffrida, 2006) will also affect the tomato physiology and even fruit shape, size and yield.

Murphy *et al.*, (2011) conducted genotype × environment (G × E) interactions for Ca, Cu, Fe, Mg, Mn, P, and Zn concentrations are not well understood, particularly in the context of organic farming systems. The objectives of this study were to: (i) investigate G×E interactions for mineral nutrient concentration in organically grown wheat; and, (ii) assess whether grain mineral concentration is a broadly or narrowly adapted trait when grown in contrasting environments over time. We evaluated 18 spring wheat (*Triticum aestivum* L.) cultivars on three organic farms in Washington State for mineral concentration and for grain yield in 2008 and 2009. The G × Year (Y) interactions were found for grain yield and all minerals except Fe, Mn, and P and G × Location (L) interactions were found for grain yield and all minerals except Fe. The G × E (G×L×Y) interactions were found for grain yield and all minerals except for Mn. Grain yield was not consistently correlated with mineral nutrients across years and locations. Among minerals, Mg:P, P:Zn, and

Mg:Zn were positively correlated in at least five of six site-years, suggesting the potential for simultaneous selection of these minerals. Grain mineral concentrations of Cu, Fe, and P showed relatively broad adaptation across years when compared with Ca and Mg concentrations. Fewer cultivars were broadly adapted spatially than temporally for stable levels of mineral concentration. Several cultivars had relatively high concentrations of two or more minerals across locations, indicating the potential for farmer utilization of broadly adapted cultivars and varietal blends that will significantly increase grain mineral concentration.

Murphy *et al.,* (2011) conducted multi-environment trials to evaluate yield stability performance of genetic materials under varying environmental conditions (Yan and Rajcan, 2002). The relative performance of genotypes for quantitative characteristics such as yield and other characteristics, which influence yield vary from an environment to another. Consequently, to develop a genotype with high yielding ability and consistency, high attention should be given to the importance of stable performance for the genotypes under different environments and their interactions which had important bearing on breeding for better varieties buffering (Allard and Bradshow, 1964). Kang (1998) mentioned that gene expression is subject to modification by the environment; therefore, genotypic expression of a phenotype is environmentally dependent. Stability in performance of a genotype over a wide range of environments is a desirable attribute and depends largely upon magnitude of genotype-environment interaction (Ahmad *et al.,* 1996). For stabilizing yield, it is necessary to identify the stable genotypes suitable for a wide range of environments. To identify such genotypes, genotype environment interactions are of major concern for a breeder, because such interactions confound the selection of the superior cultivars by altering their relative productiveness in different environments (Eagles and Frey, 1977). Stability analysis is a good technique for measuring the adaptability of different crop varieties to varying environments (Morales *et al.,* 1991).

Al-Aysh (2013) conducted an experiment with fourteen landraces of tomato (*Lycopersicon esculentum* Mill.) to estimate the magnitude of genotype-environment interaction and phenotypic stability for number of primary branches per plant, number of fruits per plant, fruit average weight (g) and fruit yield per plant (kg). For a given characteristic, a desirable, widely adaptable and stable genotype was defined as one with an individual mean performance greater than the grand mean, a regression coefficient (bi = 1), and deviation mean squares (S2di = 0). Mean squares due to genotypes (landraces), environments (years) and genotype-environment interaction were highly significant ($P \leq 0.01$) for most of the characteristics studied. The genotype-environment interaction (linear) components along with pooled deviation were significant for number of fruits per plant; suggesting importance of both linear and non-linear components in building up total G x E interaction. Five landraces; 20198, 20292, 20339, 20364 and 20402 were considered high yielding, performance stable and suitable for all environments for fruit yield. While only one landrace 20303 was considered high yielding, stable and specifically adapted under favorable or rich environments. These landraces may be exploited for commercial cultivation in tomato growing areas of Dara'a Governorate after an extensive testing concerning quality characteristics.

Tiwari *et al.*, (2013) evaluated with twenty five genotypes of tomato in RBD with three replications under four environments to study the stability behavior of genotypes under the four environmental conditions created with different doses of plant bio regulators viz. NAA 50ppm (E1), GA + PCPA (combined) each 50ppm (E2), 2,4-D 5ppm (E3) and control (E4). Pooled analysis of variance exhibited significant mean squares due to genotypes for all the traits. There was enough variability due to environments for all the traits except plant height. Significant variation due to G x E interaction was observed for all the traits except fruit weight. Pant T-5 and ARTH-3 were found to be only desirable stable genotypes for fruit yield per plant. They can be used as parents in hybridization program or could be suggested for planting under varying type of environments as specified in the present investigation.

Naveen Garg(2012) conducted the study to identify F1 hybrids heterozygous at rin, nor, or alc loci having wider adaptability across main and late planting conditions, besides possessing higher yield and better shelf life than check hybrids. Development of high-yielding cultivars with better shelf life and consistent performance across seasons is one of the important objectives of tomato (*Lycopersicon esculentum* Miller) breeding programs. Heterozygous individuals, i.e., F_1 hybrids, are reported to be more stable to environmental variation than homozygous ones due to their ability to perform better under stress conditions. The variation among environments was linear. All hybrids showed genotype × environment interactions for all traits. Shelf life of different hybrids significantly fluctuated from their respective linear response to environments and was non-predictable, while yield attributes (total yield/plant and number of fruits/plant) did not fluctuate and were predictable. Most of the tomato hybrids heterozygous at rin, nor, or alc loci showed above average stability for shelf life and yield attributes. However, 19 hybrids showed below average stability for total yield/plant and were suitable for main season planting only. The most stable hybrid was Spectrum × alc-IIHR-2050 having high-mean yield (1.25 kg/plant), nearing unity regression coefficient (0.91) and no significant deviation from regression (-0.11). It possessed higher yield and better shelf life index (9.31) than check hybrids viz., TH-1 (0.92 kg/ plant, 5.49) and Naveen (0.84 kg/plant, 6.01) and is recommended for multilocation trials across the state for cultivation in main and late planting conditions.

Zhou *et al.,* (2012) observed genotype by environment interaction (G x E) influences and complicates the selection of superior genotypes in trials by confounding the determination of true genetic values. In South Africa, variety trials are planted at several locations and harvested in the plant to third ratoon crops. The objective of this study was to determine the trends in components of G x E and their implications. The mixed procedure of Statistical Analysis System (SAS) was used to estimate variance components. Genotype by location interaction was significant for the irrigated and coastal long-cycle programs, indicating the importance of identifying and characterizing sites.

Genotype by crop-year interaction was larger and more significant for rain-fed than for irrigated cropping system, indicating the importance of ratooning ability in rain-fed regions. Genotype by location by crop-year interaction was significant ($P < 0.01$) for yield and sucrose content, highlighting the complexity associated with breeding sugarcane. The coastal long-cycle program was the most complex and generally characterized by large G x E. Separating the coastal hinterland and coastal average potential would be recommended to reduce G x E.

Roselloa *et al.,* (2010) conducted a study on the evaluation of the genotype, environment and its interaction on carotenoid and ascorbic acid accumulation in tomato germplasm. Tomatoes are an important source of antioxidants (carotenoids, vitamin C, etc.) due to their high level of consumption. There is a great interest in developing cultivars with increased levels of lycopene, β-carotene or L-ascorbic acid. There is necessary to survey new sources of variation. In this study, the potential of improvement for each character in tomato breeding programs, in a single or joint approach, and the nature of genotype (G), environment (E) and G x E interaction effects in the expression of these characters were investigated. The content of lycopene, â-carotene and ascorbic acid determined was very high in some phenotypes (up to 281, 35 and 346 mg kg-1 respectively). The important differences in the three environments studied (with some stressing conditions in several situations) had a remarkable influence in the phenotypic expression of the functional characters evaluated. Nevertheless, the major contribution came from the genotypic effect along with a considerable G x E interaction. The joint accumulation of lycopene and â-carotene has a high genetic component. It is possible to select elite genotypes with high content of both carotenoids in tomato breeding programs but multi-environment trials are recommended. The improvement of ascorbic acid content is more difficult because the interference of uncontrolled factors mask the real genetic potential. Among the accessions evaluated, there are four accessions with an amazing genetic potential for functional properties that can be used as donor parents in tomato breeding programs or for direct consumption in quality markets.

Mandal et al., (2000) tested twenty tomato genotypes under three environments for stability analysis following the model of Eberhart and Russel (1996). Among the five characters, viz., plant height, primary branch number, fruit number, fruit weight and yield studied, only fruit yield had the significant genotype-environment interaction and the same was due to linear component, Relative judgment of the genotypes from their stability parameters i.e. bi, S2 di and P1 revealed that Punjab Chhuhara, Kalyani Eunish, Pusa Ruby and Sel.7 were adapted specifically to favorably/better/rich environments and Arka Vikas, Marglobe Supreme, KBT-1 and Anand T-1 were adapted specifically to poor/unfavorable environments.

The old alluvial zone of West Bengal has the ample scope for tomato cultivation. Here the soil type, land situation and climate are very much congenial for tomato growing during robi season. Yield of tomato is severely affected with the changing environments. Ortiz and Izzuierdo (1994) also reported that the environment subsequently affects the performance of tomato genotypes in Latin America and the Carribbeans (LAC). In the present investigation, an attempt was made to screen out the promising tomato genotypes which would perform well in this region. In this context, a good collection of tomato genotypes were made from different sources and tested for their yield potentiality in this zone.

Beaver and Johnson (1981) studied yield stability of determinate and indeterminate soybean and found that a significant portion, but not all the genotypes × environment interaction could be explained by regression. The group, indeterminate cultivars in this study possessed desirable stability characteristics having average or greater than average seed yield response to environments of varying levels of productivity and minimum deviations from regression.

Das *et al.*, (1982) conducted an experiment with nine cultivars of soybean involving six quantitative characters in winter and summer seasons indicated that Bragg had higher seed yield, 100-seed weight and pods/plant than all the others and Lee74 and Clark63 followed Bragg in these characters. Significant genotype × environment interaction was observed for all characters except days to flowering. Seed yield was positively correlated with pods/plant.

Patel *et al.*, (1983) evaluated ten promising spreading groundnut varieties in comparison with "M13" to have average stability and high level of performance for pod yield. They found significant differences in pod yield among the varieties in both the years. Variety × environment interactions were also significant. The varieties differed significantly for linear response to environmental effects and also for the deviation from linearity.

Das *et al.*, (1983) conducted an experiment with four soybean varieties. The genotype-environment interactions were operative in two characters. The genotype-environment interactions were accounted for both linear and non-linear functions of the environmental means. The major G × E interaction was due to linear relationship between environments and the genotypes. Real difference between the genotypes existed in relation to response (b) and stability (S^2b). Genetic diversity was obtained between the genotypes. On the basis of mean, response and stability, selection of varieties (i) Bossisr, Bragg and Rillito in case of pods/plant for all environments and (ii) Bragg in case of seed yield and (iii) Lee 74 in case of pods/plant and seed yield for unfavorable environments was effective.

In groundnut Kumar *et al.*, (1984) reported a significant genotype × environment interaction for pod yield as well as four yield related and quality characters in twelve genotypes over three environments. They also reported a significant interaction for both linear and nonlinear components for all the characters under study except pod yield, where only the later was significant. The non-linear component had the higher value for all characters except pod yield and days to maturity.

Singh and Chaudhary (1985) studied 32 soybean genotypes in three artificial environments and all 32 genotypes were found to be stable, except Bragg, HM33, SH2 and HM8 for days to maturity, yield, oil content and protein content, respectively. HM93, PK73-94, PK321, PK73-92, Bragg and SH_1 had the greatest stability, above average response and high seed yields. Correlation studies indicated that response and stability were governed by different genetic system.

Sumarno (1985) studied one hundred F_5 derived lines from 10 crosses in West Java during the 1982-83 dry and wet seasons at the same location and found that yield correlation between the seasons was $r = 0.4$. Interaction between genotype and season was significant indicating differential adaptation of genotypes to seasons. It was affirmed from the findings that separate breeding programs for specific seasonal adaptation might not be necessary.

Tawar *et al.*, (1985) observed that, though both general and specific combining ability effects were operative in the populations over locations, gca seemed to be more important for the traits under study. The inheritance studies through all three approaches of diallel cross analysis further indicated the reliability of combining ability studies in comparison to other two methods. However, the information was more or less complementary to each other and thus provided the essential information about the appropriate breeding methodology for the improvement of characters under consideration. The genotype × location interaction played an important role in the expression of inconsistency for most of the genetic components like mean degree of dominance and heritability estimates of the traits under study.

Biswas and Mondal (1986) observed five soybean genotypes over two years and found significant differences in days to flowering (50%), days to maturity (90%), plant height, number of pods/plant, 100-seed weight and seed yield/ha, but number of seed/pods, seed yield/plant were found non-significant in both the years. The genotype Ph-1 yielded highest in both the years. The variety

Bragg yielded poor in both the years. The variety Davis was found late in respect of other genotypes.

Simmonds (1991) regressions of yield of cultivars upon means of sets of cultivars over diverse environments are often used as measures of stability/ adaptability. Prolonged selection for performance in environment of high yield potential has generally led to unconscious selection for high regression. If an adaptation to poor environment is required, common sense suggests that low regressions could be exploited for the purpose. Simulations show that systematic selection in the poor environments is required not merely trials of potential cultivars exploitation of a genotype-environment interaction effect is proposed. The effects are large enough to reduce correlated responses in different environment to zero. Orderly experimental studies are needed but not available.

Jovanovic *et al*., (1992) determined the effect of genotype and environment interaction on oil content in grain. 15 soybean varieties in 3 maturity group were investigated for two years. The results suggested that the varieties with short vegetative period had high stability of oil content value.

Bevilaqua *et al*., (1996) conducted a greenhouse experiment with soybean cv. IAS 5 which way given the equivalent of 200 or 400 kg PK/ha applied at sowing next to the seed, 2 or 4 cm below the seed, or 2 or 4 cm to the side and below the seed. Compared with controls which was given no fertilizer, fertilizer had no significant effect on dry weight or length of roots above ground parts, but increased P and K uptake. With 400 kg PK, emergence percentage, P and K uptake, and root and shoot dry matter were reduced by placement next to the seed.

Deka and Talukder (1997) reported stability behavior of twenty one accessions of soybean for yield and some of the yield attributes under five different environments. Significant genotype × environment interactions were observed for almost all the characters. For characters like 100 seed weight and yield per plant, only the linear component contributed significantly towards G-E interaction variance. The rest of the characters both linear and non-linear components contributed towards G-E interaction variance.

Gupta *et al.*, (1998) evaluated forty genotypes of pea at four environments (Janta Mahavidyalay, Ajitmal and Garampani) during rabi 1992-93 and 1993-94 to study the nature and magnitude of G × E interaction. Highly significant differences were observed among the genotypes and environment for all characters under observation; viz. number of pods/plant, pod length, no. of seeds/pod and pod weight/plant. Highly significant G × E interactions were observed for all the characters. On the basis of their stability parameters and mean performance. Arkel and Azad pea-1 were found to be promising genotypes for number of pods/plant, pod length, number of seeds/pod and pod weight/plant.

Hoque *et al.*, (1999) reported that response of soybean to inocula, Bradyrhizobium Japonicum strains viz. TAL 102 and RCR 3407 as single culture and mixture and fertilizer S and Mo in different combinations showed that inoculation either alone or in combinations with S and Mo increased nodule number and grain yield significantly as compared to control (un inoculated and unfertilized).

Manivannan (1999) studied the genotype × environment interaction in black gram (*Phaseolus mungo*) and evaluated the stability for seed yield in 21 black gram genotypes, grown in 4 environments (seasons), during 1995-97 at Vamban, India. The analysis of variance for stability of seed yield showed significant differences amongst the genotypes. In the experiment, nine genotypes appeared stable for seed yield and these results combined with genotype grouping indicated that three genotypes namely VBG 42, VBG 52 and VBG 57 were the most superior.

Rocha *et al.*, (1999) had a study on genotype × location interaction for yield in soybean. A total of 188 soybean lines developed by the Department of

Genetics, University of Sao, Paulo, Brazil, classified in four maturity cycles, were studied at 3 locations (Anhembi, Areas and ESALQ) in the summer season of 1996/97. Effects of lines (G), location (L) and G×L interaction were detected in four maturity cycles. Anhembi was the most favorable locality for the expression of the seed yield potential in the semi-yearly intermediate and semi-late maturity lines; ESALQ offered the best environmental conditions and Area was unfavorable for all, maturity cycles. Seed yield of the lines varied according to the maturity cycle: intermediate semi-early, early and semi-late maturity.

Zewdie and Bosland (2000) worked on evaluation of genotype, environment, and genotype × environment interaction for capsaicinoids in chilli (*Capsicum anmum*). Significant differences were observed by the authors among the genotypes and genotype × environment interactions for capsaicinoids in chilli over the environments. Among the genotypes in an environment, the within-genotype variances were also significantly different. For Had 270, the genotype × environment interaction was negligible for individual and total capsaicinoids, indicating stability across environments.

Arias *et al*., (2000) suggested that data from four cultivars and lines and their derived sets of F_2, F_3, F_7, F_8, F_9 and F_{10} generations assayed in 17 environments were analyzed to allow an insight of the genetic control of soybean yield under different environmental conditions. Complications such as epistasis, linkage and macro and micro genotype × environment interaction were also commonly detected. The overall heritability was 0.29. The relative magnitude of the additive effects and the complicating factors allowed the inference that the latter are not a serious problem to the breeder. The low heritability values and the considerable magnitude of G×E interactions for yield, however, indicated that careful evaluation was necessary for successful selection.

Vollmann *et al*., (2000) observed that in a set of 60 genotypes, protein content increased both by late nitrogen fertilization before the onset of seed filling and by inoculation of seed with nitrogen-fixing rhizobia. Despite of high degree of environmental modification genetic variation of seed protein content was considerable and genotype × environmental interaction was of low magnitude.

Islam and Newaz (2001) studied in 10 genotypes of dry bean under five different cultural environments during rabi season of 1998-99 at BAU, Mymensingh. Significant variation for genotype (G), environment (E) and G × E interactions were found for the characters days to maturity, pod length, seeds/pod, 20-seed weight and seed yield/plant but not for seeds/pod and 20-seed weight in environment. On the basis of stability parameters genotypes PB 135, PB 139 and PB 142 could be considered stable for seed yield but suitable only under poor environments.

Pradeepkumar *et al.,* (2001) conducted an experiment to quantify genetic variation in tomato for yield and resistance to Bacterial Wilt based on the idea that proper and systematic evaluation of genetic resources was essential to understand and estimate the genetic variability, heritability, genetic advance and genotype - environment interaction. Data were recorded on plant height, days to maturity, number of fruits plant -1, pericarp thickness, locale number, total soluble solids, average fruit weight, number of harvest per plant and plant yield. They observed highly significant differences among the genotypes for all the traits as well as high genotypic coefficient of variation for all the characters. Higher heritability estimates and high genetic advance for all the characters indicated lesser influence of environment and higher role of additive gene action, respectively.

Hannan *et al.,* (2007a) investigated heterosis, combining ability and genetics of brix, days to first fruit ripening and yield in tomato (Lycopersicon esculentum Mill.).The study was conducted on a 10 × 10 diallel set of tomato excluding reciprocals to quantify the extent of heterosis, combining ability and nature of gene action for yield with two important quality traits: brix% and days to first fruit ripening. They obtained significant differences among genotypes with environment interaction for all the traits. They found positive significant heterosis for yield (211.00, 232.00, and 286.00), for brix % (61.06, 106.70, and

37.76) and for DFFR (8.92, 9.33 and 8.07) over mid parent, the better and standard parent, respectively. The magnitudes of variance due to general and specific combining ability were highly significant indicating the importance of both additive and non-additive gene action. However, degree of dominance revealed the prevalence of a non-additive gene effect. They found cross combinations P9 × P7 (0.66), P5 × P2 (7.85) and P9 × P6 (1.22) as best specific combiners for brix%, DFFR and yield per plant. They concluded that predominance of non-additive gene action by genotype-environment interaction played a greater role in the inheritance of brix% and DFFR in tomato.

Chishti *et al.*, (2008) conducted a study on the analysis of combining ability for yield, yield components and quality characters in tomato (*Lycopersicon esculentum* Mill.), on plant material comprising 12 parental lines and their F1 hybrids (direct crosses). They recorded data on days to flowering, number of flowers per cluster, number of fruits per cluster, number of marketable fruits per plant, fruit length, fruit width, and fruit weight, fruit yield per plant, pericarp thickness, and fruit firmness at red stage, total soluble solids and pH of juice. Analysis of variance revealed highly significant differences among genotype environment interaction, parents and hybrids, as well as highly significant mean squares due to GCA and SCA for all the characters. The ratio of s2g/s2s indicated that non-additive variance prevailed in genetic determination of most of the characters. None of the parents exhibited good GCA effects for all characters. They identified the crosses UC134 × Roma, 88572 × Lyp No.1 and Cchaus × RioFuego as best combinations on the basis of yield performance.

Singh *et al.*, (1993) conducted an experiment on heterosis breeding in tomato. Eight cultivars with diverse values for quantitative characters were crossed in a diallel set. Data on yield and nine component traits were recorded for the 28 F1 hybrids and parents. Hybrids Punjab Chhuhara × 84-8, HS102 × Pusa Ruby, 37.76) and for DFFR (8.92, 9.33 and 8.07) over mid parent, the better and standard parent, respectively. The magnitudes of variance due to general and specific combining ability were highly significant indicating the importance of both additive and non-additive gene action. However, degree of dominance revealed the prevalence of a non-additive gene effect. They found cross combinations P9 × P7 (0.66), P5 × P2 (7.85) and P9 × P6 (1.22) as best specific combiners for brix%, DFFR and yield per plant. They concluded that predominance of non-additive gene action by genotype-environment interaction played a greater role in the inheritance of brix% and DFFR in tomato.

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Suresh *et al.,* (1995) carried out heterosis study for fruit yield and its components in seven tomato lines, their 21 F1s and three commercial hybrids. Greatest heterosis over superior parents was observed for average fruit weight (30.8%), fruit numbers (143.1%), early yield (41.6%) and total yield (72.2%). These were also significantly influence by G × E interaction and best for total yield. They recommended three most promising crosses (Hisar Arun × Sel-30, Sel-30 × Flora-dade and Antey ×Flora-dade) for commercial use.

Rai *et al.,* (1997) carried out an experiment on G × E interaction of yield and yield components in tomato. Seven genetically diverse tomato parents were crossed in a diallel mating design (excluding reciprocals). They suggested that both additive and non-additive components played major role in the control of yield and yield components. They recommended that both heterosis breeding (non-additive) and simple recurrent selection (additive) were greatly influence by environment and may be used to exploit genetic components of variations in tomato.

Chadha *et al.,* (2001) conducted an experiment pertaining to number of combinations evincing combining ability for days to flowering and found that out of 40 F1s, 3% showed good specific combining ability association with cold environment. Dhaliwal *et al.,* (2002) reported that concerning combining ability to environmental studies for days to flowering in tomato, highly significant variance for GCA and SCA were observed. Similarly, Cheema *et* *al.,* (2003) also detected highly significant variances for General and Specific combining abilities in tomato (*Lycopersicon esculentum* Mill.).

Dhaliwal *et al.,* (2005) studied the inheritance of important quality attributes of tomato to assess the genetic control of fruit quality attributes. They reported that Additive × Additive interaction effects were more important only for pH and TSS%. Dominance × Dominance di genic interaction effects were significant and positive for pH and lycopene in cross-1 but negative and significant for pH and TSS% in cross-11. They recommended pure line breeding for genetic improvement of tomato with respect to the three quality attributes studied, based on the magnitude and direction of gene effects and self-pollinated nature of the crop.

Ashraf *et al.,* (2001) conducted an experiment with thirteen advance lines and three checks were planted at nine locations to estimate genotype-environment interaction. Both the linear and nonlinear components were highly significant, indicating the presence of both predictable and un-predictable components of G × E interaction. The stability parameters for the individual genotype revealed that the genotype, 89R-35 and 90R-36 showed the regression closer to unity along with low deviation from regression and thus may be stated as stable genotypes.

Shah *et al.,* (2009) conducted stability analysis with ten wheat varieties at nine different locations for three years. Variety-location interactions were highly significant for all characters. The relative magnitude of interaction variance components indicated that relative performance of varieties for plant height, productive tillers, 1000-grain weight and grain yield were more inconsistent across locations. The stability parameters within variety mean square (Si^2), variety coefficient of variation (CVi%), equivalence (Wi^2), variety interaction variance (σi^2), regression coefficient (bi), deviation from regression mean square (δi^2) and coefficient of determination (Ri^2), revealed a range of stability for all characters.

With the trials conducted in two locations and over two years, the adaptation and stability statistics of 20 bread wheat genotypes were estimated for yield performances (Aycicek and Yildirim, 2006). There were differences in stability performances among the genotypes for the traits of plant height, grains spike-1, grain weight spike-1 , 1000 kernels weight and grain yield. The instability for plant height and grain weight spike among the genotypes were originated from the mean squares of deviation from regression; for the other traits it was resulted from not only the mean squares of deviation from regression but also from the differences among regression coefficients of genotypes.

Ten genotypes of wheat were evaluated with respect to grain yield and its components to characterize their stability under four growing environments (Amin *et al.*, 1993). Significant G × E interaction was observed in the materials for all the characters. Based on phenotypic index, regression coefficient and deviation from regression parameter, only Aghrani was found as stable genotypes with wider adaptation which was conferred by the stability of spikes m^{-2}. Varieties like Kanchan and Akbar found suitable only for favorable environments. Lines BAW-59, BAW-60 and BAW-61 were found suitable for cultivation under marginal condition i. e. slightly unfavorable environments. The rest of genotypes exhibited different response over different environments for different characters.

Twenty genotypes of bread wheat were evaluated at three locations. Genotypes x locations interaction vis-a-vis stability were studied for days to maturity and grain yield (Barma *el al.,* 1994). Genotypes, locations and G x E interactions were found significant for both the traits. Significant genotypes x environments (linear) interactions also occurred for both maturity and yield indicating differential response among the genotypes. Estimated stability parameters (bi and S^2di) for days to maturity indicated that the lines BAW-80, BAW-109. BAW-166 with least response to environments (bi=l) and minimum deviation from regression (S^2di=0) were found stable over locations. However, the high yielding genotypes, BAW-78, BAW-87, BAW-106, BAW-121 and Kanchan were highly sensitive (bi>1.0) to location changes having minimum deviation from regression ($S^2di=0$) indicating suitability only for high yielding environments.

Hamam *et al.,* (2009) conducted an experiment with 12 genotypes to assess genotype- environment interaction. The combined analysis of variance revealed highly significant genotype-environmental interaction for biomass and grain yield. The other linear and non- linear components of variance were highly significant for both the traits. Based on stability parameter the genotypes differed in their stability for biomass and grain yield.

Broccoli *et al.,* (2004) conducted an experiment by which fourteen commercial popcorn maize hybrids were evaluated in a randomized block design in three locations for two years in the region of the Buenos Aires province, Argentina. The interaction genotype x environment revealed environments favorable towards yield but which were simultaneously unfavorable towards expansion capacity, as well as genotypes stable for one of these variables but unstable for the other. However, some environments and genotypes were simultaneously favorable to both. Only a weak negative correlation was found between grain yield and expansion capacity, suggesting this relationship may not be very strong in these modern hybrids. Rounded grains showed higher expansion capacities, but this characteristic was negatively correlated to yield; roundness is therefore not recommended as a selection criterion. The prolificacy index correlated positively with yield but not with expansion volume, and is therefore a potential selection criterion.

An experiment was conducted by Mashark *et al.,* in 2007 to determine the importance of genotype by environment interaction (GE) in late maturing lowland maize varieties to determine yield stability of the genotypes and use the information to exploit GE for the development of high and stable yielding varieties. Seven out of the nine genotypes were stable, when b-values alone were considered. When the b-values and the deviations from regression (S^2d) were considered, (GH24 x 1368) x 5012 and (GH22 x 1368) x 5012, were the most stable, but when the coefficient of determination was added to the b-value and S^2d, GH132 - 28 was the most stable genotype. Kpeve consistently produced above average grain yields and was the most stable location. A good level of precision was obtained with two replications, when genotypes were evaluated for 4 years at *8* locations.

Fifteen maize genotypes were tested by Admassu *et al* (2008) al nine different locations in 2005under rain fed condition to determine stable maize genotypes for grain yield and determine genotypes with high yield and form homogenous grouping of environments and genotypes. There was considerable variation among genotypes and environments for grain yield. Stability was estimated using the Additive Main Effects and Multiplicative Interactions (AMMI). Basedon the stability analysis, genotypes 30H83, BH-540, Ambo Synth-1, AMH-800 and BHQP-543were found to be stable for grain yield. The first two Interaction Principal Component axis(IPCA1 and IPCA2) were significant (pcO.Ol) and cumulatively contributed 70.27% of the total genotype by environment interaction. The coefficient of determination (R^2) for genotypes 30H83 was as high as 0.92, confirming its high predictability to stability. Among the genotypes, the highest grain yield was obtained from genotype 30H83 and BH-541 (8.98 and 8.05 t ha-1) across environments. Clustering of AMMI-estimate values grouped genotypes in to four clusters and the environment in to three clusters. Environment Goffa was unique as it is grouped differently from all other environments.

Gezahegn *et al.,* (2009) used eight drought tolerant maize lines and their 28 crosses with two local hybrids and evaluated separately in *12* environments to estimate the magnitude of genotype x environment interaction (GEI) and relationships between parents and progenies in stability. An additive main effects and multiplicative interaction (AMMI) model was used to analyze the grain yield data. The first two IPCAs of the AMMI 2 analysis accounted for 56 % of the GEI sum squares in trials of the hybrids. High yielding hybrids like O, P, S, Z, U, G and one of the checks (BH140) showed minimum GEI, indicating wide adaptation of these varieties over environments. In contrast, high yielding hybrids such as A, D and J adapted to unfavorable environments and K and T to favorable environments. Most of the crosses from drought tolerant parents were better than the check (BH540) in mean grain yield and stability. Although no considerable association in stability was observed between crosses and their parents, increased stability occurred in most of the crosses due to increased stress tolerance.

Baleslre *et al.,* (2009) constructed an experiment and evaluated the phenotypic and genotypic stability and adaptability of hybrids using the additive main effect and multiplicative interaction (AMMI) and genotype x genotype-environment interaction (GGE) biplot models. They found that, the GGE biplot method to be superior to the AMM1 1 graph, due to more retention of GE and G + GE in the graph analysis. However, based on cross-validation results, the GGE biplot was less accurate than the AMMI 1 graph, inferring that the quantity of GE or G + GE retained in the graph analysis alone is not a good parameter for choice of stabilities and adaptabilities when comparing AMMI and GGE analyses.

Rahman *et al.,*(2010) carried out stability analysis to study stability in performance and genotype x environment interactions for 18 maize hybrids across three locations of NWFP during 2006.Data were recorded on different morphological and yield parameters. Analysis of variance indicated significant differences among the three locations for all the traits studied. Hybrids showed significant differences for all parameters except anthesis silking interval (ASI) and ear height, which were non-significant across the three locations. The hybrid x location interactions also revealed significant differences for days to 50% silking, days to 50% anthesis, ASI, grain moisture at harvest and grain yield per hectare while non-significant differences were observed for plant height and ear height. Based on yield performance of hybrids across the three locations, Baffa ranked first as compared to the other two locations.

Chapter 3
Materials and Methods

CHAPTER III

MATERIALS AND METHODS

An experiment was conducted at the Horticulture farm, Sher-e-Bangla Agricultural University, Dhaka-1207, Bangladesh during the period from December 2012 to March 2013 to study on the Genotype × Environment interaction in tomato *(Solanum lycopersicum L.)*. The experiments were conducted to deal with major objectives of this work. The materials and methods of this experiment are presented in this chapter under the following headings:

3.1 Experimental site

The experimental area was situated at 23°46' N latitude and 90°22'E longitude at an altitude of 8.6 meter above the sea level (Anon., 1988). The experimental field belongs to the Agro-ecological zone of "The Modhupur Tract", AEZ-28 (Anon., 1988). This was a region of complex relief and soils developed over the Modhupur clay, where floodplain sediments buried the dissected edges of the Modhupur Tract leaving small hillocks of red soils as `islands' surrounded by floodplain (Anon., 1988).

3.2 Soil and climate

The land belongs to Agro-ecological region of 'Madhupur Tract' (AEZ 28) of Nodda soil series. The soil was sandy loam in texture having pH 5.47- 5.63. The mean temperature of the growing period was 24.36° C with average maximum and minimum being 30° C and 18.67° C respectively. Weather information and physicochemical properties of the soil are presented in (Appendix I and Appendix II respectively).

3.3 Plant materials

Ten genotypes of tomato were used for the present research work. Seeds of all the genotypes were collected from BARI (Bangladesh Agricultural Research Institute), Gazipur.

Table 1: Name and origin of 10 tomato genotypes used in the present study

Sl. No.	Genotypes No.	Name/Acc No. (BD)	Origin
1	G_1	BD-7279	PGRC,BARI
2	G_2	BD-7281	PGRC, BARI
3	G_3	BD-7289	PGRC, BARI
4	G_4	BD-7759	PGRC, BARI
5	G_5	BD-7306	PGRC, BARI
6	G_6	BD-7292	PGRC, BARI
7	G_7	BARI Tomato-8	HRC, BARI
8	G_8	BARI Tomato-9	HRC, BARI
9	G_9	BARI Tomato-14	HRC, BARI
10	G_{10}	BARI Tomato-15	HRC, BARI

PGRC=Plant Genetic Research Centre, HRC= Horticulture Research Centre BARI=Bangladesh Agricultural Research Institute

3.4 Experimental plan and cultural environments

G×E interaction study was pursued using five cultural environments as detailed in Table 2. Organic fertilizer and other inputs used in creating the environments were at recommended rates, and for common inputs same rate was used in different environments.

Table 2: Cultural environments and rates of inputs used in the studies

Cultural environments	Rates of inputs for cultural environments (Expt. 1 and 2)
Env-1: Compost	Compost (for seeds) @ 5000 kg/ha
Env-2: Urea + TSP	Manure @ 10000 kg/ha
Env-3: Manure (cow dung)	Urea @ 550 kg/ha
Env-4: Cow dung + TSP + MP	TSP @ 450 kg/ha
Env-5: Control (Cow dung + Urea + TSP + MP	MP @ 250 kg/ha

3.5 Land preparation

Land preparation was started in first December with a tractor; later on, cross ploughing and laddering was done to have a proper tilth of soil. Weeds and stubbles were removed from experimental plot before final land preparation with application of manure and chemical fertilizers according to the schedule of cultural environments.

The fertilizers/manure (well rotten compost and cow dung) was uniformly and thoroughly mixed with the soil. One third of the urea was applied during land preparation and the remaining two-thirds applied in two equal splits as top dress, one at the vegetative phase (25 DAS) and the other at flowering stage (40 DAS).

3.6 Experimental design

The design of the experiment was randomized complete block (RCB) with three replications. The unit plot size in a rep. measured 4m in length and 1 m in width, accumulated with 3-rows of spacing 40 cm × 60 cm. The genotypes were sown randomly as per schedule and design. The sampling for growth analysis was done at six regular intervals following standard procedure, commencing at 30 DAS.

Compost and manure (cow dung) were applied to the soil properly with recommended dose. Synthetic fertilizers were use as in the unit plot as cited in Table 3.3. Seeds for each plot was taken in a plastic pot and sowed in the field on 19th December, 2012.

3.7 Sowing of seed and intercultural operation

Seeds were sown in a seed bed for raising seedlings. The seeds were sown on the 19th December 2012. For transplanting of seedlings, it is maintained in rows keeping the row to row distance of 40 cm and plant to plant distance of 60 cm.

There was an incidence of infestation with harmful insects in some experimental plots. Mechanical control (hand picking) of insects was done when the infested leaves with larvae were removed.

3.8 Harvesting and post harvesting processing

The fruits of tomato were harvested at full maturity at different stages. Such maturity came with whitish to yellowish of fruits. Different varieties were harvested at different labels with differential maturity periods, also conditioned by the variation of cultural environments.

3.9 Plant sampling/data recording in growth studies

The first plant sampling was done from each unit plot at 30 days after transplanting which was followed by every 10 days' intervals up to final harvest. From each line, 5 plants were selected randomly.

3.10 Data collection in G×E interaction studies

Data were recorded on an individual plant basis from 5 randomly selected plants per genotype in a replicate.

The criteria used in recording of data are as follows:

3.10.1 Days to first flowering

The number of days was counted from the date of sowing to days to first flowering.

3.10.2 Days to 50% flowering

The number of days was counted from the date of sowing to 50 per cent of plants flowered.

3.10.3 Days to maturity

The number of days was counted from the date of sowing to first harvesting.

3.10.4 Plant height (cm)

The plant height was measured from ground level to tip of the plant expressed in centimeters (cm) and mean was computed.

3.10.5. Number of branches per plant

The number of branches arising from the main stem above the ground was recorded at 70 days after transplanting.

3.10.6. Number of fruits per plant

The total number of marketable fruits harvested from the five plants was counted and the average number of fruits per plant was calculated.

3.10.7. Fruit Diameter (cm)

It was measured from fruit breadth at highest bulged portion of the fruit by using veneer caliper.

3.10.8. Fruit weight (g)

The total number of marketable fruits from each plot was weighed and the fruit weight was worked out and expressed in grams (kg).

3.11. Statistical analysis

The data on growth parameters and other plant characters were statistically analyzed following standard procedure. For G×E interaction and stability analysis, the procedure outlined by Eberhart and Russell (1966) was followed. For yield data, G×E analysis was extended to include the grouping technique by Francis and Kenninberg (1978) also.

3.11.1 Eberhart and Russell's method of stability analysis

The model considered in this analysis is as follows:

Yij = μi +bi Ij +δij (i = 1, 2 --------- n and j = 1, 2 ---------- l)

Where,

Yij is the mean of the ith variety at jth environment

μi is the mean of the ith variety over all environment

biIj is the regression coefficient that measures the response of the ith variety to environment index.

i.e:

$$b_i = \sum_{J=1}^{n} YijIj / \sum_{J=1}^{n} Ij^2$$

Ij is the environmental index which is defined as the deviation of mean of all varieties at a given time from over all mean

i.e. $I_j = \bar{Y}_{.j} - \bar{y}_{..}$

where,

$\bar{Y}_{.j}$ = Mean at j^{th} environment.

$\bar{Y}_{..}$ = Over all mean

δ_{ij} is the deviation from regression of the i^{th} variety at the j^{th} environment i.e.

$$\sum_j \delta ij = \left[\sum_j yij^2 - \frac{Yi^2}{t}\right] - \frac{\left(\sum_j Yij\, Ij\right)^2}{\sum_j I_j^2}$$

Where t is the number of environment

The term phenotypic index (Ram *et al.* 1970) has been introduced in the Eberhart and Russell (1966) model for easy interpretation and quick conclusion. The phenotypic index of a genotype may be considered as one of the stability parameters in place of overall variety mean and can be represented as $pi = \bar{Y}i - \bar{Y}..$ i.e deviation of variety mean from grand mean.

With the restriction $\sum pi = 0$, where pi = phenotypic index for ith genotype; the Eberhart and Russell's model was slightly modified by substituting pi for overall variety mean (μi) as follows:

$Yij = (\bar{Y}.. + Pi) + biIj + \delta ij$

and another stability parameter, S^2di was calculated as.

$S^2di = \left[\sum_j \delta ij^2 / S^{-2}\right] - (Se^2/r)$

Where S = no. of environments

S^2e = MS for pooled error and

r = number of replications

The hypothesis that these is no response of variety to location (Ho: b = 0) and there is no deviation from regression (Ho: $S^2d = 0$) were tested approximately by the F-test. Ho: b= 0 where, F = MS due to linear regression/error MS Ho: $S^2d = 0$

Where, F= MS due to deviation/pooled error MS. The individual variety response (Regression co-efficient) and their deviation from regression were tested by using appropriate t-test and F-test against the hypothesis that it did not differ significantly from unity and zero respectively as-

$$t = \left| \frac{1 - bi}{S_E(b)} \right|$$

where,

$$S_E(b) = \frac{\sqrt{\text{MS due to pooled deviation}}}{\Sigma_i I_i^2}$$

With (n-1) d.f, n = number of genotypes and F = $\left[\sum_j \delta^2 ij^2 / S - 2\right]$ pooled error.

The pooled error mean square was calculated from the combined (pooled) analyses for specific set of time. Linear regression analysis of grain yield, yield contributing characters and agronomic characters of the genotype on environment indices were undertaken to determine the adaptability and stability of individual genotype.

Chapter 4

Results and Discussion

CHAPTER IV

RESULTS AND DISCUSSION

The overall results have been presented and discussed in this chapter. The results of combined analysis of variance for eight characters of ten tomato genotypes
at different environments are presented below.

4.1 Combined analysis of variance

Highly significant mean squares for both genotypes and environments revealed the
presence of genetic variability in the material under investigation for all the characters studied except fruit diameter. The genotype × environment interactions when tested against error mean square was significant which suggesting that the data might be extended for stability analysis.

The environment highly significant mean squares due to environments (linear) indicated the difference between the environments. Genotype × environment interactions were significant for all the traits indicated that the genotypes responded well in seasonal fluctuations (bi) and to their stability (S^2di). Eberhart and Russel (1966) emphasized in this model, regression coefficient (bi) is considered as a parameter of response and deviation from regression (S^2di) as the parameter of stability.

All the parameters influenced significantly by environment and also by different genotypes except fruit diameter. G × E interaction had significant influence on the parameters that were studied under the present experiment (Table-3). Genotype-1 (BD-7279) showed highly significant mean square values considering days to first flower, days to 50% flowering, branches per plant, fruit per plant and fruit yield per plant. Genotype-2 (BD-7281) showed highly significant mean square values considering fruit per plant, fruit diameter (cm) and fruit yield per plant. Genotype-3 (BD-7289) showed highly significant mean square values considering 50% flowering and fruit yield per plant. Genotype-4 (BD-7759) showed highly significant mean square values considering branches per plant days to maturity (3.58*). Genotype-5 (BD-7306) showed significant mean square values considering days to 50% flowering, fruit per plant. Genotype-6 (BD-7292) showed significant mean square values considering branches per plant, fruit yield per plant. Genotype-7 (BARI Tomato-8) showed significant mean square for all the character except fruit per plant.Genotype-8 (BARI Tomato-9) showed significant mean square values for all the character studied. It was followed by Genotype-9 (BARI Tomato-14) and Genotype-10 (BARI Tomato-15)

Table 3: Combined analysis of variance for eight characters of ten tomato genotypes

Source of variation	D.f.	First Flowering DAT	50% Flowering DAT	Days of Maturity	Plant Height (cm)	Branches Per Plant	Fruit per Plant	Fruit Diameter (cm)	Fruit Yield per Plant (g)
Replication	2	1.36	2.38	1.06	1.24	2.11	3.21	1.14	2.16
Environments	4	3.44**	4.29**	3.89*	4.65**	3.64*	4.26**	3.26	4.22**
Genotypes	9	6.35*	4.31**	5.14*	6.34**	5.18*	6.11*	5.17	5.48*
G × E interaction	36	8.42**	7.26**	6.59**	8.29**	9.24**	8.34*	6.29*	7.46**
G × E linear	9	10.54**	8.37*	7.38*	9.12*	10.22*	9.26**	8.34*	8.89*
BD-7279	1	2.14**	2.22**	3.64*	2.88*	1.23**	2.19**	3.12	3.64**
BD-7281	1	1.56*	2.36	3.25*	3.64	2.45*	2.45**	4.22**	3.85**
BD-7289	1	2.77	3.24**	2.64	2.96*	3.69*	3.27*	3.54*	2.91**
BD-7759	1	2.11	2.58	3.58*	4.22	2.68**	2.96	3.68	3.86
BD-7306	1	3.66*	3.74**	4.12	3.28*	3.12*	3.54**	3.22*	2.47*
BD-7292	1	4.66	4.65	5.23	3.19	2.67**	4.66*	2.64	3.68**
BARI Tomato-8	1	3.12**	1.33**	3.21**	2.46**	1.54*	3.45	3.47*	5.12**
BARI Tomato-9	1	4.29**	3.84*	2.67*	3.77*	2.11**	3.44**	2.58*	2.69**
BARI Tomato-14	1	5.68**	5.12**	4.82*	2.75**	3.56*	2.47**	4.16**	3.45**
BARI Tomato-15	1	3.24**	4.32**	3.29**	4.12*	2.18**	2.11*	2.48**	2.48**
Error	90	2.16	2.68	2.11	3.12*	3.14**	4.17**	2.43**	3.26**

4.2 Days to first flowering

The average number of days to the first flowering along with the value of phenotypic indices *(Pi),* regression co-efficient (bi) and stability parameters (S^2di) are presented in Table4.

Among the genotypes, G_1 (BD-7279) and G_9 (BARI Tomato-14) took minimum and maximum days to first flowering, respectively. The genotypic means for days to first flowering ranged from 38.65 to 44.35 while environmental means varied from 38.38 to 42.47 over all environments.

The environmental index (Ij) directly reflected the favorable and unfavorable environments in terms of positive and negative Ij, respectively. However for this trait, positive environmental index (Ij) is the favorable environment for early days to first flowering. Thus Env-4 (Cow dung + TSP + MP) and Env-5 (Control) (Cow dung + Urea + TSP + MP) was favorable environment for days to first flowering. The rest environments had negative influence days to first flowering.

Four out of ten genotypes namely G_2 (BD-7281), G_4 (BD-7759), G_8 (BARI Tomato-9) and G_9 (BARI Tomato-14) exhibited negative phenotypic indices which represent these genotypes were not desirable for early days to first flowering. The rest genotypes showed positive phenotypic indices which represent the desirability for early days to first flowering or undesirability for late days to first flowering.

Six genotypes showed significant regression co-efficient (bi) viz. G_1 (BD-7279), G_2 (BD-7281), G_3 (BD-7289), G_6 (BD-7292), G_8 (BARI Tomato-9) and G_{10} (BARI Tomato-15) which were different from unity. Deviation from regression co-efficient (Sdi) of eight genotypes were significantly different from zero. So, linear prediction of these genotypes was not possible.

Table 4: Mean performance of days to first flowering, phenotypic indices (Pi), regression coefficient (bi), and deviation from linearity (S^2di) for 10 tomato genotypes under 5 environments

Genotypes	Environments					Mean (Gi)	Phenotypic indices (Pi)	Regression coefficient (bi)	Deviation from linearity (S^2di)
	Env-1	Env-2	Env-3	Env-4	Env-5				
BD-7279 (G_1)	39.75	39.75	36.75	39.00	38.00	38.65	2.44	5.11**	13.88**
BD-7281 (G_2)	40.67	40.00	40.25	40.33	38.33	39.92	-4.88	4.10**	5.72**
BD-7289 (G_3)	39.50	41.58	41.50	40.75	38.83	40.43	3.10	-2.04**	5.80**
BD-7759 (G_4)	38.83	41.50	41.17	39.67	38.42	39.92	-1.92	-1.12	20.11**
BD-7306 (G_5)	41.17	38.83	40.42	39.25	38.33	39.60	1.42	0.72	16.32**
BD-7292 (G_6)	39.25	37.33	40.17	41.08	38.75	39.32	1.60	-3.11**	3.12
BARI Tomato-8 (G_7)	39.75	41.75	41.33	39.00	38.67	40.10	1.12	2.90	11.88**
BARI Tomato-9 (G_8)	39.08	40.50	40.67	39.75	37.42	39.48	-0.68	4.50**	-2.42
BARI Tomato-14 (G_9)	39.83	64.92	39.42	39.67	37.92	44.35	-2.09	0.17	13.04**
BARI Tomato-15 (G_{10})	40.25	38.50	40.42	39.00	39.08	39.45	1.18	1.12**	10.42**
Mean (Ej)	39.81	42.47	40.21	39.75	38.38	40.12			
Env. Index (Ij)	-0.86	-0.84	-0.68	0.78	0.74				

In figure1, it was observed that the genotypes have been categorized into four classes. Four genotypes namely G_1(BD-7279), G_5(BD-7306), G_7(BARI Tomato-8)and G_{10}(BARI Tomato-15)have been categorized in the maximum days to first flowering with high sensitivity class having Pi and bi value greater than zero and one, respectively. Another three genotypes namely G_2 (BD-7281), G_8 (BARI Tomato-9) and G_9 (BARI Tomato-14) have been fall in early first flowering with high sensitivity block hence, these genotypes were suitable under rich environment, whereas G_5 (BD-7306) and G_8 (BARI Tomato-9) have been found in late flowering with less sensitivity class having positive Pi and negative bi value hence desirable for late flowering. Again, G_4(BD-7759) has been categorized in the maximum days to first flowering with poor sensitivity class having Pi and bi value is greater than one and less than zero, respectively.

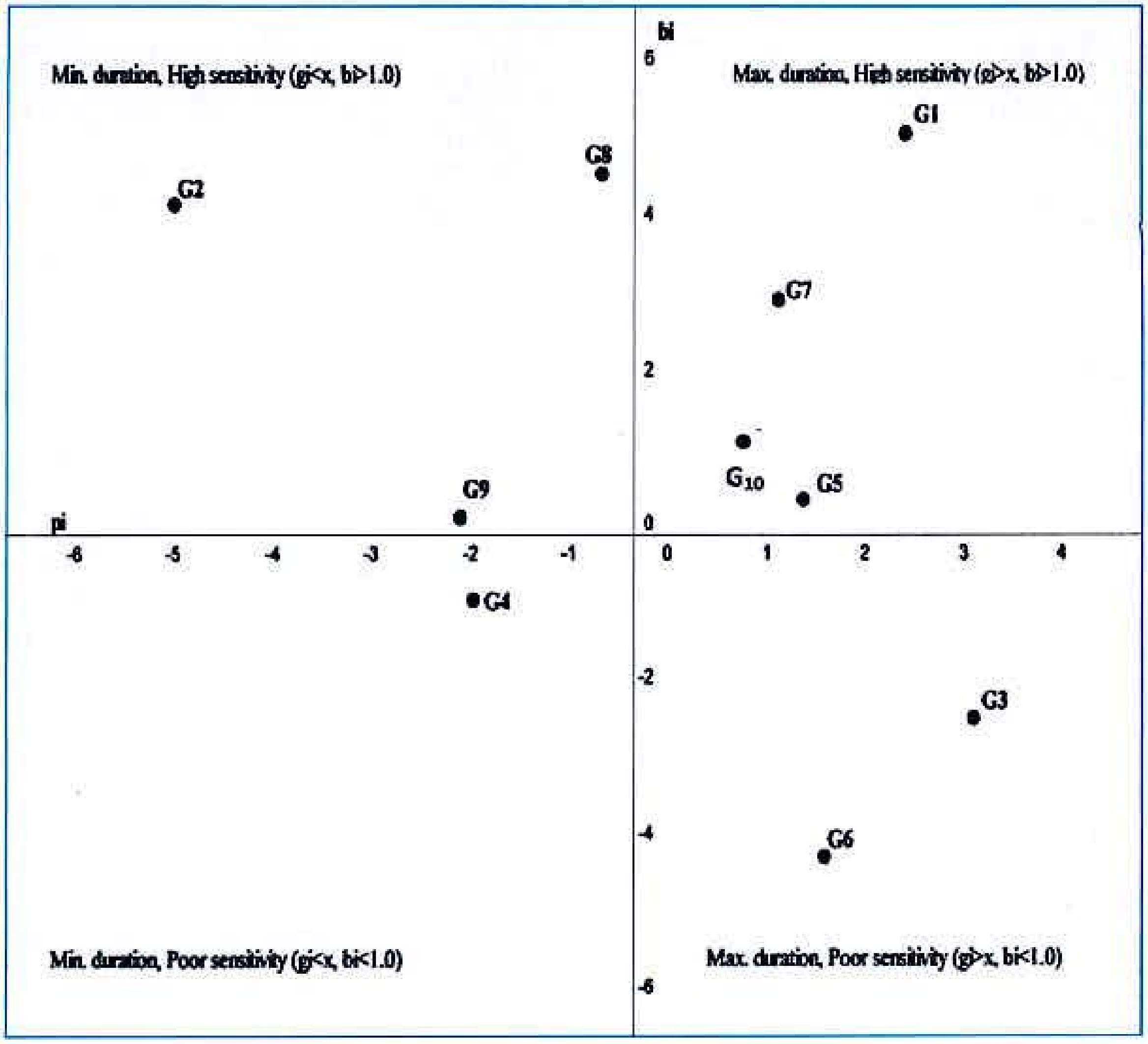

Figure1: Adaptive specificities of 10 tomato genotypes for days to first flowering

4.3 Days to 50% flowering

The average number of days to 50% flowering along with the value of phenotypic indices *(Pi)*, regression coefficient (bi) and stability parameters (S^2di)
are presented in Table: 05.

Among the genotypes, G_{10} (BARI Tomato-15) and G_9 (BARI Tomato-14) took minimum and maximum days to 50% flowering, respectively. The genotypic means for days to 50% flowering ranged from 55.00 to 63.42while environmental means varied from 55.51 to 59.82 over all environments.

The environmental index (Ij) directly reflected the favorable and unfavorable environments in terms of positive and negative Ij, respectively. However for this
trait, positive environmental index (Ij) is the favorable environment for early days to 50% flowering. Thus Env-4 (Cow dung + TSP + MP) and Env-5 (Control) (Cow dung + Urea + TSP + MP) was favorable environment for days to 50% flowering. The rest environments had negative influence on days to 50% flowering.

Three out of ten genotypes namely G_2 (BD-7281), G_4 (BD-7759) and G_8 (BARI Tomato-9) exhibited negative phenotypic indices which represent these genotypes were not desirable for early days to 50% flowering. The rest genotypes showed positive phenotypic indices which represents the desirability for early days to 50% flowering or undesirability for late days to 50% flowering.

Five genotypes showed significant regression co-efficient (bi) viz. G_1 (BD-7279), G_4 (BD-7759), G_5 (BD-7306), G_7 (BARI Tomato-8) and G_{10} (BARI Tomato-15) which were different from unity. Deviation from regression co-efficient (Sdi) of five genotypes were significantly different from zero. So, linear prediction of these genotypes was not possible.

Table 5: Mean performance of days to 50% flowering, phenotypic indices (Pi), regression co-efficient (bi), and deviation from linearity (S^2di) for 10 tomato genotypes under 5 environments

Genotypes	Environments					Mean (Gi)	Phenotypic indices (Pi)	Regression coefficient (bi)	Deviation from linearity (S^2di)
	Env-1	Env-2	Env-3	Env-4	Env-5				
BD-7279 (G_1)	55.75	55.00	55.50	55.42	54.58	55.25	2.30	6.18	12.11**
BD-7281 (G_2)	56.58	56.00	56.17	56.50	56.58	56.37	-3.88	5.09**	6.58
BD-7289 (G_3)	56.25	55.75	56.17	55.58	54.67	55.68	3.20	-3.62*	6.10
BD-7759 (G_4)	56.33	56.25	55.83	56.33	56.83	56.31	-2.04	-2.12	18.36**
BD-7306 (G_5)	56.17	56.50	56.17	56.50	55.08	56.08	2.32	1.08	15.42**
BD-7292 (G_6)	54.75	56.25	55.08	56.17	56.08	55.67	1.78	-3.64*	4.26
BARI Tomato-8 (G_7)	53.75	55.42	55.17	55.50	55.58	55.08	0.84	2.72	10.88**
BARI Tomato-9 (G_8)	56.25	55.50	55.08	54.83	55.08	55.35	-3.24	4.94**	-3.12
BARI Tomato-14 (G_9)	54.92	55.33	54.58	97.17	55.08	63.42	2.18	1.26	14.24
BARI Tomato-15 (G_{10})	54.58	55.42	55.25	54.17	55.58	55.00	0.75	1.12	4.56*
Mean (Ej)	55.53	55.74	55.50	59.82	55.51	56.42			
Env. Index (Ij)	-0.42	-0.688	-0.67	0.86	0.92				

In figure2, it was observed that the genotypes have been categorized into four classes. Four genotypes namely G_1 (BD-7279), G_5 (BD-7306), G_7 (BARI Tomato-8)and G_{10} (BARI Tomato-15)have been categorized in the maximum days to 50%t flowering with high sensitivity class having Pi and bi value greater than zero and one, respectively. Another two genotypes namely G_2(BD-7281) and G_9 (BARI Tomato-14)have been fall in early 50% flowering with high sensitivity block hence, these genotypes were suitable under rich environment, whereas G_5(BD-7306) and G_8(BARI Tomato-9)have been found in late flowering with less sensitivity class having positive Pi and negative bi value hence desirable for late flowering. Again, G_4 (BD-7759) has been categorized in the maximum days to 50% flowering with poor sensitivity class having Pi and bi value is greater than one and less than zero respectively.

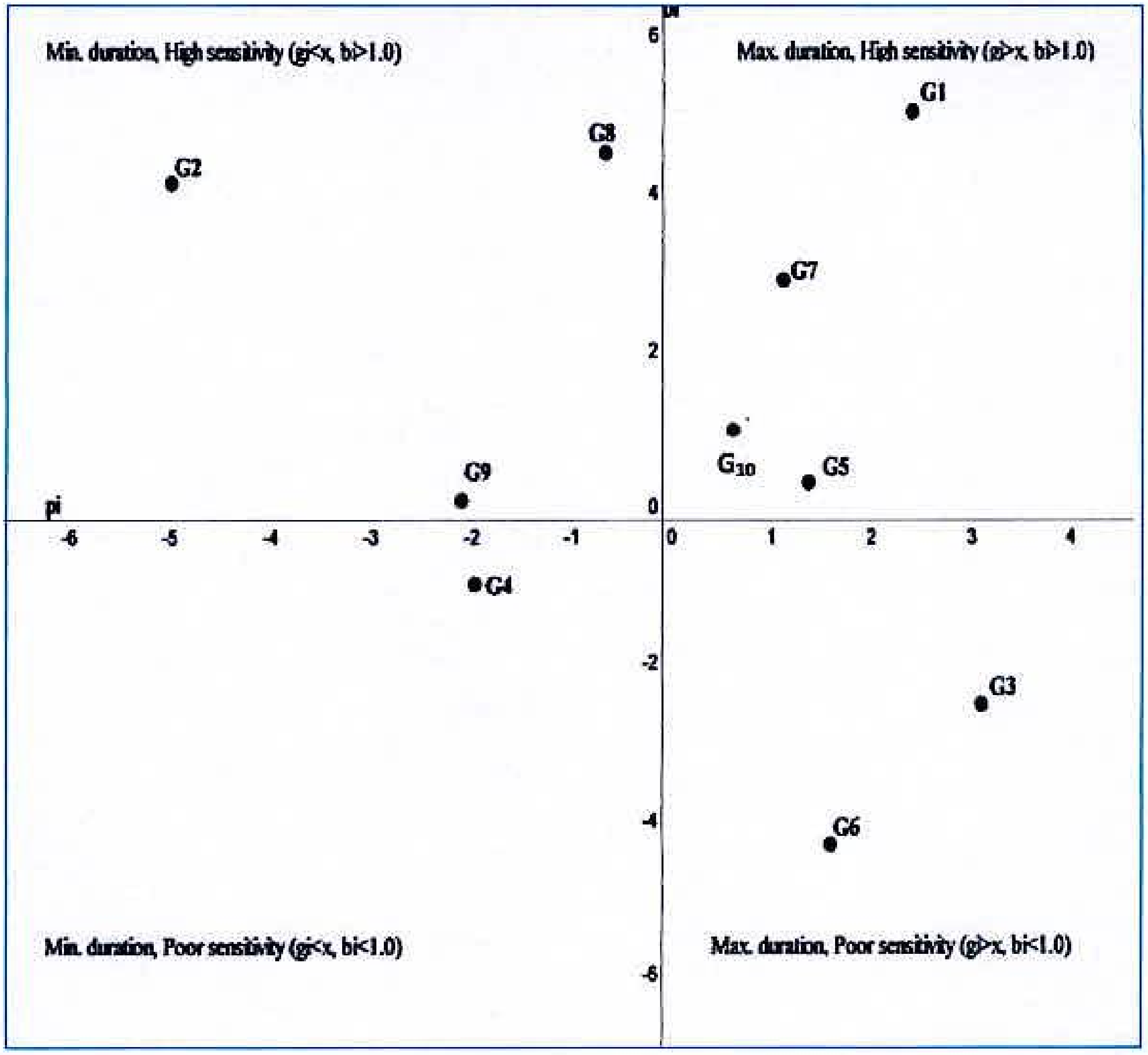

Figure2: Adaptive specificities of 10 tomato genotypes for days to 50% flowering

4.4 Days to maturity

The average number of days required for fruit maturity along with the value of phenotypic indices (Pi), regression coefficient (bi) and stability parameters (Sdi) are presented in Table6.

The genotypic means for days to fruit maturity ranged from 70.75 to 71.65 while environmental means varied from 70.88 to 71.00 over all environments. Among the genotypes, G_9 (BARI Tomato-14) and G_5 (BD-7306) took maximum and minimum days for fruit maturity, respectively. Four genotypes showed significant regression co-efficient (bi) viz. G_1 (BD-7279), G_4 (BD-7759), G_6 (BD-7292) and G_7 (BARI Tomato-8) which were different from unity. Deviation from regression co-efficient (S^2di) of four genotypes were significantly different from zero. So, linear prediction of these genotypes was not possible.

The environmental index (Ij) directly reflects the favorable and unfavorable environments in terms of positive and negative Ij respectively. For early fruit maturity, Env-1: Compost, Env-2: Urea + TSP, Env-4: Cow dung + TSP + MP and Env-5: Control (Cow dung + Urea + TSP + MP was favorable environment. Thus Env-5: Control (Cow dung + Urea + TSP + MP and Env-4: Cow dung + TSP + MP were considered as favorable or rich, Env-1: Compost is medium and Env-2: Urea + TSP is poor environment. Seven out of ten genotypes exhibited negative phenotypic indices which represent these genotypes were desirable for early fruit maturity. G_3 (BD-7289), G_6 (BD-7292) and G_{10} (BARI Tomato-15) showed positive phenotypic indices thus desirable for late maturity.

Genotype, G_2 (BD-7281), G_5 (BD-7306), G_8 (BARI Tomato-9) and G_9 (BARI Tomato-14) could be considered as early fruit maturity with stable performance. This was due to highest negative Pi value, insignificant bi and S^2di value. G_7 (BARI Tomato-8) exhibits highest negative Pi value but not stable. This is due to highly significant bi and S^2di value. So, it was desirable for rich environment only. G_3 (BD-7289), G_6 (BD-7292) and G_{10} (BARI Tomato-15) showed positive phenotypic indices thus desirable for late fruit maturity and fluctuate with environmental variation. Considering days to fruit maturity, Akhter and Sneller (1996) were found no one of significant and predictable genotype in soybean.

Table 6: Mean performance of Days to maturity, phenotypic indices (Pi), regression coefficient (bi), and deviation from linearity (S^2di) for 10 tomato genotypes under 5 environments

Genotypes	Environments					Mean (Gi)	Phenotypic indices (Pi)	Regression coefficient (bi)	Deviation from linearity (S^2di)
	Env-1	Env-2	Env-3	Env-4	Env-5				
BD-7279 (G_1)	70.83	71.42	71.75	71.58	70.92	71.30	-2.88	2.40**	-2.56
BD-7281 (G_2)	71.17	70.00	71.67	71.42	71.67	71.19	-3.67	1.52	-2.36
BD-7289 (G_3)	72.42	70.50	71.92	70.67	71.00	71.30	12.40	0.56	30.24**
BD-7759 (G_4)	71.33	71.42	71.25	71.83	70.58	71.28	-2.98	0.12**	15.49**
BD-7306 (G_5)	72.67	70.50	71.25	71.67	72.17	71.65	-2.30	1.03	-1.55
BD-7292 (G_6)	72.50	71.50	72.00	71.08	69.67	71.35	8.48	1.99**	4.47
BARI Tomato-8 (G_7)	70.92	71.00	71.33	70.08	71.33	70.93	-4.26	-0.53**	3.88**
BARI Tomato-9 (G_8)	70.92	71.25	70.67	70.83	71.25	70.98	-3.26	1.32	-2.86
BARI Tomato-14 (G_9)	71.33	69.50	71.17	71.42	70.33	70.75	-1.55	0.57	3.94
BARI Tomato-15 (G_{10})	70.92	71.75	71.17	71.00	71.08	71.18	2.53	1.14	6.11**
Mean (Ej)	71.50	70.88	71.42	71.16	71.00	71.19			
Env. Index (Ij)	0.62	0.36	-2.11	0.89	0.93				

In figure 3, it was observed that the genotypes have been categorized into four classes. Three genotypes namely G_3 (BD-7289), G_6 (BD-7292) and G_{10} (BARI Tomato-15) have been categorized in the maximum days to maturity with high sensitivity class having Pi and bi value greater than zero and one, respectively. Another two genotypes namely G_1 (BD-7279), G_2 (BD-7281), G_4 (BD-7759), G_5 (BD-7306), G_8 (BARI Tomato-9) and G_9 (BARI Tomato-14) have been fall in early maturity with high sensitivity block hence, these genotypes were suitable under rich environment, whereas G_7 (BARI Tomato-8) have been found in late flowering with less sensitivity class having positive Pi and negative bi value hence desirable for late flowering.

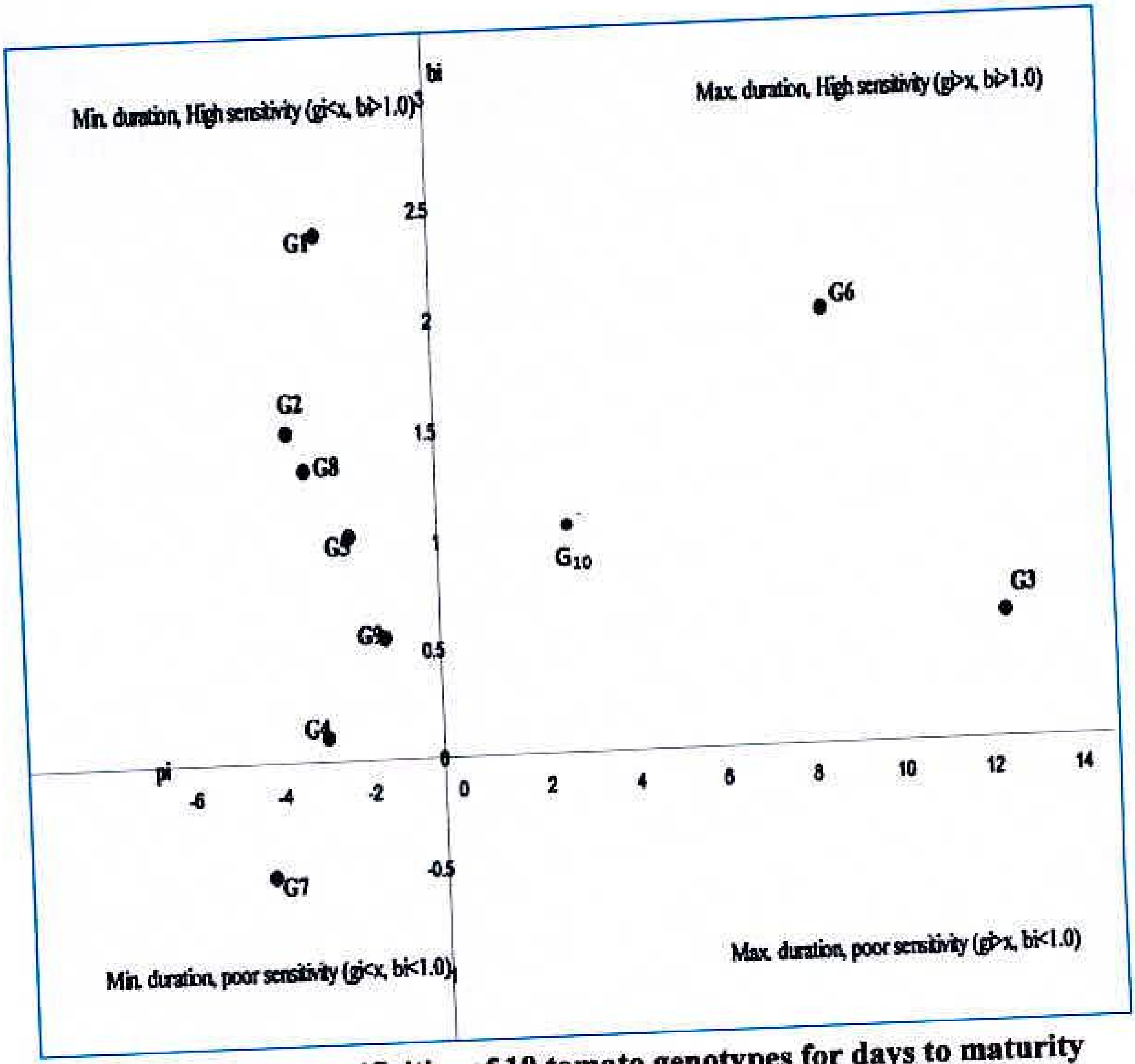

Figure 3: Adaptive specificities of 10 tomato genotypes for days to maturity

4.5 Plant height

The average plant height along with the value of phenotypic indices (Pi), egression coefficient (bi) and stability parameters (Sdi) are presented in Table 7.

The genotypic means for plant height ranged from 74.90 to 82.77 while environmental means varied from 74.44 to 82.77 over all environments. Among the genotypes, G_5 (BD-7306) and G_9 (BARI Tomato-14) took maximum and minimum plant height respectively.

Three genotypes showed significant regression co-efficient (bi) viz. G_1 (BD-7279),

G_4(BD-7759) and G_5(BD-7306) which were different from unity. Deviation from regression co-efficient (S^2di) of five genotypes were significantly different from zero. So, linear prediction of these genotypes was not possible.

The environmental index (Ij) directly reflects the favorable and unfavorable environments in terms of positive and negative Ij respectively. For plant height, Env-2: Urea + TSP, Env-4: Cow dung + TSP + MP and Env-5: Control (Cow dung + Urea + TSP + MP was favorable environment. Thus Env-5: Control (Cow dung + Urea + TSP + MP were considered as favorable or rich, Env-2: Urea + TSP and Env-4: Cow dung + TSP + MP were considered as medium favorable environment.

Five out of ten genotypes exhibited negative phenotypic indices which represent these genotypes were desirable for lower plant height. G_3 (BD-7289), G_6 (BD-7292), G_9 (BARI Tomato-14) and G_{10} (BARI Tomato-15) showed positive phenotypic indices thus desirable for higher plant height.

Genotype, G_2 (BD-7281) and G_5 (BD-7306) could be considered as best plant height with stable performance. This was due to highest positive Pi value, insignificant bi and S^2di value. G_3 (BD-7289) exhibits highest positive Pi value but not stable. This is due to highly non-significant bi and significant S^2di value. So, it was desirable for rich environment only.

Table7: Mean performance of plant height, phenotypic indices (Pi), regression coefficient (bi), and deviation from linearity (S^2di) for 10 tomato genotypes under 5 environments

Genotypes	Environments					Mean (Gi)	Phenotypic indices (Pi)	Regression coefficient (bi)	Deviation from linearity (S^2di)
	Env-1	Env-2	Env-3	Env-4	Env-5				
BD-7279 (G_1)	84.00	80.42	86.00	68.50	72.42	78.27	-0.07	3.35**	-0.01
BD-7281 (G_2)	78.42	82.58	79.83	81.83	79.92	80.52	-0.88	0.57	1.72
BD-7289 (G_3)	77.25	75.08	78.75	76.75	80.33	77.63	1.52	1.70	0.58**
BD-7759 (G_4)	70.83	78.58	72.50	82.42	76.25	76.12	-0.51	-0.25**	0.07
BD-7306 (G_5)	87.33	84.75	76.83	81.92	75.08	81.18	0.34	1.52	-0.001
BD-7292 (G_6)	71.00	69.08	66.75	68.17	68.50	68.70	0.80	2.06**	0.28**
BARI Tomato-8 (G_7)	128.92	62.92	71.08	63.58	70.00	79.30	-0.55	0.64	0.88
BARI Tomato-9 (G_8)	65.33	68.83	72.25	70.58	67.08	68.81	-0.88	1.34	0.009**
BARI Tomato-14 (G_9)	81.17	75.67	71.42	69.67	76.58	74.90	0.90	1.15	0.09*
BARI Tomato-15 (G_{10})	83.42	81.58	74.83	81.42	78.25	79.90	1.32	2.32	0.89**
Mean (Ej)	82.77	75.95	75.02	74.48	74.44	76.50			
Env. Index (Ij)	-0.52	0.64	-0.44	0.67	0.81				

In figure 4, it was observed that the genotypes have been categorized into four classes. Three genotypes namely G_3(BD-7289), G_6(BD-7292) and G_9(BARI Tomato-14) have been categorized in the maximum plant height with high sensitivity class having Pi and bi value greater than zero and one, respectively. Another two genotypes namely G_1 (BD-7279), G_2 (BD-7281), G_7 (BARI Tomato-8) and G_8 (BARI Tomato-9) have been fall in minimum plant height with high sensitivity block hence, these genotypes were suitable under rich environment, whereas G_4 (BD-7759) and G_5 (BD-7306) has been categorized in the minimum plant height with poor sensitivity class having Pi and bi value is greater than one and less than zero respectively.

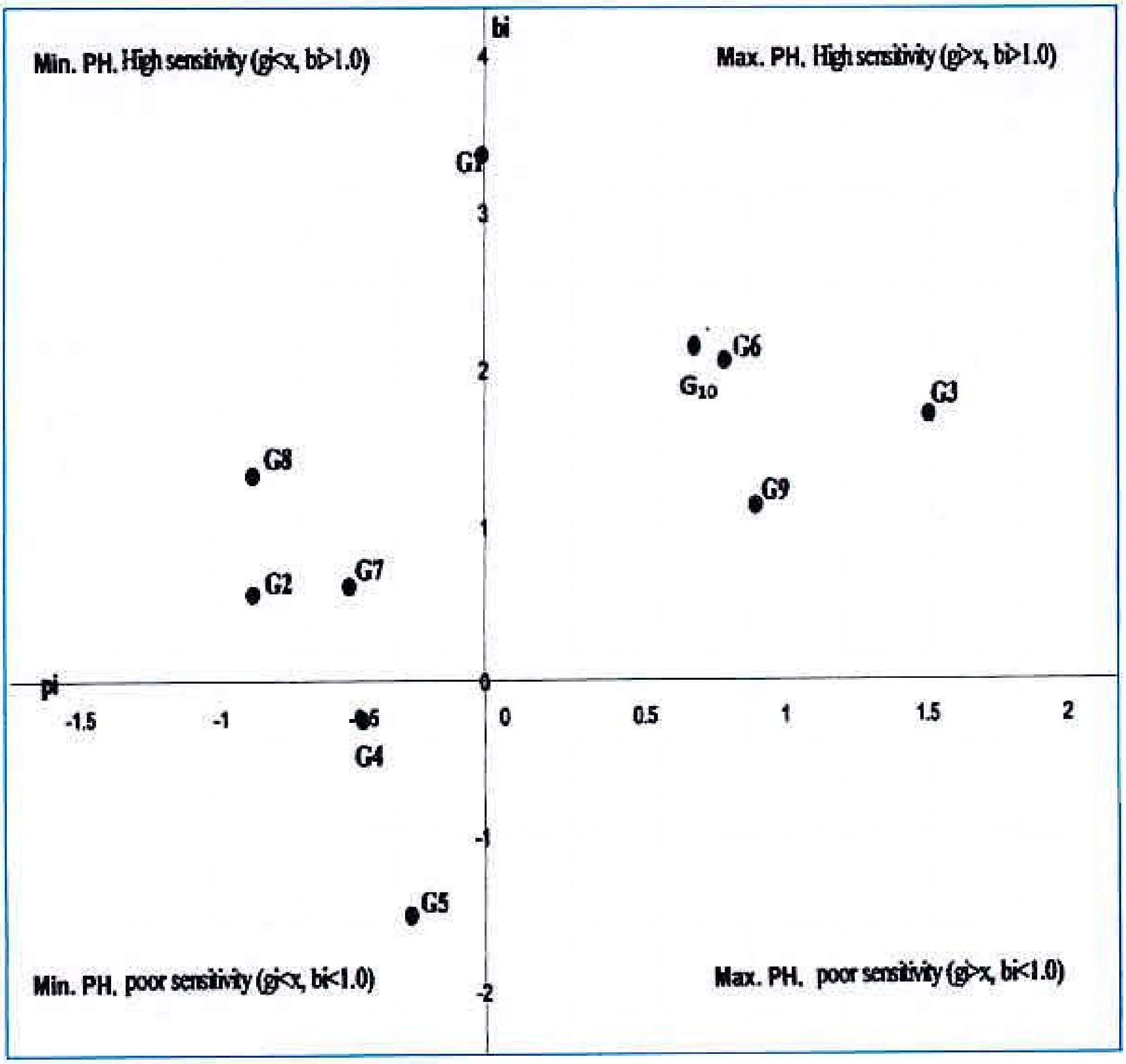

Figure4: Adaptive specificities of 10 tomato genotypes for plant height

4.6 Number of branches per plant

The average plant height along with the value of phenotypic indices (Pi), egression coefficient (bi) and stability parameters (Sdi) are presented in Table 8.

The genotypic means for number of branches per plant ranged from 4.68 to 5.50 while environmental means varied from 4.42 to 5.62 over all environments. Among the genotypes, G_5 (BD-7306) and G_4 (BD-7759) took maximum and minimum number of branches per plant respectively.

Three genotypes showed significant regression co-efficient (bi) viz. G_1 (BD-7279), G_4 (BD-7759) and G_5 (BD-7306) which were different from unity. Deviation from regression co-efficient (S^2di) of seven genotypes were significantly different from zero. So, linear prediction of these genotypes was not possible.

The environmental index (Ij) directly reflects the favorable and unfavorable environments in terms of positive and negative Ij respectively. For number of branches per plant, Env-4: Cow dung + TSP + MP and Env-5: Control (Cow dung + Urea + TSP + MP were more favorable for environment than Env-1: Compost and Env-2: Urea + TSP.

Two out of ten genotypes exhibited negative phenotypic indices which represent these genotypes were desirable for early number of branches per plant. The rest of the genotypes showed positive phenotypic indices thus desirable for higher number of branches per plant.

Table 8: Mean performance of number of branches per plant, phenotypic indices (Pi), regression coefficient (bi), and deviation from linearity (S^2di) for 10 tomato genotypes under 5 environments

Genotypes	Environments					Mean (Gi)	Phenotypic indices (Pi)	Regression coefficient (bi)	Deviation from linearity (S^2di)
	Env-1	Env-2	Env-3	Env-4	Env-5				
BD-7279 (G_1)	4.75	5.50	5.67	4.50	4.08	4.90	2.36	1.30**	-10.84
BD-7281 (G_2)	5.33	4.75	5.17	5.33	5.58	5.23	6.98	2.38	-2.87
BD-7289 (G_3)	5.00	5.08	5.67	4.17	4.33	4.85	-7.30	0.88	-9.43
BD-7759 (G_4)	4.42	4.17	5.58	4.00	5.25	4.68	-4.05	0.06**	26.80
BD-7306 (G_5)	6.83	4.92	5.42	5.42	4.92	5.50	0.49	0.63**	-11.47
BD-7292 (G_6)	5.50	4.92	5.83	5.00	5.33	5.32	5.86	1.55	-9.54
BARI Tomato-8 (G_7)	5.50	5.25	6.17	3.75	4.42	5.02	2.96	1.59	-12.39
BARI Tomato-9 (G_8)	5.25	5.08	6.00	4.17	4.08	4.92	2.96	-0.03	-10.90
BARI Tomato-14 (G_9)	5.75	4.83	5.00	3.67	3.67	4.58	1.36	0.63	-6.22
BARI Tomato-15 (G_{10})	4.50	4.58	5.67	4.17	4.42	4.67	3.52	1.02	-6.88
Mean (Ej)	5.28	4.91	5.62	4.42	4.61	4.96			
Env. Index (Ij)	0.37	0.42	-0.28	0.54	0.78				

In figure 5, it was observed that the genotypes have been categorized into four classes. Five genotypes namely G_1(BD-7279), G_3(BD-7289), G_5(BD-7306), G_9(BARI Tomato-14)and G_{10}(BARI Tomato-15)have been categorized in the maximum number of branches/plant with high sensitivity class having Pi and bi value greater than zero and one, respectively. Only one genotype, G_2 (BD-7281) was included in maximum brunches/plant with high sensitivity class possess Pi and bi value less than zero and greater than one respectively, hence, this genotype was suitable under rich environment. Four genotypes, namely G_4 (BD-7759), G_6 (BD-7292), G_7 (BARI Tomato-8) and G_8 (BARI Tomato-9) was included in minimum brunches/plant with less sensitivity class possess Pi and bi value less than zero. Hence, this genotype was suitable under poor environment.

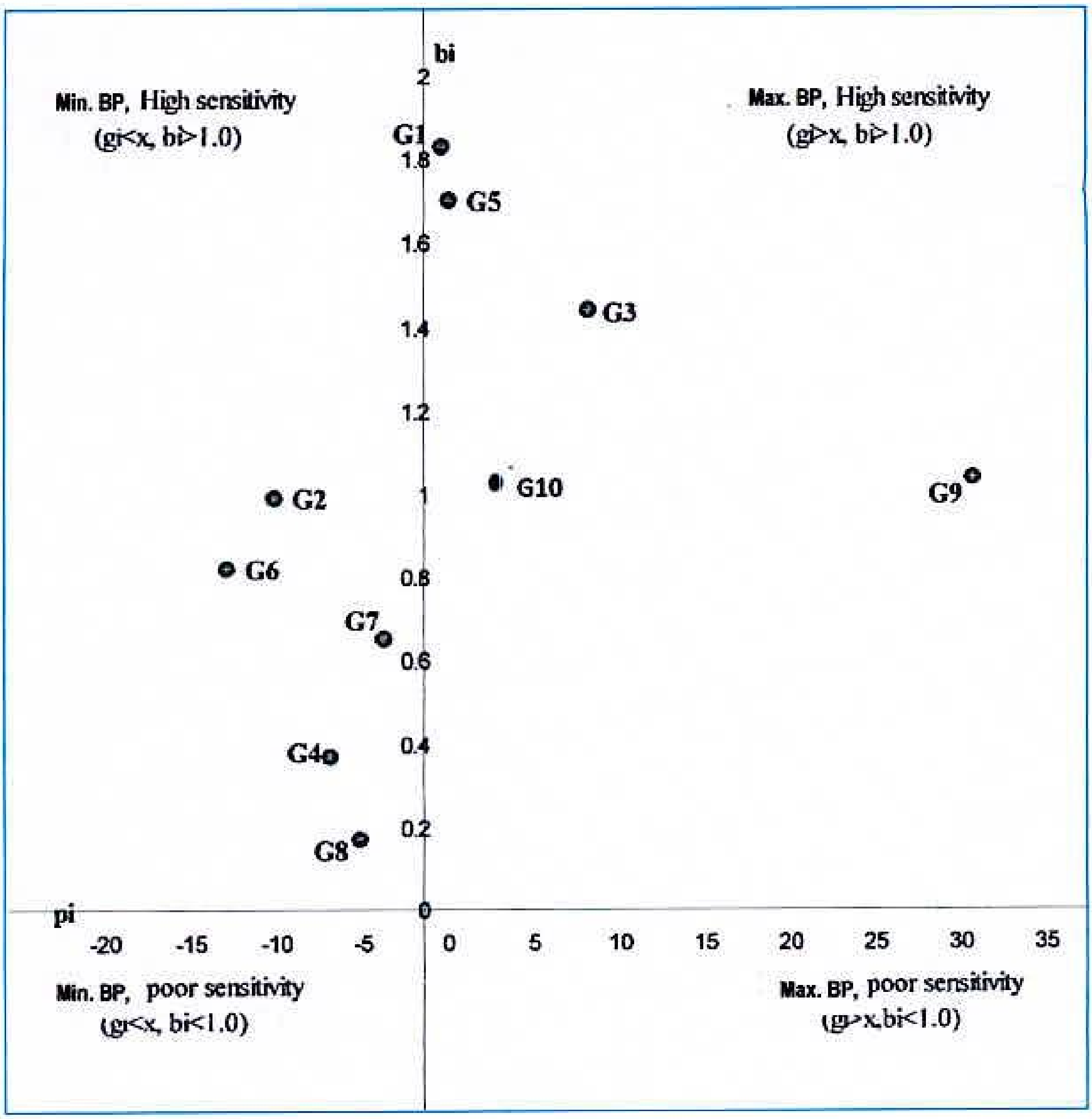

Figure 5: Adaptive specificities of 10 tomato genotypes for number of branches per plant

4.7 Number of Fruits per Plant

The average number of fruits per plant along with the value of phenotypic indices (Pi), regression coefficient (bi) and stability parameters (S^2di) are presented in Table 9.

Genotypes G_3 (BD-7289), G_4 (BD-7759), G_6 (BD-7292) and G_7 (BARI Tomato-8) exhibited negative phenotypic indices which represented undesirability of these genotypes for number of fruits per plant. Other six genotypes provided positive phenotypic indices which expressed the desirability for higher number of fruits per plant or undesirability for lower number of fruits per plant.

Among the genotypes, G_2 (BD-7281) and G_{10} (BARI Tomato-15) took minimum and maximum number of fruits per plant respectively. The genotypic means for number of fruits per plant ranged from 30.18 to36.62 while environmental means varied from 30.52 to 40.83 over all environments.

The environmental index (Ij) directly reflects the favorable and unfavorable environments in terms of positive and negative Ij, respectively. However for this trait, positive environmental index (Ij) was the favorable environment for number of fruits per plant. Thus Env-4: Cow dung + TSP + MP and Env-5: Cow dung + Urea + TSP + MP were favorable environment for higher number of fruits per plant.

Only two out of ten genotypes namely G_2 (BD-7281) and G_4 (BD-7759) exhibited significant regression co-efficient (bi) which were different from unity. Deviation from regression co-efficient (S^2di) of eight genotypes were significantly different from zero. So, linear prediction of these genotypes was not possible.

Table 9: Mean performance of number of fruits per plant, phenotypic indices (Pi), regression coefficient (bi), and deviation from linearity (S^2di) for 10 tomato genotypes under 5 environments

Genotypes	Environments					Mean (Gi)	Phenotypic indices (Pi)	Regression coefficient (bi)	Deviation from linearity (S^2di)
	Env-1	Env-2	Env-3	Env-4	Env-5				
BD-7279 (G_1)	31.22	30.16	29.63	35.66	35.31	32.40	3.46	1.26	3.94
BD-7281 (G_2)	26.00	25.25	26.16	36.45	37.05	30.18	5.18	1.99**	-5.36
BD-7289 (G_3)	30.00	27.24	26.26	38.21	39.35	32.21	-1.26	0.66	4.48**
BD-7759 (G_4)	30.22	34.28	33.37	34.52	36.14	33.71	-0.66	-0.05**	-8.55**
BD-7306 (G_5)	30.33	29.37	30.05	39.34	40.45	33.91	1.78	1.17	0.58
BD-7292 (G_6)	32.89	34.55	33.56	40.34	41.21	36.51	-1.84	1.09	-2.20
BARI Tomato-8 (G_7)	33.00	36.52	34.40	43.33	45.90	38.63	-0.77	1.24	1.17
BARI Tomato-9 (G_8)	30.55	31.35	30.23	44.64	41.92	35.74	0.28	0.97	9.06
BARI Tomato-14 (G_9)	31.11	31.30	30.94	42.36	43.69	35.88	3.32	0.67	0.32
BARI Tomato-15 (G_{10})	30.55	27.87	30.58	46.77	47.31	36.62	1.14	0.48	5.12
Mean (Ej)	30.59	30.79	30.52	40.16	40.83	34.50			
Env. Index (Ij)	0.36	-0.32	-0.26	0.68	0.84				

In figure6, it was observed that the genotypes have been categorized into four classes. Four genotypes namely G_1(BD-7279), G_2(BD-7281), G_{10}(BARI Tomato-15) and G_8(BARI Tomato-9) have been categorized in the maximum number of fruits/plant with high sensitivity class having Pi and bi value greater than zero and one, respectively. Another four genotypes namely G_3 (BD-7289), G_5 (BD-7306), G_6 (BD-7292) and G_9 (BARI Tomato-14) have been fall in minimum number of fruits/plant with high sensitivity block hence, these genotypes were suitable under rich environment, whereas G_4 (BD-7759) have been found in maximum number of fruits/plant with less sensitivity class having positive Pi and negative bi value hence desirable for late flowering.

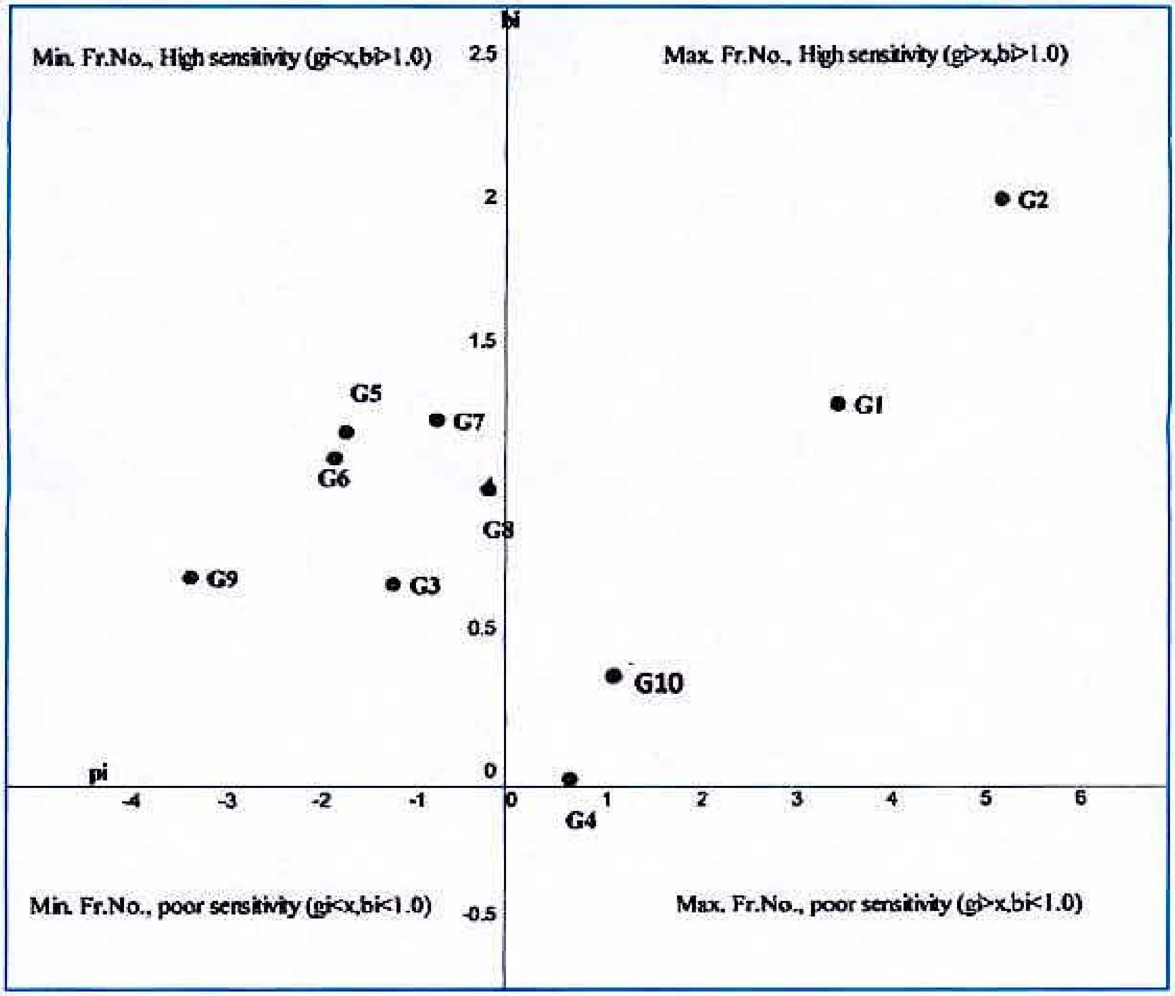

Figure 6: Adaptive specificities of 10 tomato genotypes for number of fruits per plant

4.8 Fruit Diameter

The average fruit diameter along with the value of phenotypic indices (Pi), regression coefficient (bi) and stability parameters (S^2di) are presented in Table10.

Genotypes G_2 (BD-7281), G_4 (BD-7759) and G_7 (BARI Tomato-8) exhibited negative phenotypic indices which represented undesirability of these genotypes for fruit diameter. Other five genotypes provided positive phenotypic indices which expressed the desirability for higher fruit diameter.

Among the genotypes, G_{10} (BARI Tomato-15) and G_3 (BD-7289) took maximum and minimum fruit diameter respectively. The genotypic means for number of fruits per plant ranged from 4.40 to 7.93 while environmental means varied from 5.43 to 6.45 over all environments.

The environmental index (Ij) directly reflects the favorable and unfavorable environments in terms of positive and negative Ij, respectively. However for this trait, positive environmental index (Ij) was the favorable environment for fruit diameter. Thus Env-4: Cow dung + TSP + MP and Env-5: Control (Cow dung + Urea + TSP + MP were favorable environment for higher fruit diameter.

Only three out of ten genotypes namely G_3 (BD-7289), G_1 (BD-7279) and G_5 (BD-7306) exhibited significant regression co-efficient (bi) which were different from unity. Deviation from regression co-efficient (S^2di) of eight genotypes were significantly different from zero. So, linear prediction of these genotypes was not possible.

Table10: Mean performance of fruit diameter, phenotypic indices (Pi), regression coefficient (bi), and deviation from linearity (S^2di) for 10 tomato genotypes under 5 environments

Genotypes	Environments					Mean (Gi)	Phenotypic indices (Pi)	Regression coefficient (bi)	Deviation from linearity (S^2di)
	Env-1	Env-2	Env-3	Env-4	Env-5				
BD-7279 (G_1)	5.45	4.79	4.69	4.93	5.41	5.05	0.32	1.84**	0.08
BD-7281 (G_2)	4.56	4.12	4.16	4.15	4.99	4.40	-4.09	0.97	5.92
BD-7289 (G_3)	4.68	4.27	4.03	4.26	4.75	4.40	8.23	1.46**	3.33**
BD-7759 (G_4)	5.21	5.01	4.35	5.01	5.56	5.03	-3.85	0.36	39.58
BD-7306 (G_5)	8.56	7.31	6.99	6.87	7.78	7.50	0.09	1.72*	0.22
BD-7292 (G_6)	5.62	5.05	4.84	5.20	6.13	5.37	2.88	0.83	9.72
BARI Tomato-8 (G_7)	7.48	6.95	6.36	6.76	7.65	7.04	-3.72	0.66	6.24**
BARI Tomato-9 (G_8)	6.69	6.05	5.89	6.14	6.85	6.32	5.17	0.18	2.97
BARI Tomato-14 (G_9)	6.76	5.31	5.32	5.96	6.92	6.05	3.74	1.04	0.16
BARI Tomato-15 (G_{10})	8.50	7.55	7.65	7.49	8.45	7.93	4.19	0.88	4.64
Mean (Ej)	6.35	5.64	5.43	5.68	6.45	5.91			
Env. Index (Ij)	0.33	0.28	-048	0.46	0.78				

In figure 7, it was observed that the genotypes have been categorized into four classes. Seven genotypes namely G_1 (BD-7279), G_2 (BD-7281), G_5 (BD-7306), G_6 (BD-7292), G_7 (BARI Tomato-8), G_9 (BARI Tomato-14) and G_{10} (BARI Tomato-15) have been categorized in the maximum fruit diameter with high sensitivity class having Pi and bi value greater than zero and one, respectively. Another three genotypes namely G_6 (BD-7289), G_4 (BD-7759) and G_8 (BARI Tomato-9) have been fall in less fruit diameter with high sensitivity block hence, these genotypes were suitable under rich environment.

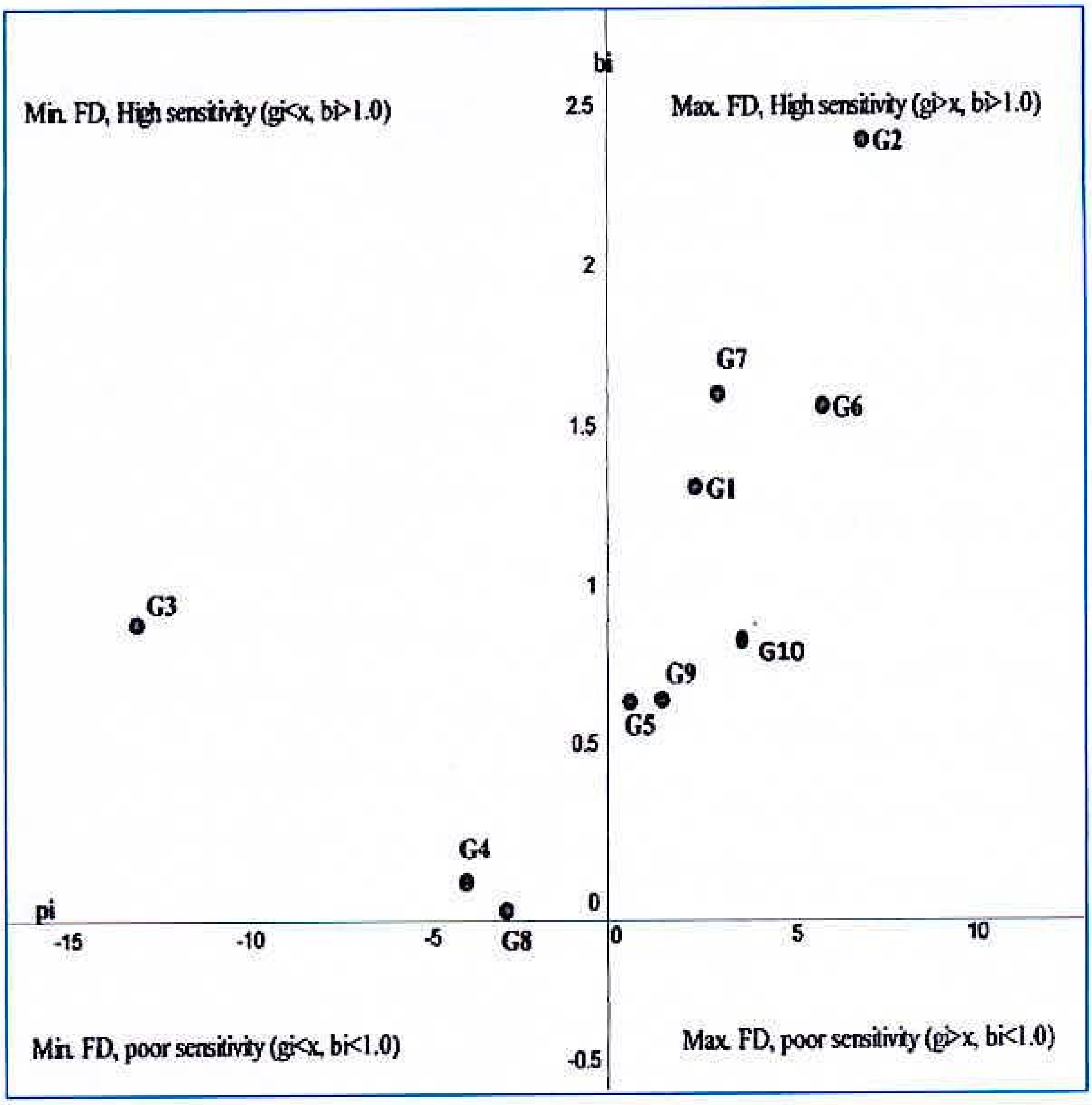

Figure 7: Adaptive specificities of 10 tomato genotypes for fruit diameter

4.9 Fruit weight/plant

The average fruit yield per plant along with the value of phenotypic indices (Pi), regression coefficient (bi) and stability parameters (S^2di)are presented in Table 11.The environmental index (Ij) directly reflects the favorable and unfavorable environments in terms of positive and negative *Ij*, respectively. Positive environmental index represents higher yield and vice-versa. Thus Env-4: Cow dung + TSP + MP and Env-5: Control (Cow dung + Urea + TSP + MP were favorable environment in respect of fruit yield per plant. The rest environment was less favorable for higher yield or favorable for lower yield.

Among the genotypes, G_{10} (BARI Tomato-15) and G_1 (BD-7279) exhibit maximum and minimum fruit yield respectively. The genotypic means for fruit yield per plant ranged from 719.47g to719.47 g while environmental means varied from 946.37 g to 1053.57 g over all environments.

Six out of ten genotypes namely G_2 (BD-7281), G_5 (BD-7306), G_7 (BARI Tomato-8), G_8 (BARI Tomato-9), G_9 (BARI Tomato-14) and G_{10} (BARI Tomato-15) exhibited positive phenotypic indices which represent these genotypes were desirable for higher fruit yield per plant. The rest genotypes showed negative phenotypic indices which represents the undesirability for higher fruit yield per plant or desirability for lower yield.

Four genotypes showed significant regression co-efficient (bj) viz. (BARI Tomato-8), (BARI Tomato-9), (BARI Tomato-14) and (BARI Tomato-15) which was different from unity. The regression co-efficient (bi) values of these genotypes ranged from 0.88 to 2.78 thus indicated that all the genotypes responded differently in different environments. This result confirmed with the findings of Pan War et al. (1995) for French bean in India.

Deviation from regression co-efficient (S^2di) of five genotypes were significantly different from zero. So, linear prediction of these genotypes was not possible. The remaining genotypes showed non-significant S^2di value indicating better adaptability of these genotypes to the fluctuating environments.

Among the genotypes G_{10} (BARI Tomato-15) could be considered as the highest yielder followed by G_7 (BARI Tomato-8), G_8 (BARI Tomato-9) and G_9 (BARI Tomato-14). Genotype G_5 (BD-7306) and G_6 (BD-7292) showed medium yield and the rest genotypes had low yield over environments. Genotype, G_{10} (BARI Tomato-15) was good yielder having high Pi value but possessed positive significant bi and S^2di value. For this reason, this genotype could be considered as high responsive to environmental condition and might be recommended for breeding program to achieve higher yield under rich environments. Based on the individual genotypes of adaptability, the genotype, G_8 (BARI Tomato-9) exhibited the highest Pi value, with insignificant bi value and S^2di value near to zero. So, this genotype was considered as the most stable with the changes of environments and possessed desired adaptability over wider range of environments.

Table11: Mean performance of Fruit weight/plant, phenotypic indices (Pi), regression coefficient (bi), and deviation from linearity (S^2di) for 10 tomato genotypes under 5 environments

Genotypes	Environments					Mean (Gi)	Phenotypic indices (Pi)	Regression coefficient (bi)	Deviation from linearity (S^2di)
	Env-1	Env-2	Env-3	Env-4	Env-5				
BD-7279 (G_1)	685.00	677.33	666.00	795.00	774.00	719.47	-0.76	1.74	0.73**
BD-7281 (G_2)	749.00	744.33	733.67	921.67	845.00	798.73	0.98	1.89	0.49**
BD-7289 (G_3)	875.33	834.67	825.00	795.67	965.00	859.13	-0.28	0.75	-0.95
BD-7759 (G_4)	747.00	740.00	729.33	732.00	838.33	757.33	-0.09	0.20	0.84**
BD-7306 (G_5)	988.67	927.00	917.33	1034.67	1080.67	989.67	0.54	1.04	0.14**
BD-7292 (G_6)	882.00	980.00	970.00	930.00	973.00	947.00	-0.85	0.83	-0.10**
BARI Tomato-8 (G_7)	1120.00	1111.67	1100.33	1166.67	1227.33	1145.20	0.38	1.05**	-0.04
BARI Tomato-9 (G_8)	1137.67	1126.67	1116.33	1183.33	1211.00	1155.00	0.28	0.88**	0.12
BARI Tomato-14 (G_9)	1134.00	1128.67	1118.67	1187.00	1222.33	1158.13	0.68	1.76**	-0.05
BARI Tomato-15 (G_{10})	1304.67	1297.33	1287.00	1351.00	1399.00	1327.80	0.74	1.78**	-0.12
Mean (Ej)	962.33	956.77	946.37	1009.70	1053.57	985.74			
Env. Index (Ij)	0.32	0.30	-0.58	0.44	0.86				

In figure 8, it was observed that the genotypes have been categorized into four classes. Five genotypes namely G_1(BD-7279), G_2(BD-7281), G_4(BD-7759), G_8(BARI Tomato-9)and G_{10}(BARI Tomato-15)have been categorized in the maximum fruit weight/plant with high sensitivity class having Pi and bi value greater than zero and one, respectively. Another five genotypes namely G_3 (BD-7289), G_5 (BD-7306), G_6 (BD-7292), G_7 (BARI Tomato-8) and G_9 (BARI Tomato-14) have been fall in less fruit weight/plant with high sensitivity block hence, these genotypes were suitable under rich environment.

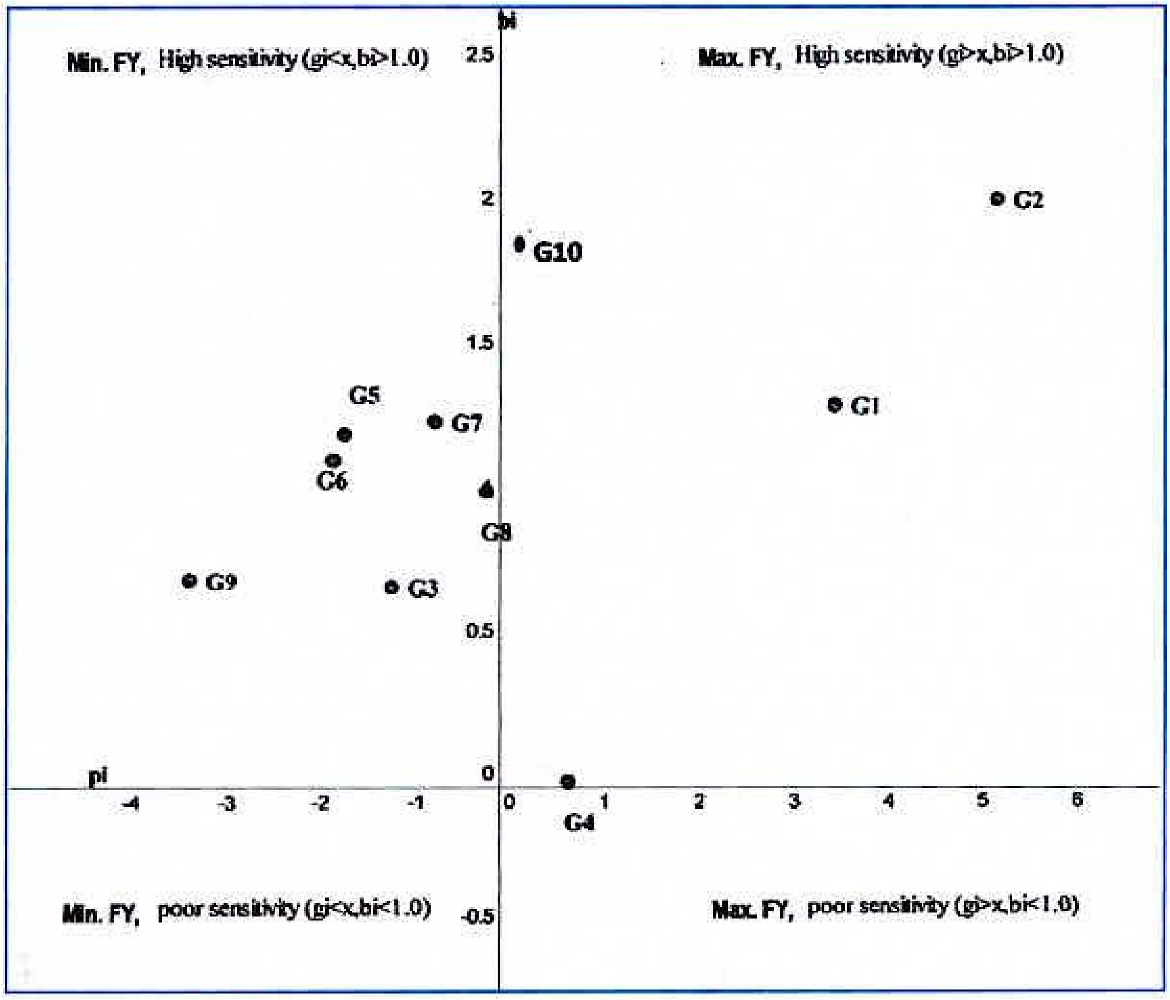

Figure 8: Adaptive specificities of 10 tomato genotypes for fruit yield per plant

Chapter 5

Summary and Conclusion

CHAPTER V
SUMMARY AND CONCLUSION

A field experiment was conducted at the Horticulture farm, Sher-e-Bangla Agricultural University, Dhaka-1207, Bangladesh during the period from December 2012 to March 2013 to study on the Genotype × environment interaction in tomato *(Solanum lycopersicum* L.) by the Department of Genetics and Plant Breeding. Randomized complete Block Design with three replications was followed in the experiment. The parental genotypes used in the study wereG_1 (BD-7279), G_2 (BD-7281), G_3 (BD-7289), G_4 (BD-7759), G_5 (BD-7306), G_6 (BD-7292), G_7 (BARI Tomato-8), G_8 (BARI Tomato-9), G_9 (BARI Tomato-14) and G_{10} (BARI Tomato-15).

The results of the investigation are summarized as follows:

Eight yield and yield contributing characters viz. days to first flowering, days to 50% flowering, days to maturity, plant height (cm), number of branches per plant, number of fruits per plant, fruit diameter (cm), fruit weight (g) were recorded. Analysis of variance for the genotypes and environments showed significant variation for all the characters among the genotype except which fruit diameter revealed the presence of considerable amount of genetic variability.

Significant genotype × environment interactions were found for all the eight characters. The environment (genotype × environment) component was highly significant except fruit diameter which indicated that the genotypes reacted differently in different environment. Highly significant mean squares due to environments (linear) indicated the difference between the environments.

Genotype × environment interactions were significant for all the traits which indicated that the genotypes responded well in environmental fluctuations (bi) and to their stability (S^2di).

All the parameters influenced significantly by environment and also by different genotypes except fruit diameter. G × E interaction had significant influence on the parameters that were studied under the present experiment.Genotype-1 (BD-7279) showed highly significant mean square values considering days to first flower, days to 50% flowering, branches per plant, fruit per plant and fruit yield per plant. Genotype-2 (BD-7281) showed highly significant mean square values considering fruit per plant, fruit diameter (cm) and fruit yield per plant. Genotype-3 (BD-7289) showed highly significant mean square values considering 50% flowering and fruit yield per plant. Genotype-4 (BD-7759) showed highly significant mean square values considering branches per plant. Genotype-5 (BD-7306) showed significant mean square values considering days to 50% flowering, fruit per plant. Genotype-6 (BD-7292) showed significant mean square values considering branches per plant, fruit yield per plant. Genotype-7 (BARI Tomato-8) showed significant mean square values consider in first flowering, 50% flowering, days of maturity, fruit yield per plant. Genotype-8 (BARI Tomato-9) showed significant mean square values for all the character studies, it was followed by Genotype-9 (BARI Tomato-14) and Genotype-10 (BARI Tomato-15)

The 5^{th}environment, Cow dung + Urea + TSP + MP was the best for all the characters studied. Environment, Env-4: Cow dung + TSP + MP was also good for all the characters it was followed by Env-1: Compost and Env-3: Manure (Cow dung).

Genotype G_8 (BARI Tomato-9) showed stable performance respecting fruit weight/plant, and similarlyG_9 (BARI Tomato-14) for days to 50% flowering, G_8 (BARI Tomato-9) and G_9 (BARI Tomato-14) and G_{10} (BARI Tomato-15) for number of fruits per plant and fruit diameter showed stable performance.

Among the genotypesG_{10} (BARI Tomato-15) could be considered as the highest yielder followed by G_7 (BARI Tomato-8), G_8 (BARI Tomato-9) and G_9 (BARI Tomato-14). Genotype G_5 (BD-7306) and G_6 (BD-7292) showed medium yield and the rest genotypes had low yield over environments. G_{10} (BARI Tomato-15) was good yielder having high Pi value but possessed positive significant bi and S^2di value. For this reason, this genotype could be considered as high responsive to environmental condition and might be recommended for breeding program to achieve higher yield under rich environments.

Based on the findings of the present investigation it can be concluded that Genotype × environment interaction was present for all the characters. Environment × genotype was also significant for the most of the characters except fruit diameter. G_7 (BARI Tomato-8), G_9 (BARI Tomato-14) and G_{10} (BARI Tomato-15) were highly responsive i.e. suitable for rich environment in terms of yield per plant. G_8 (BARI Tomato-9) showed stable performance considering fruit weight per plant.

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Appendices

Appendices

Appendix 1.The mechanical and chemical characteristics of soil of the experimental site as observed prior to experimentation (0 - 15 cm depth).

Mechanical composition:

Particle size constitution

Sand	:	40%
Silt	:	40%
Clay	:	20%
Texture	:	Loamy

Chemical composition:

Soil characters	:	Value
Organic matter	:	1.44 %
Potassium	:	0.15 meq/100 g soil
Calcium	:	3.60 meq/100 g soil
Magnesium	:	1.00 meq/100 g soil
Total nitrogen	:	0.072
Phosphorus	:	22.08 μg/g soil
Sulphur	:	25.98 μg/g soil
Boron	:	0.48 μg/g soil
Copper	:	3.54 μg/g soil
Iron	:	262.6 μg/g soil
Manganese	:	164 μg/g soil
Zinc	:	3.32 μg/g soil

Source: Soil Resources Development Institute (SRDI), Khamarbari, Dhaka

Appendix 2. Monthly records of air temperature, relative humidity, rainfall and sunshine hours during the period from October 2013 to May 2014

Month	Year	Monthly average air temperature (^0C)			Average relative humidity (%)	Total rainfall (mm)	Total sunshine (hours)
		Maximum	Minimum	Mean			
Oct	2012	29.36	18.54	23.95	74.80	Trace	218.50
Nov	2012	28.52	16.30	22.41	68.92	Trace	216.50
Dec.	2012	27.19	14.91	21.05	70.05	Trace	212.50
Jan.	2013	25.23	18.20	21.80	74.90	4.0	195.00
Feb.	2013	31.35	19.40	25.33	68.78	3.0	225.50
Mar.	2013	32.22	21.25	26.73	72.92	4.0	235.50

Source: Bangladesh Meteorological Department (Climate division), Dhaka-1212.