

**GENOTYPE X ENVIRONMENT INTERACTION
STUDIES IN CHICKPEA (*Cicer arietinum*. L)**

by

**Mr. MANGESH MAHADEO BALAPURE
(Reg. No. 11/053)**

A Thesis submitted to the

**MAHATMA PHULE KRISHI VIDYAPEETH,
RAHURI - 413 722, DIST. AHMEDNAGAR,
MAHARASHTRA.**

in partial fulfilment of the requirements for the degree

of

MASTER OF SCIENCE (AGRICULTURE)

in

AGRICULTURAL BOTANY

(GENETICS AND PLANT BREEDING)

**DEPARTMENT OF AGRICULTURAL BOTANY
POST GRADUATE INSTITUTE
MAHATMA PHULE KRISHI VIDYAPEETH,
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CANDIDATE'S DECLARATION

*I hereby declare that this thesis or a part
there of has not been submitted
by me or any other person
to any other University
or Institute for
a Degree or
Diploma.*

Place : MPKV, Rahuri

Date : / / 2013

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This is to certify that the thesis entitled, "**GENOTYPEX ENVIRONMENT INTERACTION STUDIES IN CHICKPEA (*Cicer arietinum* L)**", submitted to the Faculty of Agriculture, Mahatma Phule Krishi Vidyapeeth, Rahuri, Dist. Ahmednagar (Maharashtra State) in partial fulfilment of the requirements for the degree of **MASTER OF SCIENCE (AGRICULTURE)** in **AGRICULTURAL BOTANY (GENETICS AND PLANT BREEDING)**, embodies the results of a piece of *bona fide* research work carried out by **Mr.MANGESH MAHADEO BALAPURE**, under my guidance and supervision and that no part of the thesis has been submitted for any other Degree or Diploma.

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LIST OF ABBREVIATIONS

%	:	Percent
°C	:	Degree celcius
µg	:	Microgram
C.D.	:	Critical difference
C.V.	:	Critical variance
cm	:	Centimetre
<i>et al.</i>	:	et alli (and others)
Fig.	:	Figure
g	:	Gram
ha.	:	hectare
hrs.	:	Hours
i.e.	:	that is
kg	:	kilogram
kg/hl	:	kilogram/hectolitre
mg	:	milligram
min.	:	minute
ml	:	millilitre
nm	:	nanometre
OD	:	Optical density
ppm	:	Parts per million
S.E.	:	Standard Error
sec	:	Seconds
<i>viz.,</i>	:	Videlicet (Namely)

ABSTRACT

“GENOTYPE X ENVIRONMENT INTERACTION STUDIES IN CHICKPEA (*Cicer arietinum*. L)”

by

Mr.MANGESH MAHADEO BALAPURE

A candidate for the degree

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Research Guide : Prof. L.B. Mhase
Department : Agricultural Botany
Major discipline : Genetics and Plant Breeding

The present investigation entitled “Genotype x Environment interaction studies in chickpea (*Cicer arietinum* L.)” was undertaken with view to estimate stability parameters for seed yield and its important components and to identify most stable genotype under different environment. Eight genotypes were sown on eight different sowing dates in a Randomized Block Design, with three replications for measuring stability of genotypes for different characters. The data was subjected to statistical analysis as per Eberhart and Russell (1966) model.

In general, genotypic differences were found significant for days to 50 % flowering, days to maturity, plant height, primary branches per plant, 100 seed weight and seed yield per plot indicating the presence of genetic variability in the material. G x E interaction was found to be significant for the characters *viz.*, days to 50% flowering, days to maturity, plant height (cm), primary branches per plant (No.), pods per plant (No.), seed yield per plant (g), seed yield per plot (kg) and harvest index (%). Linear

component of G X E interaction was found significant for the characters *viz.*, days to maturity, primary branches per plant, seed per pod and 100 seed weight where as pooled deviation was found significant for the traits *viz.*, days to 50 % flowering, days to maturity, plant height, pods per plant, seed yield per plant, seed yield per plot and harvest index(%).

None of the genotype was found stable for all the characters under study.

The genotype Vijay recorded average stability for days to 50 % flowering and pods per plant. The genotypes Phule G-0204-4, Phule G-06102 and Vishal showed average stability for days to maturity. The genotypes Phule G-07101 and Phule G-09103 recorded average stability for plant height (cm). The genotypes Phule G-07102 and Phule G-06102 showed average stability for number of primary branches per plant. The genotype Vijay found stable for pods per plant. The genotypes Phule G-07102 and Digvijay recorded average stability for seed yield per plant (g). The genotypes Phule G-07102, Phule G-07101 and Phule G-09103 showed average stability for seed yield per plot (kg). The genotypes Phule G-06102 and Digvijay showed average stability for harvest index (%).

The genotype Phule G-09103 showed above average stability per days to maturity which is suitable for favourable environment.

The genotypes Phule G-07101 and Vishal showed below average stability per number of primary branches per plant which are suitable for unfavourable environment.

1. INTRODUCTION

Pulses play an important role in Indian agricultural economy because of their high nutritive value and ability to improve soil fertility by fixing atmospheric nitrogen through symbiotic association with *Rhizobium*. Pulses produce 2 to 2.5 times more protein than cereals in their seeds. So they are of prime importance in our country where most of the population is vegetarian and protein malnutrition is the major concern.

Chickpea (*Cicer arietinum* L.) is a self pollinated crop belonging to the Leguminaceae family of the Tribe Cicereae. It is a diploid species with $2n=2x=16$ chromosome. The chickpea also known as Bengal gram, *chana* and in marathi it also called as *Harbhara*. The plant grows between 20-50 cm height and has smaller feathery leaves on either side of the stem. It has pink or white flowers with blue, violet or pink veins. Chickpea need a subtropical or tropical climate with more than 400 mm of annual rain.

There are two main kinds of chickpea, Desi and Kabuli. Desi, which has small, darker seeds and a rough seed coat, cultivated mostly in Indian subcontinents, Ethiopia, Mexico and Iran. Desi (meaning country or local) is also called as Bengal gram or Chola. Desi chickpeas have markedly higher fiber content than Kabulis and hence a very low glycemic index which may make them suitable for people with blood sugar problems. Kabuli, which has white or milky white colour, larger seeds and smoother seed coat, mainly grown in southern Europe, Northern Africa, Afghanistan,

Pakistan Turkey and India. Kabuli (meaning from Kabul) is also called as Safed Chana.

Chickpea (*Cicer arietinum* L.) is the third most important food legume. It is grown in over 45 countries round the world. India is the largest producer sharing 75% of total world production. It provides high quality protein to the people. People in the developed countries consider it as a health food. Chickpea grain contains 18-24% protein, 2.0-7.0% fats, 64% total carbohydrates (47% starch, 6% soluble sugar) and 6% crude fiber. Being a legume crop it takes care of soil fertility by fixing 41-65 kg atmospheric nitrogen per hectare through *Rhizobium spp.* It is mostly used in the form of 'Dal'. About 75 per cent of the total production is consumed as 'Dal' in India.

Mature chickpeas can be cooked and eaten cold in salad. Cooked in stews, ground into flour called gram flour (also known as chickpea flour and besan and used primarily in Indian cuisine). Chickpeas are used to make curries and one of the most popular vegetarian food in India, Pakistan, Bangladesh and the UK. Green leaves/twigs of a chickpea are used in preparing a nutritious vegetable in the countries of South Asia. These are also used as high protein fodder mixed with cereal leaves. Chickpea stover is fed to the cattle/goats as nutri-rich supplement to their major cereal fodder in the lean season.

Chickpea (*Cicer arietinum* L.) is the premier pulse crop of Indian subcontinent. India is the largest chickpea producer as well as consumer in the world. Chickpea is cultivated in diverse agro-climatic conditions in India and grown under both rainfed and irrigated conditions. Majority of the area is under rainfed farming

and is one of the causes of low productivity in the country. Chickpea remarkably predominates among other pulse crops in terms of both area and production. The year 2011-12 marked significant increase in area under chickpea. India grows chickpea on about 9.01 million ha area, production 7.58 million tons which represents 35 and 46% of the National Pulse acreage and production, respectively. Productivity of the chickpea is 896 kg/ha. The six states *viz.*, Madhya Pradesh, Maharashtra, Andhra Pradesh, Karnataka, Rajasthan and Uttar Pradesh together contribute 83% of the production and 81% of the area of the country (Anonymous, 2011).

Maharashtra grows chickpea on about 10.51 lakh ha. area, production 8.15 lakh tons and the productivity of chickpea 775 kg/ha. in the year 2011-12 (Anonymous, 2011).

Crop variety developed should show stable performance under different environments, especially in India where wide range of environment are prevailing. It is a need to develop genotypes with high degree of adaptability levels over a wide range of ecogeographical conditions for successful exploitation of its inherent potential. A variety is said to be stable which can adjust its phenotypic and genotypic status in response to changing environment. The genotype x environment interaction studies is as an important as crop improvement.

Genotype x environment interaction is supposed to be one of the genetic parameter responsible for phenotypic stability and adaptation. There are many investigations done in the past and continued till today with a view to identify a stable and adaptable genotype for different yield contributing characters.

In the *rabi* tract of Maharashtra, the onset of monsoon is often delayed and *Kharif* sowing is indefinitely postponed, in that case the farmers used to undertake sowing of chickpea from September to December. This necessitates the testing of stability of newly developed promising genotypes over the sowing dates.

The major chickpea crop area is grown under rainfed condition in Maharashtra, where sowing is carried under residual soil moisture. Under such situation suitable sowing period is last week of September to first week of October for obtaining better yield from rainfed crop. For optimum sown irrigated crop suitable date is 20th October to 10th November. However, some farmers use to sow crop in the month of December or even later. In this situation, it is very important that, the genotype should perform very well or it should show stable performance during these sowing periods. Hence, there is enough scope to improve the productivity of this crop by developing stable, high yielding, disease and pest resistance, drought tolerant varieties suitable for different environments.

Therefore, the present investigation on “Genotype x Environment interaction studies in chickpea (*Cicer arietinum* L.)” was undertaken with the following objectives:

- i. To estimate stability parameters for seed yield and its important components.
- ii. To identify most stable genotype under different environment.

2. REVIEW OF LITERATURE

The literature on stability analysis of seed yield and other contributing characters of chickpea (*Cicer arietinum* L.) have been reviewed and presented under different subheadings.

2.1 Concept of stability

A specified genotype does not exhibit the same phenotypic expression under different environments and different genotype responds differently to a specified environment.

The stability in the productivity and the character of economic importance like yield is of interest to the plant breeder. The desirable genotype may show low genotype x environment interaction for the agricultural important characters and on the other hand may be more flexible for other characters. Such genotypes are said to be well buffered as those can adjust their genotypic and phenotypic status in response to the changing environmental conditions. This is also called as genetic homeostasis (Lerner, 1954).

The differential response of the genotype is due to G x E interaction. According to Frey (1964), stability is a desirable attribute of a genotype and also indicates the high mean performance of the genotypes. The linear regression slope is considered as the measure of stability and the observed values were regressed on environmental indices (Finlay and Wilkinson, 1963). Perkins and Jinks (1968) reported the same regression coefficient (b) similar to Finlay and Wilkinson (1963) method

except that the observed values were adjusted for location effects before the regression.

According to Eberhart and Russell (1966) linear (bi) and non-linear (S^2di) or residual mean squares (MS) of deviation from the regression along with high mean performance are the measures of stability.

Minimum G x E interactions is desired for a cultivar to be commercially successful, so that it can perform well across the range of environmental conditions in which the cultivar may be grown. The presence of G x E interaction reduces the correlation between phenotype and genotype and makes it difficult to judge the genetic potential of the genotype.

Environment is the sum total of physical, chemical and biological factors. Comstock and Moll (1963) have classified the environments into two categories i.e. micro and macro environments. Allard and Bradshaw (1964) coined the terms predictable and unpredictable environments.

The predictable environment includes the permanent features of environments such as climate, soil type, day length etc. and controlled variables i.e. level of fertilizer application, sowing date, etc. The unpredictable environment includes factors beyond the control of human beings i.e. amount and distribution of rainfall, temperature, etc.

Stability of cultivar refers to its consistency in performance across environments and is affected by the presence of G x E interaction. In the presence of significant G x E interaction, the stability parameters are estimated to determine

the superiority of individual genotype across the range of environments.

A genotype which maintains its deviation from the mean yield value when tested at all sites is considered as ecologically stable, or in other words the genotype is considered environmentally stable when a unit change in the genotype performance corresponds to a unit change in environmental index (Mahil *et al.*, 1984). Thus, the aim should be to develop suitable genotype for a given ecological area which has high yield stability (Nedelia *et al.*, 1984).

The adaptable varieties react strongly and quickly to improved conditions, but react less strongly to unfavourable environmental changes. Their yield reduction in poor environment is less than that of unstable varieties (Rosochora, 1987).

In developing countries, where the availability of agricultural inputs is scarce, in the case stability of a genotype is most important and intercropping or mixed cropping with stable varieties is best mean to reduce the risk.

2.2 Statistics and genetics of G x E interaction

Mather (1949) provided the biometrical approach to workout additive, dominance and epistatic gene action to genotype and G x E interaction. Partitioning of genotype x location interactions (σ^2_{gl}) for each genotype was also discussed by Plaisted and Peterson (1959). A genotype was considered more stable which contributed least towards σ^2_{gl} .

Plaisted and Peterson (1959) developed a method to characterize the stability of yield performance when several varieties were tested at number of locations within one year. A combined analysis was computed for each pair of varieties, $n(n-1)/2$ pairs of n varieties and or estimate of σ^2v was obtained from each genotype. The genotype with the smallest variance would be one that contributes the least genotype x location interactions and thus would be considered as the most stable genotype in the tests. Finlay and Wilkinson (1963) utilized technique to compare the performance of a set of cultivars grown at many sites for each genotype. Varietal mean yield over all environments and regression coefficients were used to classify the cultivars specially adopted at par in better yielding environments and for general adaptability. They have indicated average phenotypic stability by a regression coefficient of unit ($b_i = 1$). A cultivar with $b_i < 1$ has above average stability, $b_i > 1$ has below average stability and $b_i = 0$ has absolute phenotypic stability which means a constant gain in all environments. The ideal cultivar is one that possesses genetic potential in highest yielding environment and maximum phenotypic stability.

The approach of Finlay and Wilkinson (1963) and Eberhart and Russell (1966) are purely statistical and component of these analysis have not been related to the parameters in biometrical genetic model, Perkins and Jinks (1968) performed the second approach which is based on fitting of model which specify the contribution of genetic, environmental and G x E interaction to generation mean and variances allowing

for the contribution of additive, dominance and epistatic gene effects to the genetic and interaction components. The model is

$$Y_{ijk} = \mu + d_i + E_j + B_i E_j + e_{ij} + e_{ijk}$$

Eberhart and Russell (1966) observed that the corn hybrids with regression coefficient less than 1.00 usually yield below average. Accordingly, they suggested that a desired genotype should have high mean, regression coefficient equal to 1.00 and variance due to regression as small as possible. Thus, they modified the regression technique, which enables the partitioning of G x E interaction of each genotype into two parts. They defined both the linear (b_i) and non-linear ($S^2 d_i$) components as stability parameters. They compared two types of crosses in maize and stated that, some single crosses may show as much or more phenotypic stability than most stable three way or double crosses.

Freeman and Perkins (1971) proposed independent estimate of environmental index in following two ways.

- a. Divide the replications in two groups, so that one group may be used for measuring the average performance of varieties in different environments and the other group for estimating environmental index.
- b. Use one or more varieties as check and assess environmental index on the basis of their performance. They proposed following model.

$$Y_{ijk} = m + d_i + e_{ij} + e_{ijk}$$

2.3 Stability studies in chickpea

Tai (1971) presented a method of genetic stability based on principle structure relationship analysis where a G x E interaction of a particular genotype is partitioned into two components *viz.*, the linear response to environment effect (α) and deviation from linear response (λ).

Mehra and Ramanujam (1979) studied stability of forty six chickpea genotypes in nine environments, at three locations. G x E interaction was found to be highly significant for all characters except seeds/pod. Major portion of G x E interaction was linear and thus predictable; however non-linear interaction was also considerable. The association between adaptability parameters of yield and its component brought out the fact that main component of yield stability was stability of pods number per plant. Two populations from crosses NP-58 x 1707 and NP-1102 x 1713, respectively were found to possess specific adaptability for good environments.

Bahl *et al.* (1980) tested a set of 8 chickpea cultivars at eleven locations in peninsular India. The genotypes PG-2, BEG-482 and the check Annigeri were unstable while cultivar, BDN 9-3 was found to possess general adaptability for the peninsular zone.

Mehra *et al.* (1980) studied nature and magnitude of G x E interaction in 11 varieties of chickpea for yield in northern India at 16 locations. The M.S. due to varieties was significant for yield, seed size and plant height. The analysis of stability for

yield and three components revealed that BG- 209, Pant-114 and Pant-115 possessed wide adaptability.

Singh and Mehra (1980) evaluated twenty genotypes grown at six locations for three yield components and reported that, the genotype x environment interaction was significant for all traits except seeds per pod. The genotypes G-130, T3, Pant-104 and C-468 were stable for pods per plant. The genotype NP-53 recorded the highest 100 seed weight but was unstable for seed size.

Singh and Singh (1980) studied stability of component characters in relation with stability of yield. They analyzed how the component characters interact. The relationship among predictable behavior of G x E interaction of component traits and yield revealed that the linear response of yield was positively and significantly associated only with linear response of tillers per plant, whereas yield per spike was positively associated with number of grains per spike and test weight. The evaluation of G x E interaction gives an idea of stability of the population under study. The present investigation on chickpea deals with study of stability of promising lines of chickpea. Hence, an attempt has been made to review the literature on stability and G x E interaction.

Musa (1980) observed that optimum date of sowing (15 November) had recorded higher number of primary and secondary branches than late sown crop (15 December). He also reported that, the 100 seed weight was significantly higher in November than in October and December sown crop.

Jain *et al.* (1984) studied thirty two chickpea genotypes for yield stability at 3 locations in Pantnagar district. They observed the existence of high G x E interaction for all characters. In spite of non-significance of linear component of G x E interactions, few genotypes exhibited $b_i > 1$ or $b_i < 1$ for seed yield per plant, seeds/pod and harvest Index. Accordingly, the genotype showing wide adaptability and specific adaptation were identified, K-4 was found suitable for better management conditions. Pant G-110 showed promise for moderate input management and Kaka, NEC 240 and Pink-2 appeared worthwhile for poor environmental conditions.

Tripathi and Singh (1985) studied performance of chickpea varieties under different dates of sowing. Highest seed yield was recorded in the sowing on 5th November and yield was considerably reduced when crop was sown in December.

Sharma and Maloo (1989) evaluated twenty one diverse varieties of chickpea for their phenotypic stability in three environments. Genotype x environment interaction component was significant for number of primary branches and grain yield per plant. Linear component was of higher magnitude and significant for all the characters except number of primary branches and days to 50 per cent flowering. The high yielding genotype IC-7840 possessed stability for number of primary branches, while RSG-40 expressed wide adaptability under optimum environments for grain yield per plant.

Singh and Singh (1989) evaluated stability analysis of grain yield/plant and harvest index in 66 genotypes of chickpea

(*Cicer arietinum* L.). Highly significant differences were observed due to genotypes, environment and genotype x environment interactions. Significant linear mean squares were observed for yield/plant and harvest index. Stable genotypes for yield/plant and harvest index were P-4116-1 and PG-72-84 respectively. Genotypes ICC- 7710 and NEC-2305 (with high mean, regression coefficient- $b_i > 1$, and deviation from regression $S^2_{di} = 0$) were suitable for favourable environments. Genotypes P- 1786 and HMS-17 (with average yield, $b_i < 1$ and $S^2_{di} = 0$) maintained their inherent potentialities fully well under unfavourable environments. Twenty genotypes recorded high yield and were stable for yield/plant and harvest index.

Bousslama *et al.* (1990) studied yield stability for sixteen genotypes grown at two locations over three consecutive seasons. Linear and non-linear components were found significant for all the traits and non-linear component was higher in magnitude. ILC-6, ILC-191, ILC- 194, ILC-202, ILC-3279 were considered most adaptable.

Shrivastava *et al.* (1990) studied the response of chickpea cultivars under different dates of sowing in Chhattisgarh region of Madhya Pradesh and observed that, the seed yield was influenced significantly by sowing dates. Maximum seed yield of 2.51 t/ha was obtained in 10th December sown crop because of significantly superior plant height, plant spread, secondary branches per plant and yield per plant than the late sowing dates.

Baisakh and Nayak (1991) evaluated seventeen genotypes of chickpea to study the stability parameters for yield and maturity with 3 replications at Bhubaneswar. They reported significant differences for G, E and G x E interaction for grain yield. Linear and non-linear components were predominant in G x E interaction in maturity, whereas non-linear component in yield, secondary branches and days to 50 per cent flowering. ICC-6 was the most stable genotype for yield and maturity.

Singh *et al.* (1991) studied a set of 39 genotypes of chickpea (*Cicer arietinum* L.) for stability. The September sowing gave the highest average yield (X = 9.91 g) followed by the mid-October sowing (X = 9.36 g). The November sowing gave the poorest yield (X = 6.28 g). The yield performance of genotypes in relation to sowing dates has been discussed and the optimum sowing time suggested was from last week of September to mid-October. G x E interaction was significant for all the characters studied. The linear component of G x E interaction was significant for primary branches per plant and pods per plant. Whereas, the non-linear component was significant for secondary branches per plant, seeds per pod and seed yield per plant. The genotype BGM-418 was found suitable for early or mid-October sowing. The performance of RSG-2 genotype little influenced by different sowing dates.

Paikaray and Misra (1992) reported that, the seed yield was significantly influenced by sowing dates in the year 1988-89 and 1989-90. The highest seed yield was obtained when

the crop was sown on 18 November with maximum 100 seed weight.

Singh *et al.* (1993) grown twenty genotypes of chickpea over six environments. Stability performance analysis revealed highly significant differences due to G, E and G x E interactions for all characters except plant height. Seven genotypes were sorted out with higher grain yield than grand mean over environments, along with stability for grain yield and other yield contributing characters on the basis of $b_i=1$ and $S^2d_i = 0$.

Singh and Kumar (1993) evaluated a set of 22 advanced lines and 3 control varieties of chickpea (*Cicer arietinum* L.) to determine the stability for seed yield for days to 50 per cent flowering, days to maturity, and 100-seed weight. Significant differences were observed among genotypes and environments indicates genotype x environment (G x E) interactions. Stability analysis showed that both linear and non-linear components significantly contributed towards G x E interaction for days to maturity, whereas non-linear component predominantly contributed towards seed yield, days to 50 per cent flowering and 100- seed weight. The genotypes 'K- 850' and 'ICCV-89360' were found the most stable genotypes.

Aziz and Rahman (1994) reported the effect of dates of sowing on yield and it's components of Kabuli chickpea. They observed that chickpea crop sown on 15th October, 15th November and 15th December, produced the yield of 1.90, 2.00 and 1.57 t/ha, respectively.

Deshmukh *et al.* (1995) reported that, the plant height of chickpea genotypes varied in the range of 30 to 51 cm under different sowing conditions.

Jadhav *et al.* (1995) stated that, delay in sowing after November resulted in decrease in plant height in chickpea.

Muppaidathi *et al.* (1995) in their studies reported that, primary and secondary branches were reduced in chickpea if sowing is delayed after November and these characters were positively and significantly correlated with seed yield.

Tiwari and Tripathi (1995) found that, late sowing during the second week of December put the chickpea crop under high evaporative demand period at pod formation and grain filling stages, resulting in relatively low magnitude of all the yield attributes coupled with shortening of crop life due to forced maturity.

Aher *et al.* (1998) tested phenotypic stability of 21 promising chickpea genotypes at 3 locations in Maharashtra under irrigated condition. Pooled analysis of variance revealed that G, E and G x E interaction were significant for grain yield/plot. Stability parameters indicated that, genotype JAKI 9509 found to be most stable for grain yield. Among the other genotypes, Phule G-92028, Phule G- 91010, Phule G-8404-1, JAKI-9521 and Vijay showed high mean performance, bi value more than unity and nonsignificant S²di, which are stable under favourable environmental condition.

Popalghat (1998) recorded the highest number secondary branches in late sown chickpea genotype (22nd December).

Yadav *et al.* (1999) reported that, the numbers of primary and secondary branches in chickpea genotypes were reduced under late sown conditions (25th December).

Deshmukh *et al.* (1998) measured stability of eight promising genotypes for yield potential under five different environments. The linear component of G x E interaction was significantly higher in magnitude as compared to non-linear components. Pooled analysis revealed significant differences among G, E and G x E interaction for yield. Genotype Vijay showed high stability in yield across the locations followed by PG-82207 and PG- 87227.

Mhase *et al.* (1998) studied stability of 16 promising chickpea genotypes under rainfed condition in western Maharashtra at 5 locations. They observed significant interaction between genotypes and environment for grain yield. Linear component of G x E interaction found significant for yield and yield contributing characters and of higher magnitude than non-linear component. Vijay was found to be most stable genotype, while Chafa and JAKI- 9532 were unstable under rainfed condition. Phule G- 92028, JAKI-9507, ICCV-1 and JAKI-9523 showed above average stability ($b_i < 1$ and non-significant S^2d_i) thus suitable for poor environment. While Vishal and AKG-46 exhibited below average stability ($b_i > 1$ and non-significant S^2d_i) suitable for favourable environment.

Popalghat *et al.* (1998) evaluated nineteen (19) genotypes of chickpea under four different environments. Significant genotype G x E interaction was observed. Both linear and non-linear components of G x E interaction were significant and linear component being the predominant. On the basis of stability parameters two genotypes PG-12 and Vishal showed their suitability for average cultivation. For seed quality parameters, the genotype Vijay showed above average stability. Vishal indicated average stability for germination percentage and seedling vigour index.

Khorgade *et al.* (2000) reported significant G x E interaction for all the characters studied. The linear component was significant for days to 50 per cent flowering, number of pods per plant, seed yield per plant, both linear and non-linear components were significant for 100 seed weight. The stability analysis revealed that, among the all genotypes, PG-5 exhibited average stability whereas high yielding genotypes *viz.*, ACM-7, ACM-2 and AKG-46 were found unstable, but were highly responsive to favourable conditions.

Sood *et al.* (2000) assessed stability of 32 genetically diverse chickpea genotypes at Himachal Pradesh under four environments. They observed significant G x E interaction for all the traits under study. Eight genotypes were found promising and stable for seed yield/plant. HPG- 72 having significantly higher yield than the check C-235 was however, suitable for favourable environment only. Among the genotypes HPG-33 was

observed to be highly promising and stable for yield and other three important yield components.

Sirohi *et al.* (2001) evaluated twenty five promising genotypes of chickpea in subtropical zone of the Himachal Pradesh. Both linear and non-linear components of G x E interaction was significant for all the traits and non-linear components was of higher magnitude. Significant differences were observed due to genotype, environments and genotypes x environment interaction for all the traits. Five genotypes, *viz.*, HPG-25, HPG-17, HPG- 28, HPG-14, HPG-34 were sorted out for high seed yield along with stability for yield and other yield contributing traits on the basis of $b_i = 1$ and $S^2d_i = 0$.

Sharma and Sharma (2002) showed that, early planted crop (25th November) had higher plant height by 5.91 cm over late sown crop (25th December) in chickpea at Himachal Pradesh.

Singh *et al.* (2004) observed that, October sowing was better than early and late because the chickpea crop experienced relatively mild temperatures during which flower retention and pod filling was better and reported that biological yield decreased significantly in all genotypes when sown on 15th December as compared with the earlier sowings i.e. 15 October and 15 November. The highest yield was observed at optimum sowing i.e. 15th November.

Rao and Rao (2004) studied thirty promising genotypes of chickpea for stability parameters. Significant differences were observed due to genotypes, environments and

genotype x environment (Linear) interaction for all the traits. However G x E (non linear) was found to be non significant for plant height, harvest index, yield per plant and 100 seed weight. Five genotypes *viz.*, PG-95311, ICCV- 42, ICCV-95334, Pusa-390 and Pusa-362 were sorted out stable for yield and other yield contributing traits on the basis of $b_i = 1$ and $S^2d_i=0$.

Vijay Prakash (2005) tested a set of twenty-two chickpea genotypes to identify high yielding stable genotype for harsh and erratic environment of Rajasthan. Both linear and non-linear components of G x E interactions were significant for all the traits except primary, secondary branches/plant and grain yield. The chickpea genotypes GNG-1451, GNG-1485 and GNG- 1486 were found stable.

Singh and Sandhu (2006) studied a set of ninety genotypes of chickpea for Genotype x Environment interaction for grain yield and its components over 3 environments created by different sowing dates. Genotypes and environment were found significantly diverse. The GxE interaction were highly significant for all the characters, except seeds per pod and harvest index.

Malhotra *et al.* (2007) showed that Genotype x Environment (GxE) interaction plays a significant role in the relative expression of different cultivars in different environment. This study examined the extent and nature of GxE interaction on the yield of chickpea and identified genotypes that can produce high yield in both season. Sixteen sets of genotypes were evaluated at lattice designs at two contrasting locations in Syria

and Lebanon in both spring and winter. The dual season lines identified were FLIP98-121C, FLIP97-49C, FLIP97-50C and FLIP97-21C for Syria; FLIP98-90C, FLIP99-37C, FLIP97-56C and FLIP97-131C for Lebanon. They suggested that these genotypes be evaluated in multi-location trials with larger plots to identify the most desirable promising lines suitable for dual season planting.

Segherloo *et al.* (2008) identified genotypes that have high yield and stable performance across the different locations. The seventeen genotypes were tested at six different research stations for 2 years in Iran. They identified FLIP94-123C was most stable genotype.

Bakhsh *et al.* (2008) stated that Genotype \times environment interaction (G \times E) is a major constraint to identify single superior genotype for a number of variable environments. In order to quantify G \times E interaction effect on grain yield in chickpea, 16 chickpea genotypes were studied for grain yield at 6 locations for two years, using randomized complete block design. The parametric approach and stability parameters indicated that genotypes; BRC-1, BRC220 and BRC-224 were relatively stable in different environments.

Chaudhary and Haque (2010) evaluated forty-two lines of chickpea including two checks grown during winter season (*rabi*) for three years in twelve environment for stability parameter of Chhotanagpur region. Pooled analysis of variance revealed that, the mean sum of square due to genotypes and environment for primary branches per plant, secondary

branches per plant and grain yield per plant (g) found highly significant.

Duzdemir (2011) studied the influence of genotype x environment interactions on phenological characteristics of chickpea. The G×E interaction were highly significant for flowering period and vegetation period. Stability analysis was carried out for all characteristics according to Finlay-Wilkinson and Eberhart-Russel models. Stable genotypes for each characteristic were found for two parameters.

Rao (2011) studied over three years twenty one advanced breeding lines selected from All India Coordinated trials and one local popular variety “Annigeri” to identify high yielding stable genotypes. Genotype, environment and G x E interaction variance found to be significant. Genotypic variance over environments was significant for grain yield, pods/plant and 100 seed weight. Both linear and non linear components were found to be important for the traits studied. Significant non linear component for grain yield indicated the predictability of the trait. Of all the genotypes C-506 and C-527 were found to be stable.

Shafi *et al.* (2012) evaluated fifteen genotypes for stability of different yield parameters under three diverse environments (Bhakkar, Chakwal and Rawalpindi) in the Punjab province of Pakistan. Variance due to genotypes, environments, genotype x environment and environment (linear) was highly significant for days to flowering, plant height, number of pods per plant, 100 grain weight and grain yield per plant across the

environments. By using Eberhart and Russel method of stability analysis genetic differences among diverse cultivars were calculated. The results showed that different genotypes depicts significant genotype x environment (linear) response under contrasting conditions. Eight genotypes viz., 01067, 3CC-113, AZC-06, CMC-211-5, 3CC-116, Bittal-98, CH 24100 and Dasht were found stable for yield and other yield contributing traits.

Chaudhary *et al.* (2012) studied 50 genetically diverse genotypes for G x E interaction and stability parameters in ten quantitative characters. The linear component of genotype x environment (G x E) interaction was significant for plant height, biological yield and seed yield. The non-linear component of genotype x environment (G x E) interaction was non-significant for all the traits when tested against pooled error.

3. MATERIAL AND METHODS

The investigation on “Genotype × Environment interaction studies in chickpea (*Cicer arietinum* L)” was carried out at Pulses Improvement Project, Mahatma Phule Krishi Vidyapeeth, Rahuri during *Rabi* 2011-12. The details of the material used, methods adopted and statistical procedures followed are described below.

3.1 Experimental Material

The material used for the present study consisted of five newly developed chickpea genotypes along with three check varieties.

Table 1: List of Chickpea genotypes with their pedigree

Sr. No.	Name of Genotype	Pedigree
1	Phule G-07102	ICCV 10 x ICCL 87322
2	Phule G-0204-4	Phule G 92926 x IPC 97-7
3	Phule G-07101	ICCV 10 x Myles
4	Phule G-09103	JG 11 x ICC 3513
5	Phule G-06102	ICCV 10 x K 1189
6	Vijay(check)	P-1270 x Annigeri
7	Vishal(check)	K-850 x ICCL-80074
8	Digvijay(check)	Phule G-91028 × Bheema

The experiment was conducted with eight sowing dates during *Rabi* 2011-12 as below.

- 1) 01/10/2011(E1)
- 2) 16/10/2011(E2)
- 3) 01/11/2011(E3)
- 4) 16/11/2011(E4)
- 5) 01/12/2011(E5)
- 6) 16/12/2011(E6)
- 7) 01/01/2012(E7)
- 8) 16/01/2012(E8)

3.2 Methods

3.2.1 Experimental design

These 8 genotypes were evaluated in a Randomized Block Design with three replications for each sowing date. The gross plot size was 4.00 x 1.80 m. The rows were spaced at 30 cm apart with intra row spacing of 10 cm. A basal dose of 25: 50: 30 NPK kg/ha was applied at the time of sowing.

Field operations *viz.*, gap filling, thinning and inter cultural operations were carried out as and when required so that the field was kept free from weeds. Recommended plant protection measures were adopted for control for pests and diseases.

Seed material of these genotypes was obtained from the Principal Scientist (Pulses), Pulses Improvement Project, M.P.K.V., Rahuri.

3.2.2 Observations recorded

Randomly selected 5 competitive plants in each genotype of each replication were used for recording the observations and averages were worked out.

- 1. Days to 50 % flowering :** No. of days required from sowing to the day on which 50 % of the plants from the plots showed flower opening were recorded.
- 2. Days to maturity:** Days taken from the date of sowing to complete maturity were recorded.
- 3. Plant height (cm):** Plant height was recorded at flowering and measured in cm. from ground level to the top of main shoot.
- 4. Plant spread (cm):** Maximum spread of the plant was recorded in cm at flowering.

- 5. Primary branches per plant (No.):** Fruiting branches arising from main stem were considered as primary branches which were recorded at the time of harvesting.
- 6. Secondary branches per plant (No.):** Fruiting branches arising from primary branches were recorded at the time of harvest.
- 7. Pods per plant (No.):** Total numbers of pods on each of the 5 selected plants were counted at maturity and average was worked out.
- 8. Seeds per pod (No.):** Total numbers of seeds per pods were counted.
- 9. 100 seed weight (g):** Weight of randomly selected 100 seeds was recorded from the observational plants.
- 10. Seed yield per plant (g):** The weight of total seeds harvested from the observational plants were recorded and average was work out as seed yield per plant.
- 11. Seed yield (kg/plot):** Seed yield per plot including observational plants was recorded in gram.
- 12. Harvest index (%):** The Harvest Index per plot calculated by taking biological yield and grain yield.

3.3 Statistical analysis

The data was collected on randomly selected five plants per replication in each plot for each character. The collected data was subjected for testing the genotypic differences (Fisher, 1950).

Stability analysis was performed as per Eberhart and Russell (1966), who proposed three stability parameters to describe the performance of genotypes over different environments. According to them the regression of each variety on an

environmental index and a function of square deviation from this regression provide estimates of stability parameters.

For each genotype stability was described by three parameters *viz.*, mean performance (\bar{X}), regression coefficient (b_i) and the squared deviation from the regression ($S^2 d_i$).

These parameters are defined by using the following model.

$$Y_{ij} = \mu + \beta_i I_j + \delta_{ij} \quad (I = 1, 2, \dots, t \text{ and } j = 1, 2, \dots, S)$$

Where,

- Y_{ij} = Mean of i^{th} genotype in j^{th} environment
 μ = Mean of all genotypes over all environments
 β_i = The regression coefficient of i^{th} genotype on the environmental index, which measures response of genotype to varying environments
 I_j = The environmental index which is defined as deviation of the mean of all the genotypes at a given environment from the overall mean.

$$\frac{\sum_j Y_{ij}}{t} - \frac{\sum_j \sum_j Y_{ij}}{ts} \quad \text{with } \sum I_j = 0$$

- δ_{ij} = The deviation from regression of the i^{th} genotype of j^{th} environment

3.3.1 The stability parameters

- a. The regression coefficient (b_i) is described as under

$$b_i = \frac{\sum_j Y_{ij} I_j}{\sum_j I_j^2}$$

Where,

- $\sum_j Y_{ij} I_j$ is the sum of products
 $\sum_j I_j^2$ is the sum of squares of environmental index

b. Mean square deviation (S^2_{di}) from linear regression is calculated as

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

Where,

$$\sum_j \delta^2_{ij} = \left(\begin{array}{c} Y^2_{2i} \\ \sum_j Y^2_{ij} - \frac{(\sum_j Y_{ij} \cdot I_j)^2}{\sum_j I^2_j} \end{array} \right)$$

and

S^2_e = The estimate of pooled error

t = Number of genotypes

S = Number of environments

1. Computation of environmental index (I_j)

I_j is defined as

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

= $\frac{\text{Total of all genotypes at } j^{\text{th}} \text{ location}}{\text{Number of genotypes}} - \frac{\text{Grand total}}{\text{Total number of observations}}$

2. Computation of regression coefficient (b_i) for each genotype

$$b_i = \frac{\sum_j Y_{ij} \cdot I_j}{\sum_j I^2_j}$$

i. For each value of regression coefficient $\sum I^2_j$ is common, equal to sum of squares of environmental indices.

$$\sum_j I^2_j = (I^2_1 + I^2_2 + \dots + I^2_j)$$

- ii. The $\sum_j Y_{ij} \cdot I_j$ for each genotype of environmental index (I_j) with the corresponding mean \overline{X} of that genotype at each environment.

These values were obtained in the following manner

$$\overline{X} (I_j) = (\sum_j Y_{ij} \cdot I_j) = (S)$$

\overline{X} = Matrix of means

(I_j) = Vector of environmental index

(S) = Vector for sum of products i.e. $\sum_j Y_{ij} \cdot I_j$

- iii. The b_i value for each genotype was thus calculated by dividing $\sum_j Y_{ij} \cdot I_j$ [as calculated above in (ii)] by $\sum_j I^2_j$ obtained above under (i)

Thus,

$$b_i = \frac{\sum_j Y_{ij} \cdot I_j}{\sum_j I^2_j}$$

3. Computation of S^2_{di}

In regression analysis it is possible to partition the variance of the dependent variable (Y) into two parts, the one which explains the linearity between dependent and independent variables (variance due to regression) and the other which explains the variance due to deviations from linearity.

Symbolically

$$\sigma^2_y = \sigma^2_{\text{regression}} + \sigma^2_{\text{deviation from regression}}$$

By subtracting the variance due to regression from σ^2_y one can get the variance due to deviation from regression which in turn can be used for estimating S^2_{di} values. The variance of means over different environments was obtained as follows.

$$\sigma^2 V_i = \sum_j Y_{ij}^2 - (Y_i^2 / s)$$

Where,

$\sum_j Y_{ij}^2$ = Sum of squares of mean of i^{th} genotype over j^{th} environment.

Y_i = Sum of means of i^{th} genotype over environments.

S = Number of environments

The variance due to deviations from regression $\sum_j \sigma^2_{ij}$ for a genotype being.

$$\text{Where, } \sum_j \sigma^2_{ij} = \left[\sum_j Y_{ij}^2 - \frac{Y_i^2}{S} \right] - \frac{(\sum_j Y_{ij} \cdot I_j)^2}{\sum_j I_j^2}$$

Where,

$(\sum_j Y_{ij} - Y_i^2 / S)$ = The variance due to dependent variable

And $(\sum_j Y_{ij} \cdot I_j)^2 / \sum_j I_j^2$ = The variance due to regression

Because,

$$\frac{(\sum_j Y_{ij} \cdot I_j)^2}{\sum_j I_j^2} = \frac{(\sum_j Y_{ij} \cdot I_j) (\sum_j Y_{ij} \cdot I_j)}{\sum_j I_j^2} = b_i \sum_j Y_{ij} \cdot I_j$$

Where,

b_i values have been calculated in (2) and

$\sum_j Y_{ij} \cdot I_j$ value in 2 (ii)

The $\sum_j \sigma^2_{ij}$ values may be computed as

$$\sum_j \sigma^2_{ij} = \sigma^2 V_i - b_i \sum_j Y_{ij} \cdot I_j$$

From $\sum_j \sigma^2_{ij}$, the stability parameter $S^2 d_i$ for each genotypes was computed as follows.

$$S^2 d_i = [\sum_j \sigma^2_{ij} / (S-2)] - (S^2 e / r)$$

3.3.2 Analysis of variance

The analysis of variance partitioned into three main parts.

- a. Sum of squares due to genotypes.
- b. Sum of squares due to environment + (genotype x environment)
- c. Pooled error

The sum of squares due to genotype x environment is further partitioned into two parts.

- i. S.S. due to genotype x environment (linear) which is infact S.S. due to regression.
- ii. S.S. due to deviation from linearity of response (i.e. S.S. due to pooled deviation).

The latter can be further partitioned into as many components as the number of genotypes with (s-2) degrees of freedom (s represents number of environments).

The analysis of variance table for stability parameter was constructed in tabulated form as,

Source	d.f.	S.S.	M.S.S.
Genotypes	(t-1)	$1/s \sum_i Y_i^2 - C.F.$	MS ₁
Environments	(s-1)	$1/t \sum_i Y_i^2 - C.F.$	MS ₂
Genotype x Environments	(t-1)(s-1)	$\sum_i \sum_j Y_{ij}^2 - C.F. - G.S.S. - E.S.S.$	MS ₃
Environment + Genotype x Environment)	t(s-1)	$\sum_i \sum_j Y_{ij}^2 - Y_i^2 - /S$	MS ₄
Environment (linear)	1	$1/t[(\sum_i Y_{ij} I_j)^2 / \sum_j I_j^2]$	
Genotype x Environment (linear)	(t-1)	$\sum_i (\sum_j Y_{ij} I_j)^2 / \sum_j I_j^2 - E(1)S.S.$	MS ₅
Pooled deviation	t(s-1)	$\sum_i \sum_j \sigma^2_{ij}$	MS ₆
Pooled error	s(r-1)(t-1)		MS ₇

Where,

- t = Number of genotype
 s = Number of environment
 r = Number of replication
 G.S.S. = S.S. due to genotypes
 E.S.S. = S.S. due to environment

S.S. due to genotypes, environment and genotype x environment were calculated as per the method of pooled analysis.

The M.S. pooled error was calculated as

$$(n_1 - 1) (\text{M.S. error } L_1) + \dots + (n_s - 1) (\text{M.S. errors})$$

$$(n_1 - 1) + (n_2 - 1) + \dots + (n_s - 1)$$

Where,

M.S. error L_s = Mean sum of squares due to error for s^{th} environment.

$n_1 - 1$ = Error d.f. in environmental 1

$n_2 - 1$ = Error d.f. in environment 2

The S.S. due to remaining sources were calculated as follows :

$$\text{S.S. due to environment (Gen. x Env.)} = \sum_{ij} \sum Y_{ij} - \sum_i Y_i^2 / t$$

in fact,

$$\text{S.S. (E + G x E)} = \text{S.S.E.} + \text{S.S.G. x E}$$

Where,

$$\text{S.S.E.} = 1/t (\sum_j Y_j \cdot I_j)^2 / E_j \cdot I_j^2$$

The Y_j and I_j values are already computed and by putting appropriate values we can get S.S. environment (linear) which can also be checked as,

S.S. Environment (linear)

$$= t \times \sum_j I_j^2$$

In fact,

S.S.G. x E (linear)

$$= \sum_j [\sum_j (Y_{ij} I_j)^2 / (\sum_j I_j)^2] - \text{S.S.E. (linear)}$$

$$= b_i \sum_j Y_{ij} I_j \text{ for each genotype}$$

Thus by taking simply the sum of these values over all the genotypes, the first part of S.S., G x E (linear) can be obtained.

S.S. due to pooled deviation is simply the sum of S.S. due to deviation for individual genotype for (s-2) degrees of freedom each.

3.3.3 Test of significance

- a. The significance of difference among genotypes were tested against the M.S.S. due to G x E interaction (MS_3). The genotypic differences were also tested against pooled deviation (MS_6).
- b. The G x E interaction (MS_3) was tested against effective pooled error.
- c. The components, environment (linear), G x E (linear) was tested against pooled deviation (MS_6).
- d. Pooled deviation was tested against effective pooled error (PE/r). Individual deviation from linear regression was tested as follows.

$$F = \frac{[(\sum_j \sigma^2_{ij}) / (S - 2)]}{\text{Pooled error}}$$

- e. Stable genotype i.e. test of significance for regression coefficient.

A genotype with unit regression coefficient ($b_i \approx 1$ or not significantly deviating from unity) and deviation not significantly deviating from zero ($S^2 d_i = 0$) is said to be stable one.

$$T \text{ test } b_i = \frac{|b_i - 1|}{\text{S.E. } (b_i)}$$

Where,

$$\text{SE } b_i = \sqrt{\frac{\text{MSS due to pooled deviation}}{\sum_j I_j^2}}$$

The significance of b_i values were tested by 't' test as against unity.

$$'t' \text{ test } b_i = \frac{|b_i - 1|}{\text{S.E. } (b_i)}$$

$$\text{Mean of } b_i = \sum_i b_i / t$$

Population mean and standard error are calculated as,

$$\text{Population mean } (\mu) = \frac{\text{Grand total}}{\text{No. of observations}}$$

$$\text{S.E. (Mean)} = \frac{\text{M.S. due to pooled deviation}}{\text{Number of environments} - 1}$$

4. EXPERIMENTAL RESULTS

The present investigation entitled “Genotype x Environment interaction studies in chickpea (*Cicer arietinum* L.)” was undertaken with a view to estimate stability parameters for seed yield and its important components and to identify most stable genotypes under different environment.

4.1 Analysis of variance

The analysis of variance (MSS) for 12 characters viz., days to 50 per cent flowering, days to maturity, plant height, plant spread, number of primary branches per plant, number of secondary branches per plant, pods per plant, seeds per pod, seed yield per plant (g), seed yield per plot (kg), 100 seed weight (g) and harvest index (%) was done. The analysis revealed that 8 genotypes exhibited highly significant differences for all the characters under study except plant spread, number of secondary branches per plant, seeds per pod and 100 seed weight in E₁ (1st October), E₂ (16th October), E₃ (1st November), E₄ (16th November), E₅ (1st December), E₆ (16th December), E₇ (1st January) and E₈ (16th January) (Table 2).

4.2 Response of various chickpea genotypes to changing environments

The mean values of the genotypes for different characters studied under eight sowing dates are presented in Table 1.

1. Days to 50 % flowering

In E₁ the genotype Phule G-06102 (42.67 days) was the earliest to flower which was at par with the Vijay (44.33 days). In E₂ the genotype Phule G-06102 (43.33) was earliest followed by Phule G-09103 (44 days). In E₃ the genotype Phule G-06102 (43.33 days) was the earliest to flower which was at par with the Phule G-09103 (45 days). In E₄ the genotype Vishal (49.67 days) was the earliest to flower followed by the genotype Phule G-06102 (51.67 days). In E₅ the genotype Phule G-06102 (44.33 days) was the earliest to flower which was at par with Phule G-0204-4 (48 days). In E₆ the genotype Vijay (46.00 days) was the earliest to flower followed by the genotype Phule G-07102 (46.33 days). In E₇ the genotypes Phule G-07102 and Vishal (40.67 days) were earliest followed by the genotype Vijay (41.33 days). However, in E₈ the genotype Phule G-09103 (34.33 days) was earliest followed by the genotypes Phule G-06102 and Vijay (35.67 days).

The genotype Phule G-06102 (44.21 days) was earliest than rest of all varieties over the eight environment followed by Phule G-09103 (45.21 days) which was at par with Vijay (45.58 days).

2. Days to maturity

The genotype Phule G-09103 (98 days) matured early in E₁, followed by Vishal (109.33 days). In E₂ the genotype Phule G-09103 took 97.67 days followed by Phule G-06102 (111 days). In E₃, the genotype Phule G-09103 (97 days) matured earlier than rest of the genotypes followed by Vishal (110 days). In E₄,

Table 1.(a) Mean performance of chickpea genotypes over different sowing dates

Sr. No.	Genotypes	Days to 50% flowering								
		E1	E2	E3	E4	E5	E6	E7	E8	Mean
1	Phule G-07102	46.00	48.67	53.00	53.00	52.00	46.33	40.67	38.00	47.21
2	Phule G-0204-4	45.00	48.33	53.00	58.67	48.00	49.67	43.33	38.00	48.00
3	Phule G-07101	50.00	51.00	58.33	64.00	53.00	52.00	45.00	40.67	51.75
4	Phule G-09103	44.67	44.00	45.00	53.33	48.67	47.67	44.00	34.33	45.21
5	Phule G-06102	42.67	43.33	43.33	51.67	44.33	48.67	44.00	35.67	44.21
6	Vijay (Ch)	44.33	48.67	45.67	54.00	49.00	46.00	41.33	35.67	45.58
7	Vishal(Ch)	47.00	50.33	50.00	49.67	51.33	51.00	40.67	38.67	47.33
8	Digvijay(Ch)	49.00	56.00	53.33	57.67	51.00	51.67	45.00	42.00	50.71
	Mean	46.08	48.79	50.21	55.25	49.67	49.13	43.00	37.88	47.50
	S.E.±	1.12	1.30	2.39	2.47	2.15	2.18	1.92	0.94	0.81
	CD @ 5%	2.41	2.78	5.13	5.30	4.62	4.67	4.12	2.02	
	C. V. %	2.98	3.25	5.83	5.48	5.31	5.43	5.47	3.04	

Table 1.(b) Mean performance of chickpea genotypes over different sowing dates

Sr. No.	Genotypes	Days to maturity								
		E1	E2	E3	E4	E5	E6	E7	E8	Mean
1	Phule G-07102	113.33	114.67	115.33	115.00	103.00	96.00	94.00	89.00	105.04
2	Phule G-0204-4	110.67	112.00	110.33	110.00	105.00	99.00	91.33	88.33	103.33
3	Phule G-07101	119.67	121.67	120.33	120.00	108.00	103.00	91.67	89.67	109.25
4	Phule G-09103	98.00	97.67	97.00	95.00	91.00	91.00	92.00	87.33	93.63
5	Phule G-06102	111.00	111.00	110.33	109.33	105.00	95.33	93.33	87.67	102.88
6	Vijay (Ch)	116.67	116.33	115.33	115.33	102.67	104.33	88.00	86.67	105.67
7	Vishal(Ch)	109.33	112.00	110.00	110.33	104.00	101.67	89.67	87.00	103.00
8	Digvijay(Ch)	119.67	121.00	119.33	119.00	106.33	99.00	90.67	88.00	107.88
	Mean	112.29	113.29	112.25	111.75	103.13	98.67	91.33	87.96	103.80
	S.E.±	2.55	1.76	1.85	1.83	1.00	2.29	2.24	1.25	0.60
	CD @ 5%	5.47	3.78	3.97	3.92	2.15	4.90	-	-	
	C. V. %	2.78	1.90	2.02	2.01	1.19	2.84	3.00	1.74	

the genotype Phule G-09103 (95 days) matured early followed by Phule G-06102 (109.33 days).

In E₅, the genotypes Phule G-09103 took 91 days followed by Vijay (102.67 days). The genotype Phule G-09103 (91 days) matured early in E₆, followed by Phule G-06102 (95.33 days). In E₇, the genotype Vijay (88 days) matured early which was at par with Vishal (89.67 days). Whereas, in E₈, the genotype Vijay (86.67) matured earlier followed by Vishal (87 days).

On overall mean basis, the genotype Phule G-09103 (93.63 days) matured earlier followed by Phule G-06102 (102.88 days).

3. Plant height (cm)

The genotype Phule G-07101 was the tallest (48.19 cm) among all the genotypes. It recorded the height of 46.13 cm in E₁, 50.20 cm in E₂, 50.93 cm in E₃, 50.67 cm in E₄, 56.87 cm in E₅, 45.53 cm in E₆, 47.73 cm in E₇ and 37.47 cm in E₈, and it was at par with Phule G-07102 (47.67 cm). The mean plant height was maximum in E₅ environment (53.84 cm) followed by E₃ (48.08 cm).

4. Plant spread (cm)

The genotype Phule G-07101 had recorded largest canopy coverage (17.42 cm) among all the genotypes and the plant spread recorded in E₁, E₂, E₃, E₄, E₅, E₆, E₇ and E₈ was 14.13, 14.27, 27.27, 20.73, 20.93, 14.67, 14.20, 13.13 cm, respectively. This was followed by Phule G-09103, second largest canopy coverage i.e. 17.38 cm. In E₁, the genotype Vishal (14.40 cm), in E₂ Phule G-06102 (16.40 cm), in E₃ Phule G-09103

Table 1.(c) Mean performance of chickpea genotypes over different sowing dates

Sr. No.	Genotypes	Plant height								
		E1	E2	E3	E4	E5	E6	E7	E8	Mean
1	Phule G-07102	46.33	53.87	52.73	54.33	58.60	38.33	39.87	37.27	47.67
2	Phule G-0204-4	38.47	40.27	50.47	46.07	51.87	43.67	40.87	34.00	43.21
3	Phule G-07101	46.13	50.20	50.93	50.67	56.87	45.53	47.73	37.47	48.19
4	Phule G-09103	45.60	41.73	49.07	44.67	50.87	38.73	45.13	43.20	44.88
5	Phule G-06102	38.87	43.67	44.47	50.67	52.07	40.27	38.40	39.13	43.44
6	Vijay (Ch)	37.67	34.60	38.47	41.13	50.13	41.33	41.33	35.80	40.06
7	Vishal(Ch)	40.67	37.87	50.93	44.20	56.00	40.67	39.00	35.53	43.11
8	Digvijay(Ch)	37.00	39.27	47.53	48.33	54.33	39.73	44.73	40.07	43.88
	Mean	41.34	42.68	48.08	47.51	53.84	41.03	42.13	37.81	44.30
	S.E.±	3.46	3.53	2.60	3.41	1.35	4.37	3.98	3.60	1.15
	CD @ 5%	7.42	7.57	5.59	7.30	2.89	-	-	-	
	C. V. %	10.25	10.13	6.63	8.78	3.07	13.05	11.56	11.67	

Table 1.(d) Mean performance of chickpea genotypes over different sowing dates

Sr. No.	Genotypes	Plant spread (cm)								
		E1	E2	E3	E4	E5	E6	E7	E8	Mean
1	Phule G-07102	10.00	12.40	19.93	18.93	22.07	14.60	14.60	12.73	15.66
2	Phule G-0204-4	13.33	14.40	22.20	20.47	21.60	16.93	16.47	12.60	17.25
3	Phule G-07101	14.13	14.27	27.27	20.73	20.93	14.67	14.20	13.13	17.42
4	Phule G-09103	12.80	14.73	31.07	17.27	20.53	15.53	14.73	12.40	17.38
5	Phule G-06102	12.87	16.40	28.00	16.33	20.53	13.27	15.13	14.40	17.12
6	Vijay (Ch)	13.93	15.13	23.40	18.73	21.33	14.93	14.27	12.93	16.83
7	Vishal(Ch)	14.40	12.40	25.27	17.73	21.73	16.07	13.80	13.20	16.83
8	Digvijay(Ch)	12.73	12.07	19.07	22.87	20.37	13.33	16.07	16.53	16.63
	Mean	13.03	13.98	24.53	19.13	21.14	14.92	14.91	13.49	16.89
	S.E.±	1.51	2.31	3.65	1.86	2.58	2.15	2.26	2.38	0.69
	CD @ 5%	0.05	0.25	0.01	0.01	0.98	0.39	0.78	0.42	
	C. V. %	14.19	20.20	18.20	11.92	14.94	17.61	18.60	21.62	

(31.06 cm), in E₄ Digvijay (22.87 cm), in E₅ Phule G-07102 (22.07 cm), in E₆ Phule G-0204-4 (16.93 cm), in E₇ Phule G-0204-4 (16.47 cm) and in E₈ Digvijay (16.53 cm), had recorded maximum canopy coverage. On overall mean basis, largest canopy coverage was recorded in E₃ (24.53 cm) followed by E₅ (21.14 cm).

5. Number of primary branches per plant

In E₁, Vishal (6.47), in E₂, Phule G-06102 (3.00), in E₃, Vijay (3.4), in E₄ Phule G-07102 (3.73), in E₅ Phule G-07102 (4.8), in E₆, Phule G-07102 (4.13), in E₇, Phule G-09103 (2.93) and in E₈, the genotype Phule G-06102 (2.33) produced maximum number of primary branches per plant. The genotype Phule G-07102 (3.58) which was at par with Phule G-07101 (3.45) recorded maximum number of primary branches per plant over the eight environments. Highest number of primary branches were recorded in E₁ (5.12) followed by E₅ (4.01).

6. Number of secondary branches per plant

The genotype Phule G-09103 (15.20) in E₁ which was at par with Phule G-06102 (15.07) while genotypes Phule G-06102 (14.60) in E₂, Phule G-07101 (20.60) in E₃, Phule G-07101 (19.87) in E₄, Phule G-06102 (15.33) in E₅, Phule G-07102 (11.67) in E₆, Phule G-09103 (12.53) in E₇ and Phule G-06102 (13.47) in E₈ produced the highest number of secondary branches per plant.

On the basis of pooled mean, the genotype Phule G-07101 (14.17) produced highest number of secondary branches followed by Phule G-07102 (13.68) which was at par with Phule

Table 1.(e) Mean performance of chickpea genotypes over different sowing dates

Sr. No.	Genotypes	Primary branches per plant (No.)								
		E1	E2	E3	E4	E5	E6	E7	E8	Mean
1	Phule G-07102	4.93	2.73	3.27	3.73	4.80	4.13	2.70	2.30	3.58
2	Phule G-0204-4	4.93	2.40	3.00	2.53	3.60	2.37	2.53	2.00	2.92
3	Phule G-07101	5.93	2.67	3.20	3.00	4.60	3.20	2.80	2.23	3.45
4	Phule G-09103	5.27	2.60	3.13	2.73	3.60	2.73	2.93	2.07	3.13
5	Phule G-06102	5.07	3.00	3.00	3.00	4.13	3.00	2.60	2.33	3.27
6	Vijay (Ch)	4.27	2.27	3.40	2.60	3.93	3.47	2.20	2.10	3.03
7	Vishal(Ch)	6.47	2.40	2.80	2.47	3.93	3.13	2.53	2.13	3.23
8	Digvijay(Ch)	4.07	2.60	3.27	3.00	3.47	3.20	2.87	2.03	3.06
	Mean	5.12	2.58	3.13	2.88	4.01	3.15	2.65	2.15	3.20
	S.E.±	0.89	0.19	0.17	0.40	0.32	0.41	0.37	0.22	0.11
	CD @ 5%	0.06	0.01	0.01	0.02	0.00	0.00	0.31	0.46	
	C. V. %	21.21	8.88	6.59	16.92	9.83	15.82	17.04	12.71	

Table 1.(f) Mean performance of chickpea genotypes over different sowing dates

Sr. No.	Genotypes	Secondary branches per plant (No.)								
		E1	E2	E3	E4	E5	E6	E7	E8	Mean
1	Phule G-07102	13.27	12.47	18.53	16.33	14.87	11.67	10.87	11.40	13.68
2	Phule G-0204-4	13.53	11.67	16.40	15.87	12.53	9.40	11.67	11.40	12.81
3	Phule G-07101	13.40	13.60	20.60	19.87	13.53	9.80	10.53	12.00	14.17
4	Phule G-09103	15.20	13.67	18.20	13.27	13.33	9.27	12.53	13.20	13.58
5	Phule G-06102	15.07	14.60	17.67	16.13	15.33	6.33	10.73	13.47	13.67
6	Vijay (Ch)	14.53	12.00	16.47	15.87	14.00	10.87	11.40	13.27	13.55
7	Vishal(Ch)	14.60	11.80	13.13	14.67	13.87	8.13	10.53	13.27	12.50
8	Digvijay(Ch)	13.00	11.93	16.60	18.33	10.67	8.73	11.67	12.07	12.88
	Mean	14.08	12.72	17.20	16.29	13.52	9.28	11.24	12.51	13.35
	S.E.±	9.41	10.05	19.65	13.31	14.57	17.76	27.47	17.22	0.48
	CD @ 5%	0.11	0.02	0.13	0.01	0.06	0.01	0.96	0.58	
	C. V. %	9.41	10.05	19.65	13.31	14.57	17.76	27.47	17.22	

G-06102 (13.67) and Phule G-09103 (13.59). Highest number of secondary branches were recorded in E₃ (17.20) followed by E₄ (16.29).

7. Number of pods per plant

In E₈, the genotype Digvijay (34.53) recorded the highest pods per plant followed by Phule G-06102 (34.40). In E₇, highest pods per plant were produced by the genotype Phule G-09103 (36.40), followed by Digvijay (32.00). In E₆, the genotype Phule G-07101 (49.93) recorded the highest pods per plant followed by Vijay (37.67). In E₅, highest pods per plant were produced by the genotype Phule G-07102 (46.47) followed by Phule G-09103 (45.00). In E₄, the genotype Vijay (56.93) recorded the highest pods per plant followed by Phule G-07102 (55.20). In E₃, highest pods per plant were produced by the genotype Phule G-06102 (60.73) followed by Vishal (59.60). In E₂, the genotype Phule G-06102 (65.33) recorded the highest pods per plant followed by Phule G-09103 (60.80). However in E₁, highest pods per plant were produced by the genotype Phule G-09103 (66.60) followed by Vishal (65.73).

On overall mean performance basis, the genotype Phule G-09103 (47.70) followed by Phule G-06102 (45.24) produced maximum number of pods per plant. For pods/plant, first environment (E₁) was superior (56.05) followed by the third environment (55.17) i.e. E₃.

8. Seeds per pod

The genotypes Phule G-07102 (1.59) in E₁, Phule G-07101 (1.23) in E₂, Phule G-07102 (1.24) in E₃, Phule G-07102

Table 1.(g) Mean performance of chickpea genotypes over different sowing dates

Sr. No.	Genotypes	Pods per plant (No.)								
		E1	E2	E3	E4	E5	E6	E7	E8	Mean
1	Phule G-07102	52.47	38.67	46.07	55.20	46.47	28.00	24.87	29.53	40.16
2	Phule G-0204-4	50.40	35.80	55.00	47.53	42.27	34.33	25.40	25.27	39.50
3	Phule G-07101	52.60	50.80	55.67	53.27	44.13	49.93	22.93	29.73	44.88
4	Phule G-09103	66.60	60.80	55.60	49.67	45.00	36.13	36.40	31.40	47.70
5	Phule G-06102	47.40	65.33	60.73	49.93	43.40	29.40	31.33	34.40	45.24
6	Vijay (Ch)	60.93	45.13	50.67	56.93	44.53	37.67	28.53	26.83	43.90
7	Vishal(Ch)	65.73	35.73	59.60	48.80	43.80	30.87	28.67	24.60	42.23
8	Digvijay(Ch)	52.27	40.27	58.00	49.33	42.67	28.27	32.00	34.53	42.17
	Mean	56.05	46.57	55.17	51.33	44.03	34.33	28.77	29.54	43.22
	S.E.±	7.27	6.09	4.78	3.43	3.18	5.36	5.72	4.39	2.20
	CD @ 5%	15.60	13.07	10.25	7.35	-	11.50	-	-	
	C. V. %	15.89	16.03	10.61	8.18	8.86	19.14	24.36	18.18	

Table 1.(h) Mean performance of chickpea genotypes over different sowing dates

Sr. No.	Genotypes	Seeds per pod (No.)								
		E1	E2	E3	E4	E5	E6	E7	E8	Mean
1	Phule G-07102	1.59	1.21	1.24	1.05	1.36	1.13	1.15	1.29	1.25
2	Phule G-0204-4	1.36	1.07	1.09	1.03	1.25	1.13	1.17	1.12	1.15
3	Phule G-07101	1.38	1.23	1.13	1.01	1.21	1.12	1.23	1.09	1.18
4	Phule G-09103	1.48	1.08	1.05	0.75	1.20	1.15	1.13	1.09	1.12
5	Phule G-06102	1.09	1.03	1.16	1.03	1.37	1.27	1.12	1.11	1.15
6	Vijay (Ch)	1.25	1.03	1.05	1.04	1.15	1.11	1.13	1.31	1.13
7	Vishal(Ch)	1.40	1.12	1.11	1.04	1.23	1.16	1.20	1.36	1.20
8	Digvijay(Ch)	1.21	1.16	1.07	1.04	1.37	1.13	1.21	1.17	1.17
	Mean	1.35	1.12	1.11	1.00	1.27	1.15	1.17	1.19	1.17
	S.E.±	0.13	0.08	0.09	0.17	0.11	0.09	0.10	0.13	0.02
	CD @ 5%	0.28	0.17	-	-	-	-	-	-	
	C. V. %	11.85	8.91	9.67	20.29	10.13	9.47	10.26	13.10	

(1.05) in E₄, Digvijay (1.37) in E₅, Phule G-06102 (1.27) in E₆, Phule G-07101 (1.23) in E₇ and Vishal (1.36) in E₈ recorded the highest seeds per pod.

Over the eight environments, genotype Phule G-07102 (1.25) recorded the highest seeds per pod followed by Vishal (1.2) which was at par with Phule G-07101 (1.18) and Digvijay (1.17). Highest number of seeds per pod were recorded in E₁ (1.35) followed by E₅ (1.27).

9. 100 seed weight (g)

The genotype Phule G-0204-4 recorded the highest 100 seed weight (30.99 g) in E₁ and genotypes Vishal (29.22 g) in E₂, Phule G-0204-4 (30.86 g) in E₃, Phule G-0204-4 (30.96 g) in E₄, Vishal (29.52 g) in E₅, Vishal (31.79 g) in E₆, Phule G-0204-4 (29.17 g) in E₇ and Vishal (24.72 g) in E₈ recorded highest 100 seed weight.

On the basis of mean performance over all environments, the genotype Vishal (29.19 g) recorded highest 100 seed weight followed by Phule G-0204-4 (28.92 g).

10. Seed yield per plant (g)

The genotype Vishal (26.13 g) in E₁, Phule G-06102 (17.83 g) in E₂, Phule G-09103 (23.47 g) in E₃, Phule G-06102 (24.80 g) in E₄, Phule G-07102 (26.04 g) in E₅, Vijay (13.83 g) in E₆, Phule G-09103 (12.80 g) in E₇ and Phule G-07102 (9.47 g) in E₈ recorded the highest seed yield per plant.

Over the eight environments, genotype Phule G-07102 recorded the highest seed yield per plant (15.90 g) followed by Phule G-09103 (15.63 g) which was at par with Phule G-06102

Table 1.(i) Mean performance of chickpea genotypes over different sowing dates

Sr. No.	Genotypes	100 seed weight (g)								
		E1	E2	E3	E4	E5	E6	E7	E8	Mean
1	Phule G-07102	24.14	27.56	25.84	24.36	23.73	24.67	23.70	18.75	24.09
2	Phule G-0204-4	30.99	27.93	30.86	30.96	28.79	30.11	29.17	22.57	28.92
3	Phule G-07101	25.18	25.46	23.76	22.53	22.31	24.49	21.76	17.67	22.90
4	Phule G-09103	26.33	27.72	26.29	25.96	24.74	22.23	24.55	21.47	24.91
5	Phule G-06102	25.33	26.08	26.94	23.77	26.23	27.23	23.57	22.47	25.20
6	Vijay (Ch)	19.91	19.66	21.66	19.53	19.50	19.39	19.25	17.54	19.56
7	Vishal(Ch)	30.97	29.22	29.66	28.60	29.52	31.79	29.01	24.72	29.19
8	Digvijay(Ch)	24.75	24.40	24.37	25.64	23.97	26.91	24.79	23.06	24.74
	Mean	25.95	26.00	26.17	25.17	24.85	25.85	24.48	21.03	24.93
	S.E.±	1.27	2.07	1.07	1.58	0.64	2.57	1.35	1.03	0.42
	CD @ 5%	2.72	4.44	2.29	3.39	1.38	5.50	2.88	2.20	
	C. V. %	5.99	9.76	4.99	7.69	3.17	12.16	6.73	5.98	

Table 1.(j) Mean performance of chickpea genotypes over different sowing dates

Sr. No.	Genotypes	Seed yield per plant (g)								
		E1	E2	E3	E4	E5	E6	E7	E8	Mean
1	Phule G-07102	18.60	11.23	18.97	20.97	26.04	10.17	11.77	9.47	15.90
2	Phule G-0204-4	21.60	11.10	17.90	13.60	20.27	12.50	10.00	5.43	14.05
3	Phule G-07101	18.17	16.07	19.17	15.33	21.57	10.60	10.30	5.07	14.53
4	Phule G-09103	24.03	17.53	23.47	14.97	18.77	7.93	12.80	5.57	15.63
5	Phule G-06102	13.53	17.83	19.97	24.80	23.67	9.13	9.63	5.83	15.55
6	Vijay (Ch)	18.17	11.50	13.43	13.43	14.73	13.83	8.73	4.90	12.34
7	Vishal(Ch)	26.13	11.57	16.73	15.07	23.03	8.80	8.87	6.17	14.55
8	Digvijay(Ch)	21.53	13.47	17.37	23.50	21.43	9.30	11.07	5.20	15.36
	Mean	20.22	13.79	18.38	17.71	21.19	10.28	10.40	5.95	14.73
	S.E.±	3.78	2.15	4.14	2.91	3.09	1.80	2.27	0.95	1.07
	CD @ 5%	8.10	4.62	-	6.23	6.63	3.86	-	2.05	
	C. V. %	22.87	19.11	27.61	20.10	17.86	21.42	26.77	19.63	

(15.55 g) and Digvijay (15.36 g). On the mean performance basis over eight environments maximum seed yield per plant was recorded in fifth environment (21.19 g) followed by first (20.22 g) and third environment (18.38 g).

11. Seed yield per plot (kg)

The genotype Phule G-07102 (2.05 kg) produced the highest seed yield per plot followed by the genotype Phule G-09103 (1.89 kg) over all eight environment.

In E₁ the genotype Phule G-07101 (2.55 kg), in E₂ the genotype Phule G-07102 (2.54 kg), in E₃ the genotype Phule G-09103 (2.74 kg), in E₄ the genotype Digvijay (2.87 kg), in E₅ the genotype Phule G-07102 (2.29 kg), in E₆ the genotype Vishal (1.55 kg), in E₇ the genotype Phule G-07102 (1.63 kg) and in E₈ the genotype Digvijay (1.19 kg) produced the highest seed yield per plot.

Environment E₃ (2.43 kg) was favourable for the seed yield per plot followed by E₄ (2.29 kg).

12. Harvest index (%)

The genotype Phule G-07101 recorded highest harvest index (38.92 %) in E₁ and genotypes Phule G-06102 (32.56), Phule G-07102 (49.17), Vijay (43.00), Phule G-07102 (49.79), Vishal (45.16), Vishal (46.56), Vishal (46.13) recorded highest harvest index in E₆, E₇ and E₈, respectively.

On the basis of mean performance over all environments, the genotype Phule G-06102 (38.45) recorded highest harvest index which was at par with Digvijay (38.37). On the mean performance basis over eight environment highest harvest index percentage was recorded in fifth environment i.e. E₅ (41.18 %) followed by eighth environment i.e. E₈ (41.13 %).

Table 1.(k) Mean performance of chickpea genotypes over different sowing dates

Sr. No.	Genotypes	Seed yield per plot (kg)								
		E1	E2	E3	E4	E5	E6	E7	E8	Mean
1	Phule G-07102	2.51	2.54	2.53	2.63	2.29	2.51	1.63	0.75	2.05
2	Phule G-0204-4	1.87	2.39	2.49	2.10	1.74	1.14	1.16	1.09	1.75
3	Phule G-07101	2.55	2.40	2.32	2.25	2.00	1.01	1.30	1.01	1.85
4	Phule G-09103	2.53	2.17	2.74	2.31	1.86	1.20	1.38	0.96	1.89
5	Phule G-06102	2.00	2.53	2.20	2.15	1.59	1.42	0.98	0.74	1.70
6	Vijay (Ch)	1.87	1.88	2.32	1.93	1.84	1.37	1.22	1.18	1.70
7	Vishal (Ch)	1.86	1.91	2.57	2.05	1.94	1.56	1.08	0.74	1.71
8	Digvijay (Ch)	2.01	2.04	2.26	2.88	2.02	1.47	1.09	1.19	1.87
	Mean	2.15	2.23	2.43	2.29	1.91	1.34	1.23	0.96	1.81
	S.E.±	0.26	0.22	0.31	0.23	0.19	0.16	0.15	0.12	0.07
	CD @ 5%	0.59	0.48	-	0.50	0.42	0.34	0.32	0.26	
	C. V. %	14.82	12.30	15.67	12.35	12.49	14.67	14.96	15.23	

Table 1.(l) Mean performance of chickpea genotypes over different sowing dates

Sr. No.	Genotypes	Harvest index (%)								
		E1	E2	E3	E4	E5	E6	E7	E8	Mean
1	Phule G-07102	23.17	22.84	49.17	40.27	49.79	37.64	34.54	39.65	37.13
2	Phule G-0204-4	30.76	28.16	33.43	35.93	38.56	43.62	34.92	35.71	35.14
3	Phule G-07101	38.92	28.59	32.97	35.00	45.35	43.55	26.39	38.93	36.21
4	Phule G-09103	31.60	29.78	28.17	28.83	42.92	31.72	30.57	45.15	33.59
5	Phule G-06102	31.81	32.56	44.43	42.50	41.96	44.55	30.92	38.83	38.45
6	Vijay (Ch)	28.75	25.41	26.33	43.00	29.88	35.95	38.85	45.66	34.23
7	Vishal(Ch)	28.56	29.26	28.90	30.17	36.97	45.16	46.56	46.13	36.46
8	Digvijay(Ch)	32.82	32.29	39.50	41.30	44.04	41.57	36.48	38.97	38.37
	Mean	30.80	28.61	35.36	37.13	41.18	40.47	34.90	41.13	36.20
	S.E.±	3.85	5.08	2.86	4.32	5.04	6.18	5.06	2.95	2.06
	CD @ 5%	8.25	-	6.14	9.26	10.82	-	10.86	6.33	
	C. V. %	15.29	21.75	9.92	14.24	15.00	18.71	17.77	8.79	

Table 1(m) Mean performance of chickpea genotypes over different sowing dates

Sr. No.	Genotypes	Seed yield (kg/ha)								
		E1	E2	E3	E4	E5	E6	E7	E8	Mean
1	Phule G-07102	3486	3538	3518	3657	3191	2107	2274	1042	2852
2	Phule G-0204-4	2607	3320	3459	2927	2427	1588	1621	1524	2434
3	Phule G-07101	3546	3343	3227	3129	2782	1407	1810	1399	2581
4	Phule G-09103	3518	3010	3806	3213	2588	1667	1913	1329	2631
5	Phule G-06102	2778	3518	3060	2986	2209	1972	1361	1028	2364
6	Vijay (Ch)	2593	2611	3222	2677	2560	1903	1699	1643	2364
7	Vishal(Ch)	2588	2657	3570	2847	2695	2163	1504	1024	2381
8	Digvijay(Ch)	2788	2838	3135	3996	2802	2038	1514	1657	2596
	Mean	2988	3104	3375	3179	2657	1856	1713	1331	2514

4.3 Stability analysis

4.3.1 Analysis of variance (Pooled)

The analysis of variance representing the mean sum of square due to different sources of variation as per Eberhart and Russell (1966) for the 12 characters is presented in Table 2.

Pooled analysis of variance over eight different environment showed that, environmental variance were significant for all the characters viz., days to 50 % flowering, days to maturity, plant height, plant spread, primary branches per plant, secondary branches per plant, pods per plant, seeds per pod, 100 seed weight, seed yield per plant and harvest index, when tested against G x E interaction, pooled deviation and pooled error. Genotypic variances were found significant for the characters viz., days to 50 % flowering, days to maturity, plant height, primary branches per plant and 100 seed weight when tested against G x E interaction. Genotypic variances were found significant for the characters viz., days to 50 % flowering, days to maturity, plant height, primary branches per plant, seeds per pod and 100 seed weight, when tested against pooled deviation. Genotypic variances were also found significant for the characters viz., days to 50 % flowering, days to maturity, plant height, primary branches per plant, pods per plant, seeds per pod, 100 seed weight. Seed yield per plant and harvest index, when tested against pooled error.

G x E interactions were significant for the traits viz., days to maturity and primary branches per plant when tested

Table 2. : ANOVA for stability as per Eberhart and Russell Model (1966) in Chickpea

Sr. No.	Sources	G	E	G x E	E+ G x E	E (L)	G x E (L)	P.D. (Pooled deviation)	P.E. (Pooled error)
1	Days to 50% flowering	55.40 ++ ** ##	218.62 ++ ** ##	5.41 ##	32.07 ++ ** ##	1530.39 ** ##	6.04 ##	4.65 **	1.79
2	Days to maturity	178.93 ++ ** ##	834.25 ++ ** ##	13.50 ** ##	116.09 ++ ** ##	5839.80 ** ##	74.33 ** ##	2.94 *	1.82
3	Plant height (cm)	55.23 ++ ** ##	210.81 ++ ** ##	11.06 ##	36.03 ++ ** ##	1475.69 ** ##	13.40 #	9.34 *	5.78
4	Plant spread (cm)	2.62	141.91 ++ ** ##	4.02	21.26 ++ ** ##	993.38 ** ##	5.54	3.29	2.69
5	Primary branches per plant(No.)	0.39 + ** ##	7.11 ++ ** ##	0.15 * ##	1.02 ++ ** ##	49.78 ** ##	0.44 ** ##	0.09	0.09
6	Secondary branches per plant (No.)	2.52	52.79 ++ ** ##	2.04	8.38 ++ ** ##	369.51 ** ##	3.41	1.59	1.68
7	Pods per plant (No.)	60.23 ##	983.14 ++ ** ##	35.23 ##	153.72 ++ ** ##	6882.01 ** ##	12.51	34.14 **	13.47
8	Seeds per pod (No.)	0.01 * #	0.08 ++ ** ##	0.00	0.01 ++ ** ##	0.61 ** ##	0.01 * #	0.00	0.00
9	100 seed weight (g)	77.60 ++ ** ##	22.93 ++ ** ##	1.73	4.38 ++ ** ##	160.52 ** ##	3.39 * #	1.27	1.21
10	Seed yield per plant (g)	10.84 #	240.54 ++ ** ##	8.95 ##	37.90 ++ ** ##	1683.81 ** ##	6.80	8.14 *	3.95
11	Seed yield per plot (kg)	0.12 + * ##	2.51 ++ ** ##	0.05 ##	0.35 ++ ** ##	17.63 ** ##	0.05 #	0.04 **	0.02
12	Harvest index (%)	25.72 #	179.83 ++ ** ##	30.83 ##	49.45 * ##	1258.86 ** ##	11.68	29.78 **	10.34

+, ++ = Significant at 5 and 1 % level of significance, respectively against G x E

*, ** = Significant at 5 and 1% level of significance, respectively against the pooled deviation (PD)

#, ## = Significant at 5 and 1% level of significance, respectively against the pooled error (PE)

against pooled deviation. G x E interaction were also found significant for the traits viz., days to 50 % flowering, days to maturity, plant height, primary branches per plant, pods per plant, seed yield per plant and harvest index, when tested against pooled error.

Pooled deviation effects were significant for the traits viz., days to 50 per cent flowering, days to maturity, plant height, pods per plant, seed yield per plant and harvest index when tested against pooled error. Partitioning of G x E interaction showed that, G x E (linear) effect were significant for the characters viz., days to maturity, primary branches per plant, seeds per pod and 100 seed weight when tested against pooled deviation and pooled error. Environment (linear) effects were also significant for all the traits when tested against pooled deviation and pooled error.

4.4 Estimates of environmental indices

Estimates of environmental indices (I_j) are presented in Table, which revealed that environment E₁ (1st October) was favourable for all characters i.e. days to 50 % flowering, primary branches per plant, secondary branches per plant, pods per plant, seeds per pod, 100 seed weight, seed yield per plant, seed yield per plot except days to maturity, plant height, plant spread and harvest index.

Environment E₂ (16th October) was favourable for characters viz., pods per plant, 100 seed weight and seed yield per plot.

Table 3. Estimation of environment index (I_j) under different environments

Sr. No.	Genotypes	Environmental index (I _j)							
		E1	E2	E3	E4	E5	E6	E7	E8
1	Days to 50% flowering	-1.42	1.29	2.71	7.75	2.17	1.63	-4.50	-9.63
2	Days to maturity	8.46	9.46	8.42	7.92	-0.71	-5.17	-12.50	-15.88
3	Plant height (cm)	-2.96	-1.62	3.77	3.21	9.54	-3.27	-2.17	-6.50
4	Plant spread (cm)	-3.86	-2.91	7.64	2.24	4.25	-1.97	-1.98	-3.40
5	Primary branches per plant(No.)	1.91	-0.63	-0.08	-0.33	0.80	-0.06	-0.56	-1.06
6	Secondary branches per plant (No.)	0.72	-0.64	3.85	2.94	0.16	-4.08	-2.11	-0.85
7	Pods per plant (No.)	12.83	3.34	11.94	8.11	0.81	-8.90	-14.46	-13.69
8	Seeds per pod (No.)	0.18	-0.05	-0.06	-0.17	0.10	-0.02	0.00	0.02
9	100 seed weight (g)	1.01	1.07	1.23	0.23	-0.09	0.92	-0.46	-3.91
10	Seed yield per plant (g)	5.48	-0.95	3.64	2.97	6.45	-4.46	-4.34	-8.79
11	Seed yield per plot (kg)	0.33	0.42	0.61	0.47	0.10	-0.48	-0.59	-0.86
12	Harvest index (%)	-5.40	-7.59	-0.84	0.93	4.99	4.27	-1.29	4.93

Environment E₃ (1st November) was favourable for characters viz., plant height, plant spread, secondary branches per plant, pods per plant, 100 seed weight, seed yield per plant and seed yield per plot.

Environment E₄ (16th November) was favourable for characters viz., plant height, plant spread, secondary branches per plant, pods per plant, 100 seed weight, seed yield per plant, seed yield per plot and harvest index.

Environment E₅ (1st December) was favourable for characters viz., days to maturity, plant height, plant spread, primary branches per plant, secondary branches per plant, pods per plant, seeds per pod, seed yield per plant, seed yield per plot and harvest index.

Environment E₆ (16th December) was favourable for characters viz., days to maturity, 100 seed weight and harvest index.

Environment E₇ (1st January) was favourable for days to 50 per cent flowering and days to maturity.

Environment E₈ (16th January) was favourable for days to 50 per cent flowering, days to maturity, seeds per pod and harvest index.

In general environment E₃ was most favourable for yield and yield contributing characters.

4.5 Stability parameters for individual characters

Since G x E interaction was detected for all the characters, the stability parameters in respect of these traits were estimated and were presented in Table 4(a) to 4(d). The non-significant b_i values were considered as around unity irrespective of their high or low numerical values.

1. Days to 50 per cent flowering (No.)

Mean days to 50 per cent flowering ranged from 44.21 (Phule G-06102) to 51.75 (Phule G-07101) with a population mean of 47.50 days over eight environments. Five genotypes had mean values lower than the population mean, which is desirable for earliness.

The genotypes Phule G-07102, Phule G-07101, Phule G-09103, Phule G-06102, Vishal, Digvijay exhibited significant deviation from regression (S^2_{di}) indicting their unpredictability for this trait. None of the genotype recorded significant regression coefficient (b_i) for this trait.

The genotype Vijay had regression coefficient (1.01) near to unity, with non-significant S^2_{di} (0.59) and less mean performance (45.59) than population mean (47.50) indicating its general adaptability to earliness.

2. Days to maturity (No.)

The days to maturity ranged from 93.63 (Phule G-09103) to 109.25 (Phule G-7101) days with a population mean of 103.83 days. Four genotypes had mean value lower than the population mean which is desirable for earliness. Two genotypes

Table 4(a) Estimates of stability parameters for days to 50 % flowering and days to maturity

Sr. No.	Genotype	Days to 50% flowering			Days to maturity		
		\bar{X}	bi	S ² di	\bar{X}	bi	S ² di
1	Phule G-07102	47.21	1.00	3.45**	105.04	1.05	2.35*
2	Phule G-0204-4	48.00	1.15	1.21	103.33	0.91	-0.60
3	Phule G-07101	51.75	1.33	3.07*	109.25	1.3**	-1.14
4	Phule G-09103	45.21	0.96	3.31**	93.63	0.34**	1.40
5	Phule G-06102	44.21	0.77	4.84**	102.88	0.90	1.66
6	Vijay (Ch)	45.58	1.01	0.59	105.67	1.21	4.35**
7	Vishal(Ch)	47.33	0.82	5.08**	103.00	0.93	1.94
8	Digvijay(Ch)	50.71	0.95	2.05*	107.88	1.35**	-0.62
	Mean	47.50			103.83		
	S.E.±	0.81	0.15		0.60	0.10	

Table 4(b) Estimates of stability parameters for Plant height (cm) and primary branches per plant (No.)

Sr. No.	Genotype	Plant height (cm)			Primary branches per plant (No.)		
		\bar{X}	bi	S ² di	\bar{X}	bi	S ² di
1	Phule G-07102	47.67	1.38	15.89**	3.58	0.95	0.10
2	Phule G-0204-4	43.21	1.09	-0.68	2.92	0.97	-0.06
3	Phule G-07101	48.19	0.99	-0.71	3.45	1.28*	-0.10
4	Phule G-09103	44.88	0.57	0.37	3.13	0.99	-0.05
5	Phule G-06102	43.44	0.93	0.15	3.27	0.93	-0.08
6	Vijay (Ch)	40.06	0.71	4.74	3.03	0.82	0.01
7	Vishal(Ch)	43.11	1.29	-1.01	3.23	1.46*	0.02
8	Digvijay(Ch)	43.88	1.04	0.29	3.06	0.6*	-0.07
	Mean	44.30			3.20		
	S.E.±	1.15	0.22		0.11	0.12	

*,** = Significant at 5 and 1% level of significance, respectively

viz., Phule G-07102 and Vijay had significant values of S^2_{di} indicting their unpredictability for this trait.

The genotype Phule G-0204-4, Phule G-06102 and Vishal recorded lower mean performance (103.33, 102.87, 103.00 days, respectively), non-significant S^2_{di} (-0.60, 1.66, 1.94, respectively) and non-significant regression coefficient close to unity (0.91, 0.90, 0.93, respectively) indicating their general adaptability for this trait i.e. these genotypes perform better under all environments.

The genotype Phule G-09103 recorded lower mean performance (93.63), regression coefficient ($b_i = 0.34$) significantly lower than unity and non-significant deviation from regression ($S^2_{di} = 1.40$) indicating their stability for poor environment i.e. above average stability.

3. Plant height (cm)

The stability parameters presented in Table 4 revealed that, plant height ranged from 40.06 cm (Vijay) to 48.19 cm (Phule G-07101) with the population mean of 44.30 cm. The genotype Phule G-07102 had significant value of S^2_{di} indicating its unpredictability for this trait. None of the genotype recorded significant regression coefficient (b_i) for this trait.

The genotypes Phule G-07101 and Phule G-09103 exhibited higher mean (48.19, 44.88, respectively), non-significant regression coefficient ($b_i = 0.99, 0.57$, respectively) close to unity and non-significant deviation from regression ($S^2_{di} = -0.71, 0.37$, respectively) values indicating their average stability for this trait.

4. Primary branches per plant (No)

Primary branches per plant ranged from 2.92 (Phule G-0204-4) to 3.58 (Phule G-07102) with population mean of 3.20.

The genotypes Phule G-07102 (3.58), Phule G-06102 (3.27) and Vishal (3.23) exhibited superior mean than population mean (3.20), non significant regression coefficient ($b_i = 0.95, 0.93$, respectively) close to unity with non-significant S^2_{di} (0.10, -0.08, respectively) indicating their average stability i.e. suitable for all environments.

The genotypes Phule G-07101 and Vishal recorded high mean performance (3.45 and 3.23, respectively), regression coefficient ($b_i = 1.28$ and 1.46 respectively) significantly greater than unity and non-significant deviation from regression ($S^2_{di} = -0.10$ and 0.02 , respectively) indicating their stability for favourable environment i.e. below average stability.

5. Pods per plant (No.)

The number of pods per plant ranged from 39.50 (Phule G-0204-4) to 47.70 (Phule G-09103), four genotypes viz., Phule G-07101 (44.88), Phule G-09103 (47.70), Phule G-06102 (45.24) and Vijay (43.90) produced more number of pods than the population mean (43.22).

The genotypes Phule G-07101, Phule G-09103, Phule G-06102 and Vishal exhibited significant values of S^2_{di} (33.37, 22.93, 65.78 and 20.86, respectively) indicating their unpredictability for the given character.

Table 4(c) Estimates of stability parameters for Pods per plant (No.) and Seeds yield per plant (g)

Sr. No.	Genotype	Pods per plant (No.)			Seed yield per plant (g)		
		\bar{X}	bi	S ² di	\bar{X}	bi	S ² di
1	Phule G-07102	40.16	0.96	12.23	15.90	1.00	3.44
2	Phule G-0204-4	39.50	0.96	-0.25	14.05	0.94	0.22
3	Phule G-07101	44.88	0.92	33.37**	14.53	0.96	-1.73
4	Phule G-09103	47.70	1.03	22.93*	15.63	1.07	7.55*
5	Phule G-06102	45.24	0.94	65.78**	15.55	1.06	14.93**
6	Vijay (Ch)	43.90	1.07	0.68	12.34	0.62	1.15
7	Vishal(Ch)	42.23	1.26	20.86*	14.55	1.21	3.60
8	Digvijay(Ch)	42.17	0.87	5.28	15.36	1.15	0.74
	Mean	43.22			14.73		
	S.E.±	2.20	0.19		1.07	0.19	

*,** = Significant at 5 and 1% level of significance, respectively

Table 4(d) Estimates of stability parameters for seed yield per plot (kg) and harvest index (%)

Sr. No.	Genotype	Seed yield per plot (kg)			Harvest index (%)		
		\bar{X}	bi	S ² di	\bar{X}	bi	S ² di
1	Phule G-07102	2.05	1.17	0.01	37.13	1.64	40.16**
2	Phule G-0204-4	1.75	0.96	0.00	35.14	0.86	-4.16
3	Phule G-07101	1.86	1.09	0.02	36.21	0.94	19.25*
4	Phule G-09103	1.89	1.13	0.00	33.59	0.88	19.37*
5	Phule G-06102	1.70	1.06	0.02	38.45	0.85	9.68
6	Vijay (Ch)	1.70	0.69*	-0.02	34.23	0.94	36.45**
7	Vishal(Ch)	1.71	0.96	0.02	36.46	1.09	38.32**
8	Digvijay(Ch)	1.87	0.94	0.05*	38.37	0.80	-6.67
	Mean	1.81			36.19		
	S.E.±	0.07	0.14		2.06	0.43	

*,** = Significant at 5 and 1% level of significance, respectively

The genotype Vijay had higher mean performance (43.90) than population mean (43.22), non significant regression coefficient ($b_i = 1.07$) close to unity, non significant deviation from regression ($S^2_{di} = 0.68$), indicating its average stability for this trait.

6. Seed yield per plant (g)

Seed yield per plant ranged from 12.34 (Vijay) to 15.90 (Phule G-07102) with the population mean of 14.73 g.

The genotypes Phule G-09103 and Phule G-06102 exhibited significant deviation from regression ($S^2_{di} = 7.55$ and 14.93 respectively) values indicating unpredictable performance of these genotypes.

The genotypes Phule G-07102 and Digvijay had superior mean (15.90 g and 15.36 g, respectively) than the population mean of 14.73 g, non significant regression coefficient ($b_i = 1.00$ and 1.15, respectively), non-significant deviation from regression ($S^2_{di} = 3.44$ and 0.74, respectively) indicating their average stability for this character.

7. Seed yield per plot (kg)

The seed yield per plot ranged from 1.70 (Phule G-06102 and Vijay) to 2.05 (Phule G-07102) with a population mean of 1.81 kg.

The genotype Digvijay had significant value of S^2_{di} i.e. 0.05 indicating its unpredictability for this character.

The genotypes Phule G-07102, Phule G-07101 and Phule G-09103 had superior mean (2.05, 1.86 and 1.89 kg, respectively), non-significant regression coefficient ($b_i = 1.17$,

1.09 and 1.13, respectively) close to unity, non-significant deviation from regression ($S^2_{di} = 0.01, 0.02$ and 0.00 , respectively) value indicating their average stability for this trait.

8. Harvest index (%)

Harvest index ranged from 33.59 (Phule G-09103) to 38.45 (Phule G-06102) with the population mean of 36.19.

The genotypes Phule G-07102, Phule G-07101, Phule G-09103, Vijay and Vishal exhibited significant values of deviation from regression ($S^2_{di} = 40.16, 19.25, 19.37, 36.45$ and 38.32 , respectively) indicating their unpredictable performance for given character.

The genotypes Phule G-06102 and Digvijay had superior mean (38.45 and 38.37, respectively) than the population mean (36.19), non-significant regression coefficient ($b_i = 0.85$ and 0.80 , respectively), non-significant deviation from regression ($S^2_{di} = 9.68$ and -6.67), indicating their average stability for this trait.

5. DISCUSSION

As a consequence of latitudinal differences across a country and due to considerable variation in preceding crops and in the pattern of rainfall, the time of sowing varies in different regions. Therefore, genotypes performing well under different sowing time are necessary to have optimum yield level when sown at different time. Therefore, in this investigation studies on the performance of different genotypes at eight sowing dates were taken and the results have been discussed in this chapter under appropriate sub-headings.

5.1 **Response of chickpea genotypes to changing environments**

It is revealed that, the mean number of days required to 50 per cent flowering and physiological maturity were greatly influenced by different dates of sowing. The genotype Phule G-06102 recorded lower number of days for 50 per cent flowering i.e. 44.21 days and it was followed by the genotype Phule G-09103 (45.21 days) which was at par with Vijay (45.58 days). Lowest number of days to 50 per cent flowering were recorded by eighth sowing date (16th January). The genotype Phule G-09103 (93.63 days) was earliest to maturity among the all genotypes over the eight environments, followed by Phule G-06102 (102.88 days). The eighth sowing date (16th January) was earliest for maturity followed by seventh sowing date (1st January). Present study revealed that under very late sowing condition, all the varieties took more number of days to flower but less number of

days to mature. This was due to delayed flowering and early maturity due to delayed sowing; this reduced the sink filling period and ultimately resulted in lower seed yield. These findings are in conformity with findings of Tiwari and Tripathi (1995), Singh *et al.* (2004) in chickpea.

It is seen from the mean data presented for plant height that, the highest mean plant height was recorded in environment E₅. Genotype Phule G-07101 (48.19 cm) was the tallest among all genotypes considering the mean of the eight different environments. Similar results were obtained by Venkateswarelu (1998).

The maximum plant spread was recorded by the genotype Phule G-07101 (17.42 cm) over the environments which was at par with genotype Phule G-09103 (17.38 cm). Superior canopy was exhibited in E₃ environment. Similar results were obtained by Dahiya *et al.* (1993).

Maximum number of primary branches were recorded by the genotype Phule G-07102 (3.58) which was at par with genotype Phule G-07101 (3.45) over all the environments. Number of primary and secondary branches played important role in determining seed yield in chickpea (Tripathi and Singh, 1985). Maximum number of primary branches were recorded in environment E₁ followed by environment E₅.

Maximum number of secondary branches were recorded by the genotype Phule G-07101 (14.17) followed by the genotype Phule G-07102 (13.68) which was at par with the genotypes Phule G-06102 (13.67) and Phule G-09103 (13.58).

Maximum number of secondary branches were recorded in environment E₃ followed by environment E₄.

Pods per plant is an important yield component, reported to be significantly positively correlated with seed yield per plant and is affected by sowing time (Tripathi and Singh, 1985). Higher number of pods per plant was recorded in the genotype Phule G-09103 (47.70). The maximum number of pods were recorded in E₁ environment followed by E₃.

Seeds per pod also got affected due to different sowing period. The genotype Phule G-07102 (1.25) recorded highest number of seeds per pod over all eight environments. The maximum number of seeds per pod were recorded in E₁ environment. Similar results were recorded by Aziz and Rahman (1994) and Shrivastava *et al.* (1990).

Highest 100 seed weight recorded by the genotype Vishal (29.19 g) over all eight environments followed by the genotype Phule G-0204-4 (28.92 g). The highest 100 seed weight was recorded in third environment (E₃) followed by the second environment i.e. E₂. These findings are in conformity with the results obtained by Musa and Taha (1980) and Paikaray and Misra (1992) in chickpea.

From the results, it is observed that, the seed yield per plant and seed yield per plot were affected due to different sowing dates. Maximum seed yield per plant was produced by the genotype Phule G-07102 (15.90 g) followed by Phule G-09103 (15.63 g) over all eight environments. The maximum seed yield per plot was produced by the genotype Phule G-07102 (2.05 kg)

followed by genotype Phule G-09103 (1.89 kg). The maximum seed yield was recorded in E₅ environment and decreased drastically for E₆, E₇ and E₈ environments. This might be due to the availability of more congenial growing conditions of photoperiod, temperature etc., in optimum sowing environment i.e. E₅ as compared to other sowing dates. Similar results were obtained by Tripathi and Singh (1985), Paikaray and Misra (1992), Azin and Rahman (1994) and Singh *et al.* (2004).

The highest percentage of harvest index was recorded by the genotype Phule G-06102 (38.45 %) followed by the genotype Digvijay (38.37 %). For harvest index environment E₅ was found superior.

5.2 Genotype x environment interaction studies

Productivity of the population is the function of its adaptability. Significant achievement in crop production may be possible by breeding varieties for their stability for yield and yield components. Plant breeding is said to be the management of genetic variability. Plant breeders look for greater variability in crop plants for evolving strains which give maximum yield over the environments and show consistent performance. There is no direct measurement for genetic variability. However, the same can be inferred from the phenotype, which is a linear function of genotypes, environment and their interaction. Phenotype usually gets changed when a genotype is grown over varying environments. It has been shown that, interactions are widely present irrespective of nature of material. This sets limits to the expected progress. The interactions of genetic and non genetic

factors on phenotypic expression is called genotype x environment (G x E) interaction which is widely present and substantially contributes to the non realization of expected gain from selection (Comstock and Moll, 1963).

Stable genotypes are particularly of great importance in the country like India, where the crops are grown as a risk under varied environmental conditions.

G x E interaction certainly plays an important role in the evaluation and execution of breeding programmes. Allard and Bradshaw (1964) have critically reviewed this phenomenon and brought out its implications in applied plant breeding. Thus, G x E interaction is important in the expression of quantitative characters, which are controlled by polygenic systems and largely influenced by environmental fluctuations.

The process of identification of stable genotype is difficult because of G x E interaction. Although the plant breeders have observed genetic differences for adaptability, they have been unable to fully exploit these differences in breeding stable genotypes. This has been largely due to the problem of defining and measuring phenotypic stability. Various attempts were made to characterize the behaviours of genotypes in response to varying environments. Statistically approach of Finlay and Wilkinson (1963) has proved considerably useful to measure the phenotypic stability in the performance of genotype. They considered linear regression slope (b_i) as a measure of stability. This regression analysis proposed by Finlay and Wilkinson (1963) was improved upon by Eberhart and Russell

(1966). They introduced one more parameter, deviation from regression (S^2_{di}) which accounts for unpredictable irregularities in the response of genotypes to varying environments.

Mechanism of stability falls into four general categories.

1. Genetic heterogeneity
2. Yield component compensation
3. Stress tolerance and
4. Capacity to recover rapidly from stress

Various methods have been proposed for statistical analysis of G x E interaction from time to time. Growing a set of genotypes under a large number of environments and combined analysis is useful in assessing the G x E interaction and comparing different types of populations, but it did not go any further towards dynamic interpretation of the stability of individual genotypes. The most widely used approach in this respect is the regression technique in which G x E interaction component of variability partitioned into its linear and non linear portions for assessing the stability of genotypes over a range of environments. This is known as joint regression analysis. Many workers have contributed to the development of this approach, notable amongst them are, Finlay and Wilkinson (1963), Eberhart and Russell (1966), Freeman and Perkins (1971).

The information on the relative stability of the genotypes for different yield components is essential. The results obtained on different stability parameters estimated for the

different characters separately with a view to identify suitable conditions. They are discussed in brief below.

In the present investigation eight genotypes of chickpea were studied through genotype x environment interaction and stability analysis. The material was sown on eight different dates *viz.*, 1st October, 16th October, 1st November, 16th November, 1st December, 16 December, 1st January and 16 January, 2012 and stability of genotypes assessed by following Eberhart and Russell (1966) model.

5.3 Analysis of variance

The pooled analysis of variance for phenotypic stability as per Eberhart and Russel (1966) indicated that mean differences due to genotypes were statistically significant for the characters, 50 % flowering, days to maturity, plant height, primary branches per plant and 100 seed weight when tested against G x E interaction (Table 2). This observation suggested that, there is substantial variability in the genotypes evaluated. Similarly the mean differences among the genotypes were found to be significant for the characters, days to 50 per cent flowering, days to maturity, plant height, primary branches per plant, seeds per pod and 100 seed weight when tested against pooled deviation and pooled error.

The highly significant G x E interaction observed for the characters *viz.*, days to 50 % flowering, days to maturity, plant height, primary branches per plant, pods per plant, seed yield per plant and harvest index indicated that, genotypes showed varied response to different environment.

The significance of pooled deviation (non-linear) effects for the characters, days to 50 % flowering, days to maturity, plant height, pods per plant, seed yield per plant and harvest index confirmed the presence of G x E interaction for various traits.

Prakash Vijay (2005) also observed significant linear and non-linear components of G x E interactions for all the traits except primary and secondary branches and seed yield. Deshmukh *et al.* (1998), Sirohi *et al.* (2001), Rao and Rao (2004), Rao (2011) observed significant differences among genotype, environment and G x E interaction for all the studied characters in chickpea.

5.4 Stability parameters for individual characters

Finlay and Wilkinson (1963) considered linear regression slope (b_i) and emphasized the need of both ' b_i ' and deviation from regression ' S^2_{di} ' as measure of stability. Further Eberhart and Russell (1966) showed the need of both regression coefficient (linear) (b_i) and deviation from regression (S^2_{di}) (non linear) in evaluating genotypes for phenotypic stability by measuring G x E interactions. Bains and Gupta (1972) proposed that, the most stable genotype would be one with high mean performance and regression coefficient close to unity as well as mean squares approaching to zero. They further proposed that the genotype having mean yield less than the grand mean, be considered to be poorly adapted irrespective of their ' b_i ' and S^2_{di} ' values.

These points are considered for deciding stability of genotypes i.e. the genotypes with atleast mean performance statistically greater than population mean (also with in population mean \pm S.E.) and S^2_{di} low or non significant and (1) 'bi' approaching to unity or not significantly deviating from unity are regarded with general adaptability or average stability. (2) 'bi' significantly greater than unity is considered as better adaptable to rich or favourable environment (below average stability). (3) 'bi' significantly less than unity and or having lower magnitude than unity are considered as better adaptable to poor or unfavourable environment (above average stability).

The genotypes with significant S^2_{di} components are considered as highly unpredictable. In some cases relative 'bi' values were also considered to decide specific adaptability. Eberhart and Russell (1966) method was preferred because of its explicit nature.

The estimates of environmental indices for 12 characters (Table 3) under the present study showed that environment E_3 (1st November) was favourable for all the characters including seed yield (kg/ha) except days to 50 per cent flowering, days to maturity, primary branches per plant, seeds per pod and harvest index (%). Environment E_4 (16th November) was favourable for all the characters except days to 50 per cent flowering, days to maturity, primary branches per plant and seeds per pod. Environment E_1 (1st October) was favourable for all the characters except days to maturity, plant height, plant spread and harvest index (%). Environment E_2 (16th

October) was favourable for pods per plant, 100 seed weight and seed yield per plot. Environment E₅ (1st December) was favourable for all the characters except days to 50 per cent flowering and 100 seed weight. Environment E₆ was favourable for days to maturity, 100 seed weight and harvest index (%), environment E₇ (1st January) was favourable for days to 50 per cent flowering and days to maturity and environment E₈ (16th January) was favourable for days to 50 per cent flowering, days to maturity seeds per pod and harvest index (%).

In general environment E₃ (1st November) was most favourable for yield and yield contributing characters.

The stability parameters estimated for different traits are presented in Table 4(a) to 4(d) and Figure 1 to 11 which helped to identify genotypes with general and specific adaptability. Yield is the end product depends on holding certain morphological and physiological attributes and allowing others to vary, resulting in predictable G x E interaction for ultimate character the yield. The study of stability in yield components in this respect therefore, is of great importance. The results of the present investigation carried in this direction are discussed below.

5.4.1 Days to 50 % flowering

For this trait, the genotype Vijay recorded lower mean, non-significant regression coefficient (bi) close to unity, with non significant deviation from regression (S²di) exhibited average stability for this trait.

The linear and non-linear components of G x E interaction were found to be significant. Similar results were reported by Sharma and Maloo (1989), Baisakh and Nayak (1991), Khorgade *et al.* (2000), Rao and Rao (2004), Prakash Vijay (2005), Singh and Sandhu (2006) in their stability studies in chickpea.

5.4.2 Days to maturity

As the genotype Phule G-0204-4, Phule G-06102 and Vishal had lower mean values, non-significant regression coefficient (bi) close to unity and non-significant S²di indicated their wider adaptability when earliness is desired. The genotype Phule G-09103 recorded lower mean performance, regression coefficient significantly lower than unity and non-significant deviation from regression indicating their stability for poor environment i.e. above average stability.

The linear and non-linear component of G x E interaction were significant. Singh and Kumar (1993), Baisakh and Nayak (1991), Popalghat *et al.* (1998) observed similar results.

5.4.3 Plant height (cm)

For this trait, the genotypes Phule G-07101 and Phule G-09103 recorded superior mean, non-significant regression coefficient (bi) close to unity, with non-significant deviation from regression (S²di) exhibited average stability for this trait.

The linear and non linear components of G x E interaction were significant. Mehra *et al.* (1980), Khorgade *et al.* (2000) and Vijay Prakash (2005) observed similar results.

5.4.4 Primary branches per plant

As the genotypes Phule G-07102 and Phule G-06102 had higher mean values, non-significant regression coefficient close to unity with non-significant S^2_{di} indicated their average stability for this trait.

The genotypes Phule G-07101 and Vishal recorded higher mean values, regression coefficient significantly greater than unity and non-significant deviation from regression indicating their stability for favourable environment i.e. below average stability.

Singh *et al.* (1993), Chaudhary and Haque (2010) reported that both linear and non-linear components of the G x E interaction were significant for primary branches in the chickpea.

5.4.5 Pods per plant

For pods per plant, out of eight genotypes, four genotypes (Phule G-07101, Phule G-09103, Phule G-06102 and Vijay) had higher mean than the population mean, but three of them (Phule G-07101, Phule G-09103 and Phule G-06102) exhibited the significant S^2_{di} values indicating their unpredictability for this trait. The genotype Vijay had higher mean than population mean, bi close to unity and non-significant S^2_{di} indicating their average stability for this trait.

The G x E interaction and pooled deviation (non linear component) were found significant for this trait. Sharma and

Maloo (1989), Singh *et al.* (1991), Popalghat (1998), Singh and Sandhu (2006) recorded similar results in chickpea.

5.4.6 Seed yield per plant

For seed yield per plant, the genotypes Phule G-07102 and Digvijay had superior mean than the population mean, non-significant regression coefficient close to unity and non significant deviation from regression indicating their average stability for this trait. Mehra and Ramanujan (1979), Singh *et al.* (1991), Rao and Rao (2004), Malhotra *et al.* (2007), Chaudhary and Haque (2010) reported similar results in chickpea.

5.4.7 Seed yield per plot

The seed yield per plot ranged from 1.70 kg (Phule G-06102 and Vijay) to 2.05 kg (Phule G-07102) with a population mean of 1.81 kg. The genotypes Phule G-07102, Phule G-07101 and Phule G-09103 exhibited stability for all environment i.e. average stability.

Similar results were reported by Mehra *et al.* (1980), Singh and Mehra (1980), Deshmukh *et al.* (1998), Sood *et al.* (2000), Vijay Prakash (2005) in their stability studies with chickpea.

5.4.8 Harvest index

The genotypes Phule G-06102 and Digvijay had higher mean performance (38.44 and 38.37 %, respectively) than the population mean (36.19 %), non-significant regression coefficient ($b_i = 0.85$ and 0.80 , respectively), non significant deviation from regression ($S^2_{di} = 9.68$ and -6.67 , respectively), indicating their average stability i.e. suitable for all

environmental conditions. Similar results were obtained by Singh and Singh (1989).

Table 5. Nature of stability of chickpea genotypes under different environments

Sr. No.	Character	Genotypes showing stability		
		Average stability (suitable for all environments)	Above average stability ($b_i < 1$) (suitable for poor environment)	Below average stability ($b_i > 1$) (suitable for rich environment)
1	Days to 50% flowering	Vijay	--	
2	Days to maturity	Phule G-0204-4, Phule G-06102, Vishal	Phule G-09103	--
3	Plant height (cm)	Phule G-07101, Phule G-09103	--	--
4	Primary branches per plant (No.)	Phule G-07102, Phule G-06102	--	Phule G-07101, Vishal
5	Pods per plant (No.)	Vijay	--	
6	Seed yield per plant (g)	Phule G-07102, Digvijay	--	--
7	Seed yield per plot (kg)	Phule G-07102, Phule G-07101, Phule G-09103,		
8	Harvest index (%)	Phule G-06102, Digvijay	--	--

6. SUMMARY AND CONCLUSIONS

The present studies entitled “Genotype x environment interaction studies in chickpea (*Cicer arietinum* L.)” were carried out at Pulses Improvement Project, Mahatma Phule Krishi Vidyapeeth, Rahuri with the objectives of determining the suitable genotypes for different environments under varied sowing conditions. The field experiment was conducted to evaluate 8 genotypes of chickpea under eight sowing dates viz., E₁ (1st October, 2011), E₂ (16th October, 2011), E₃ (1st November, 2011), E₄ (16th November, 2011), E₅ (1st December, 2011), E₆ (16th December, 2011), E₇ (1st January, 2012) and E₈ (16th January, 2012) at Pulses Improvement Project, M.P.K.V., Rahuri (M.S.) during 2011-12 in a Randomized Block Design with three replications. The data from each of these eight environments was collected on days to 50 % flowering, days to maturity, plant height (cm), plant spread (cm), primary branches per plant (No.), secondary branches per plant (No.), pods per plant (No.), seeds per pod (No.), 100 seed weight (g), seed yield per plant (g), seed yield per plot (kg) and harvest index (%). Stability analysis was done following the approach given by Eberhart and Russel (1966).

6.1 Response of genotypes of changing environments

Mean performance of different genotypes over eight environments indicated that the genotypes Phule G-06102, Phule G-09103 and Vijay were the earliest for days to 50 % flowering.

Mean performance of different genotypes over eight environments indicated that the genotypes Phule G-09103 and Phule G-06102 were the earliest for days to maturity.

The genotypes Phule G-07101 and Phule G-07102 for plant height and Phule G-07101 and Phule G-09103 for plant spread were observed promising.

The genotypes Phule G-07102, Phule G-07101 and Phule G-06102 were found to be promising for primary branches per plant. While the genotypes Phule G-07101, Phule G-07102, Phule G-06102 and Phule G-09103 produced maximum number of secondary branches per plant.

The genotypes Phule G-09103 and Phule G-06102 had shown promising for pods per plant and the genotypes Phule G-07102, Vishal, Phule G-07101 and Digvijay were observed promising for seeds per pod.

The genotypes Vishal and Phule G-0204-4 for 100 seed weight, the genotypes Phule G-07102, Phule G-09103, Phule G-06102 and Digvijay for seed yield per plant, and genotypes Phule G-07102, Phule G-07101 and Phule G-09103 were observed promising for seed yield per plot.

Mean performance of different genotypes over eight environments indicated that the genotypes Phule G-06102 and Digvijay were observed promising for harvest index (%).

6.2 Pooled analysis of variance

Pooled analysis of variance showed significant genotypic variances for days to 50 % flowering, days to maturity, plant height, primary branches per plant, 100 seed weight and seed

yield per plot, when tested against G x E interaction. Environmental variance was significant for all the characters when tested against G x E interaction.

Linear components of G x E interaction was found significant for the characters viz., days to maturity, primary branches per plant, seed per pod and 100 seed weight when tested against pooled deviation and pooled error whereas pooled deviation (non linear component) was found significant for the traits viz., days to 50 % flowering, days to maturity, plant height, pods per plant, seed yield per plant, seed yield per plot and harvest index.

6.3 Estimation of environmental index

The environment E₁ (1st October) was found to be favourable for all the characters except days to maturity, plant height, plant spread and harvest index (%). Environment E₂ (16th October) was favourable for pods per plant, 100 seed weight and seed yield per plot. Environment E₃ (1st November) was favourable for all the characters except days to 50 per cent flowering, days to maturity, primary branches per plant, seeds per pod and harvest index (%). Environment E₄ (16th November) was favourable for all the characters except days to 50 per cent flowering, days to maturity, primary branches per plant and seeds per pod, environment E₅ (1st December) was favourable for all the characters except days to 50 per cent flowering and 100 seed weight. Environment E₆ (16th December) was favourable for characters viz., days to maturity, 100 seed weight and harvest index (%), environment E₇ (1st January) was favourable for days to 50 per cent flowering and days to maturity, while environment E₈ (16th

January) was favourable for days to 50 per cent flowering, days to maturity, seeds per pod and harvest index (%).

An environments E₃ (1st November) was found to be most favourable for yield and yield contributing characters.

6.4 G x E interaction and stability parameters

- i. Genotype x environmental interactions was highly significant for all the characters except plant spread, secondary branches per plant, pods per plant, seed yield per plant and harvest index (%).
- ii. Non linear component of G x E interactions was highly significant for all the characters expect plant spread, secondary branches per plant, seeds per pod and 100 seed weight.

The genotypes showing wider adaptability for different characters studied are :

The genotypes Vijay recorded average stability for days to 50 % flowering. The genotypes Phule G-0204-4, Phule G-06102 and Vishal exhibited average stability for days to maturity. The genotypes Phule G-07101 and Phule G-09103 recorded average stability for plant height (cm). The genotypes Phule G-07102 and Phule G-06102 showed average stability for number of primary branches per plant. The genotype Vijay found stable for pods per plant. The genotypes Phule G-07102 and Digvijay recorded average stability for seed yield per plant (g). The genotypes Phule G-07102, Phule G-07101 and Phule G-09103 showed average stability for seed yield per plot (kg). The genotypes Phule G-06102 and Digvijay showed average stability for harvest index.

The genotype Phule G-09103 gave above average stability for days to maturity.

The genotypes Phule G-07101 and Vishal showed below average stability for number of primary branches per plant.

None of the genotype was found stable for all the characters under study.

6.5 Conclusions

1. Optimum sowing time i.e. an environment E₃ i.e. sowing of chickpea on 1st November was most favourable for expression of most of the characters including grain yield.
2. Non linear component of G x E interactions were found significant for all the characters under study except plant spread, secondary branches per plant, seeds per pod and 100 seed weight.
3. None of the genotype was found average stable for all the characters.
4. The studied genotypes showed differential stability performance for all the characters.
5. Considering the mean yield performance, the genotypes Phule G-07101 (3546 kg/ha) (E₁), Phule G-07102 (3537 kg/ha) (E₂), Phule G-09103 (3805 kg/ha) (E₃), Digvijay (3996 kg/ha) (E₄), Phule G-07102 (3190 kg/ha) (E₅), Vishal (2162 kg/ha) (E₆), Phule G-07102 (2273 kg/ha) (E₇), Digvijay (1657 kg/ha) (E₈) would be much suitable to grow under different sown conditions i.e. on 1st October, 16th October, 1st November, 16th November, 1st December, 16th December, 1st January and 16th January, respectively.

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*** Originals not seen**

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A candidate for the degree

of

MASTER OF SCIENCE (AGRICULTURE)

in

GENETICS AND PLANT BREEDING

2013

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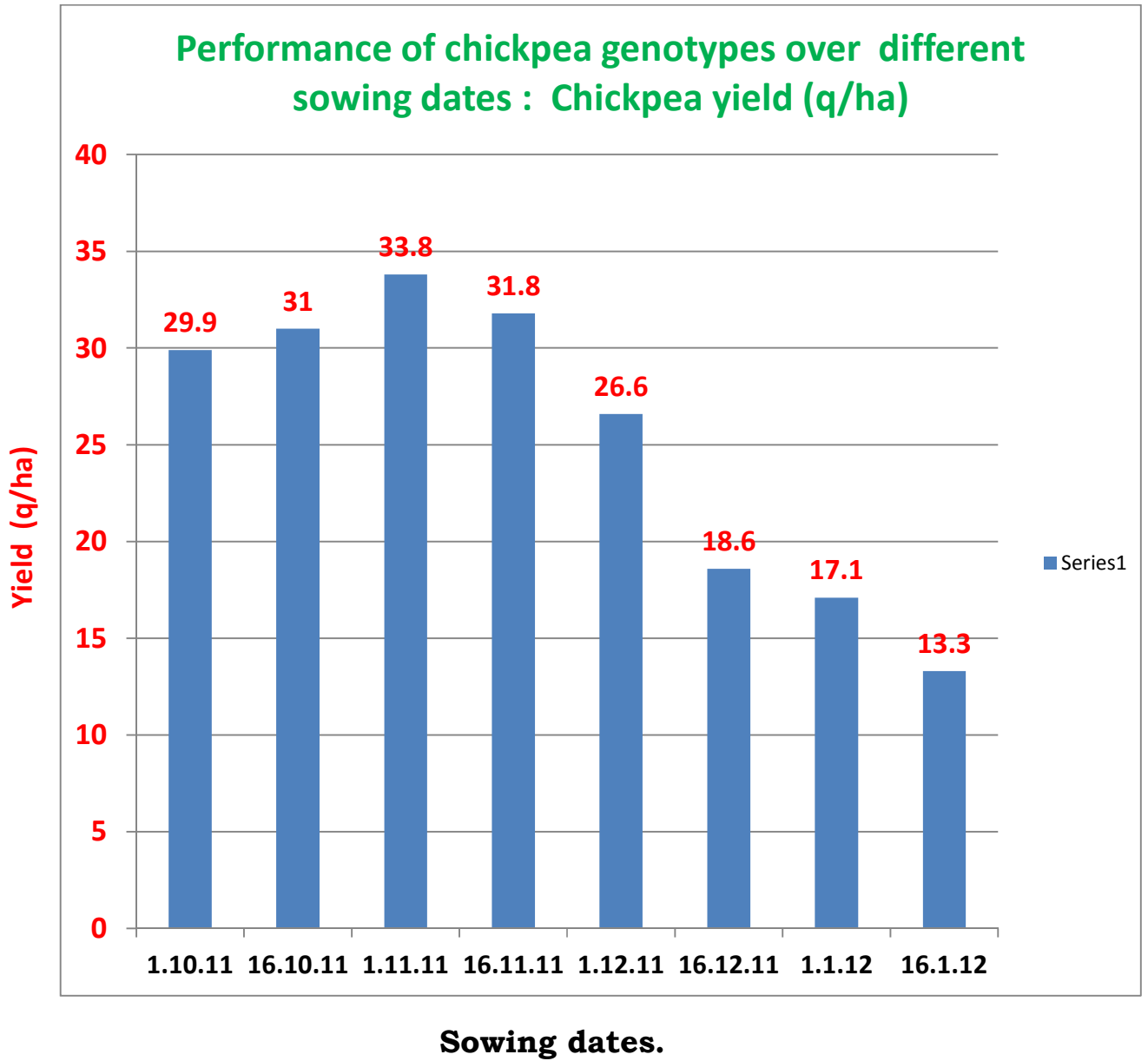


Figure 1. Performance of chickpea genotypes over different sowing dates : Chickpea yield (q/ha)

Mean performance of chickpea genotypes over different sowing dates (from 1.10.11 to 16.1.12)
Chickpea yield (q/ha)

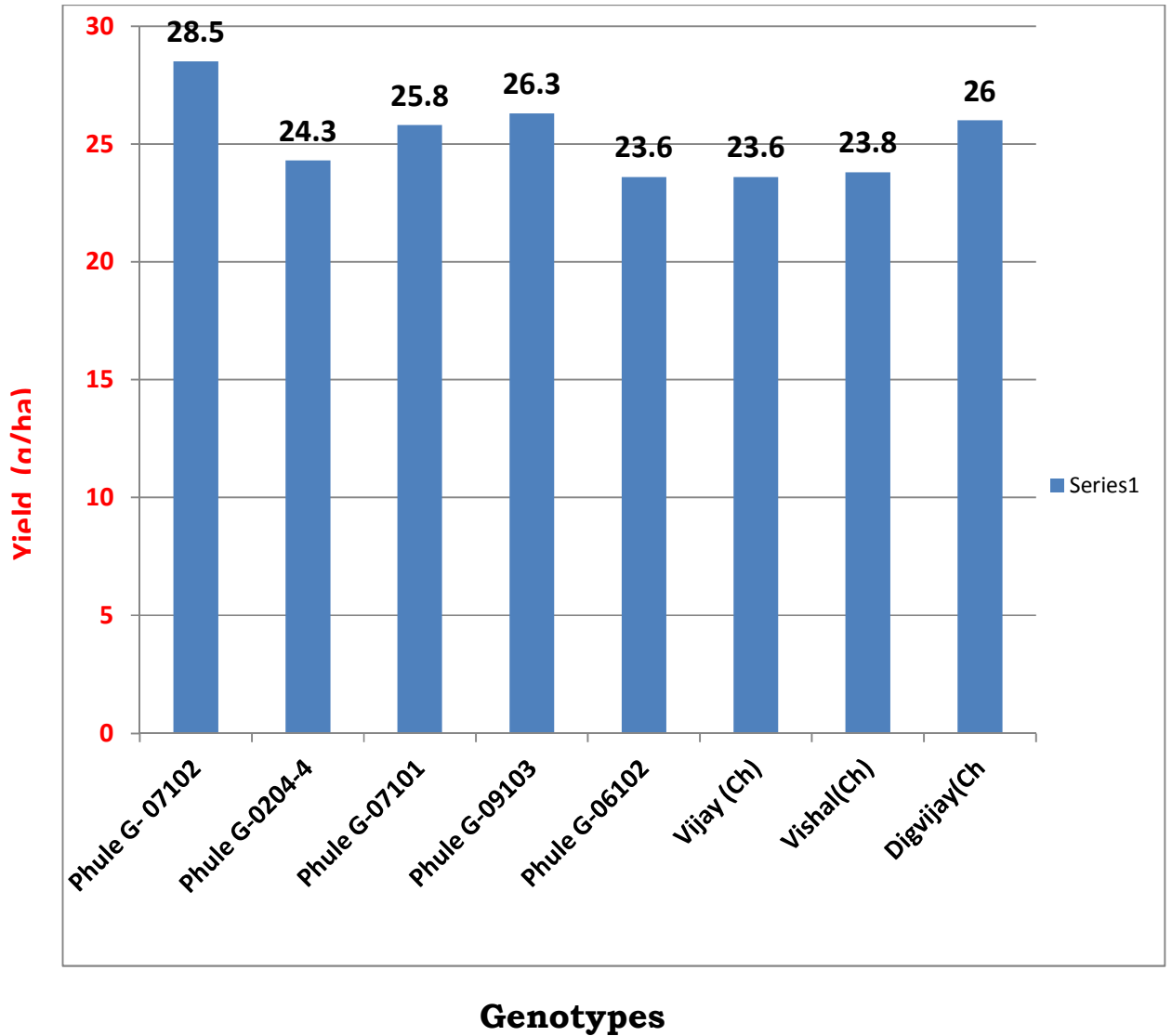


Figure. 2. Mean performance of chickpea genotypes over different sowing dates (from 1.10.11 to 16.1.12) chickpea yield (q/ha)

Performance of chickpea genotypes over different sowing dates
Chickpea yield (q/ha)

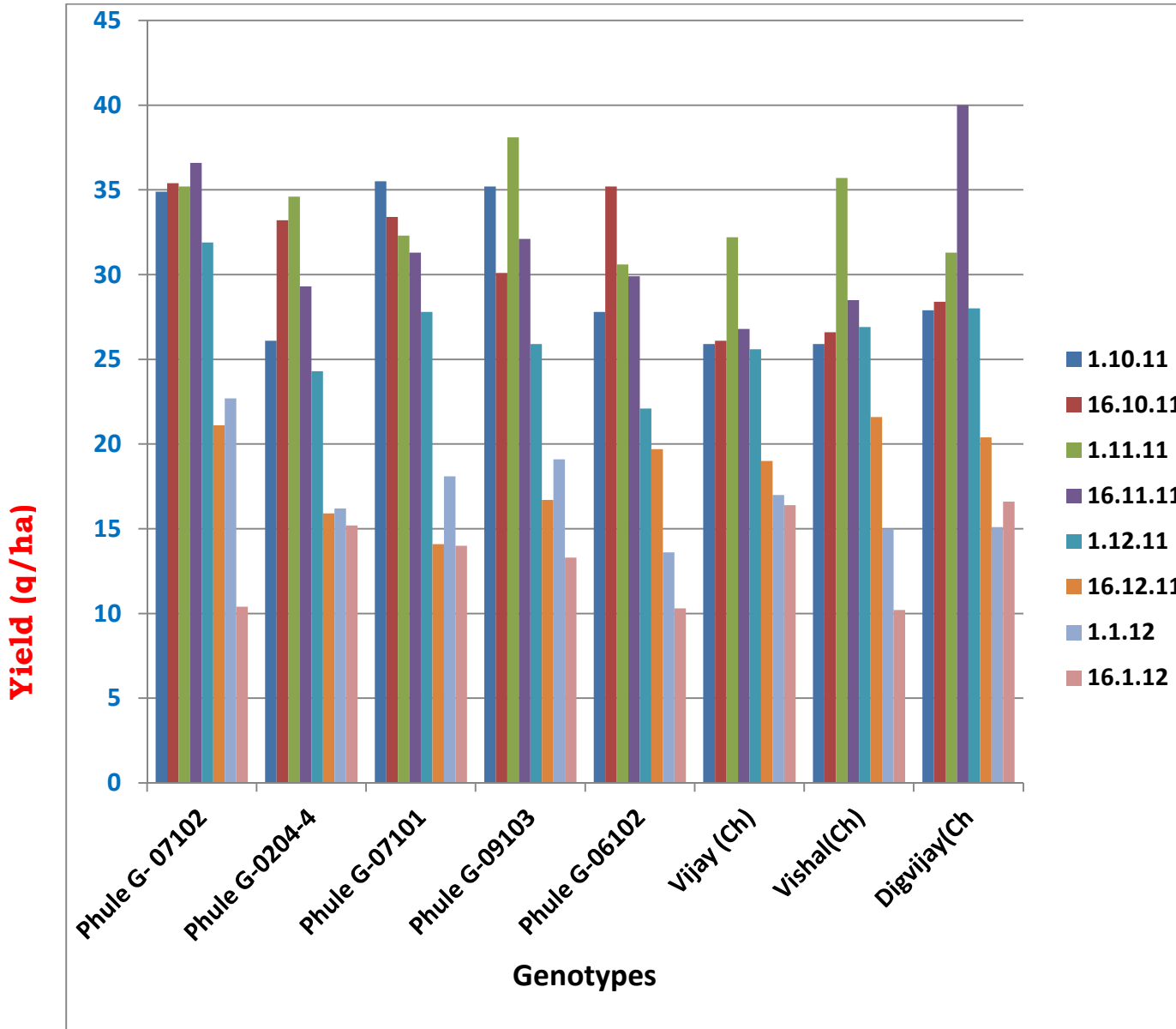
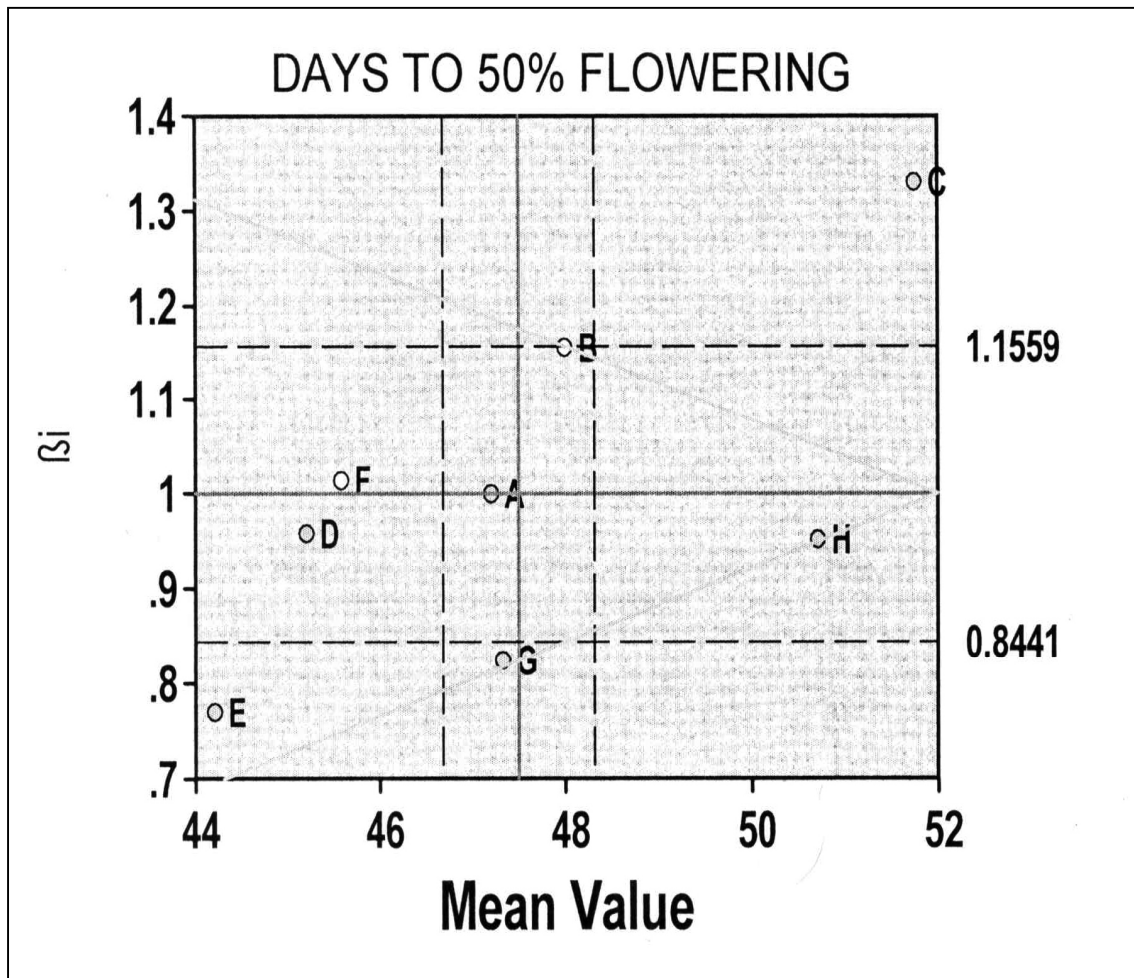


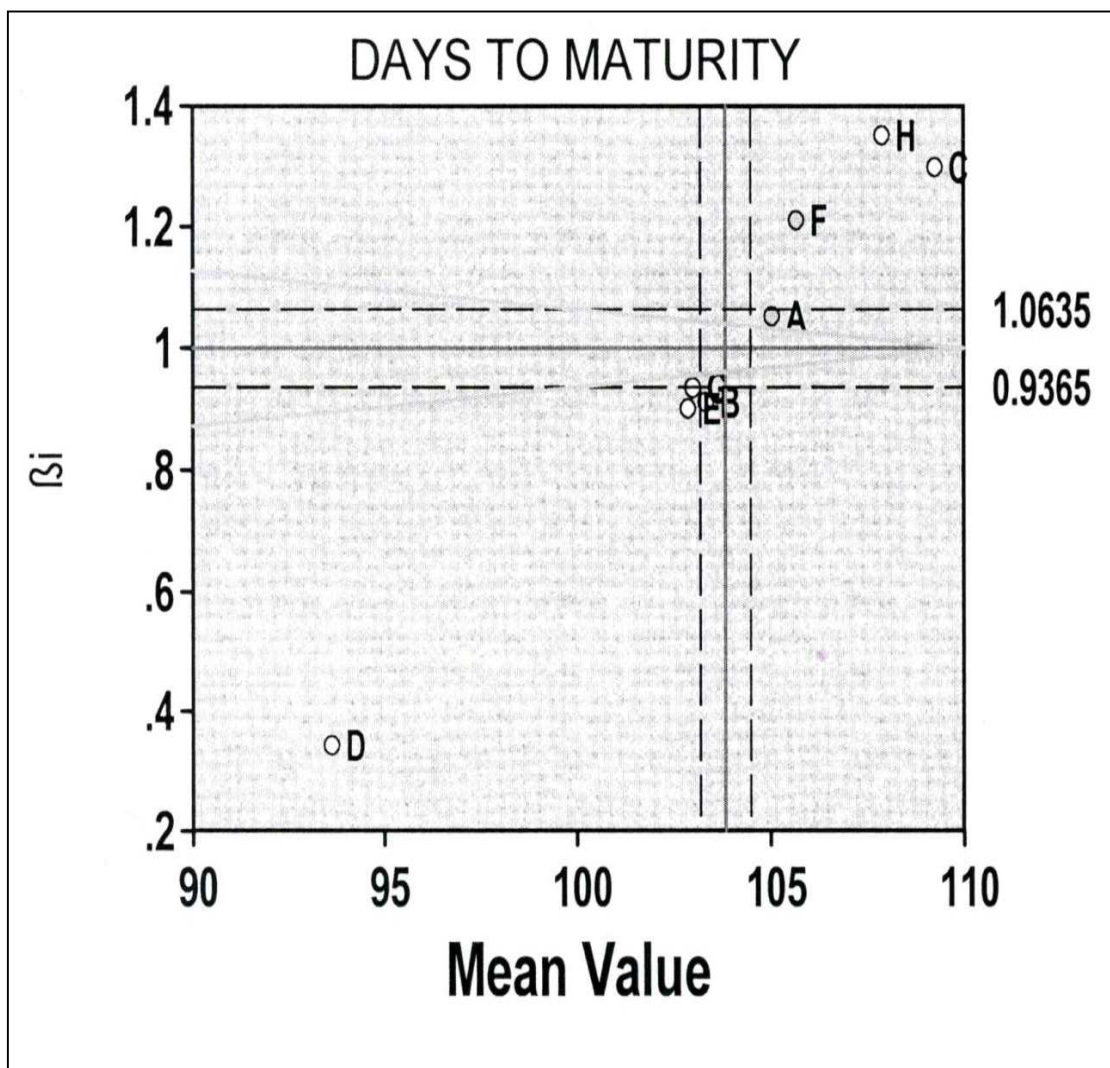
Figure. 3. Performance of chickpea genotypes over different sowing dates chickpea yield (q/ha)



Legends of figures:

A	Phule G-07102	E	Phule G-06102
B	Phule G-0204-4	F	Vijay(check)
C	Phule G-07101	G	Vishal(check)
D	Phule G-09103	H	Digvijay(check)

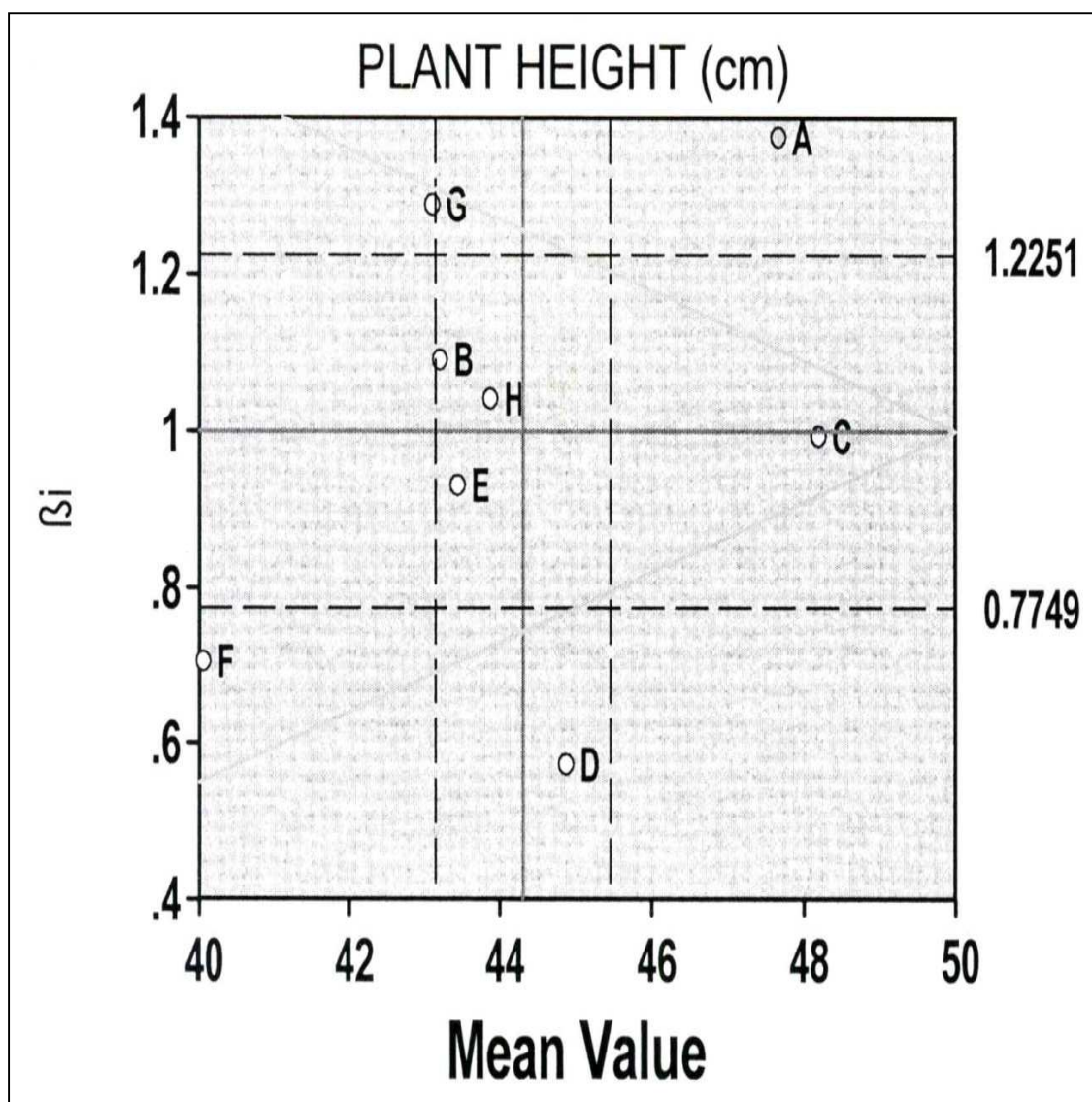
Fig 4 : Relation of days to 50 % flowering with stability



Legends of figures:

A	Phule G-07102	E	Phule G-06102
B	Phule G-0204-4	F	Vijay(check)
C	Phule G-07101	G	Vishal(check)
D	Phule G-09103	H	Digvijay(check)

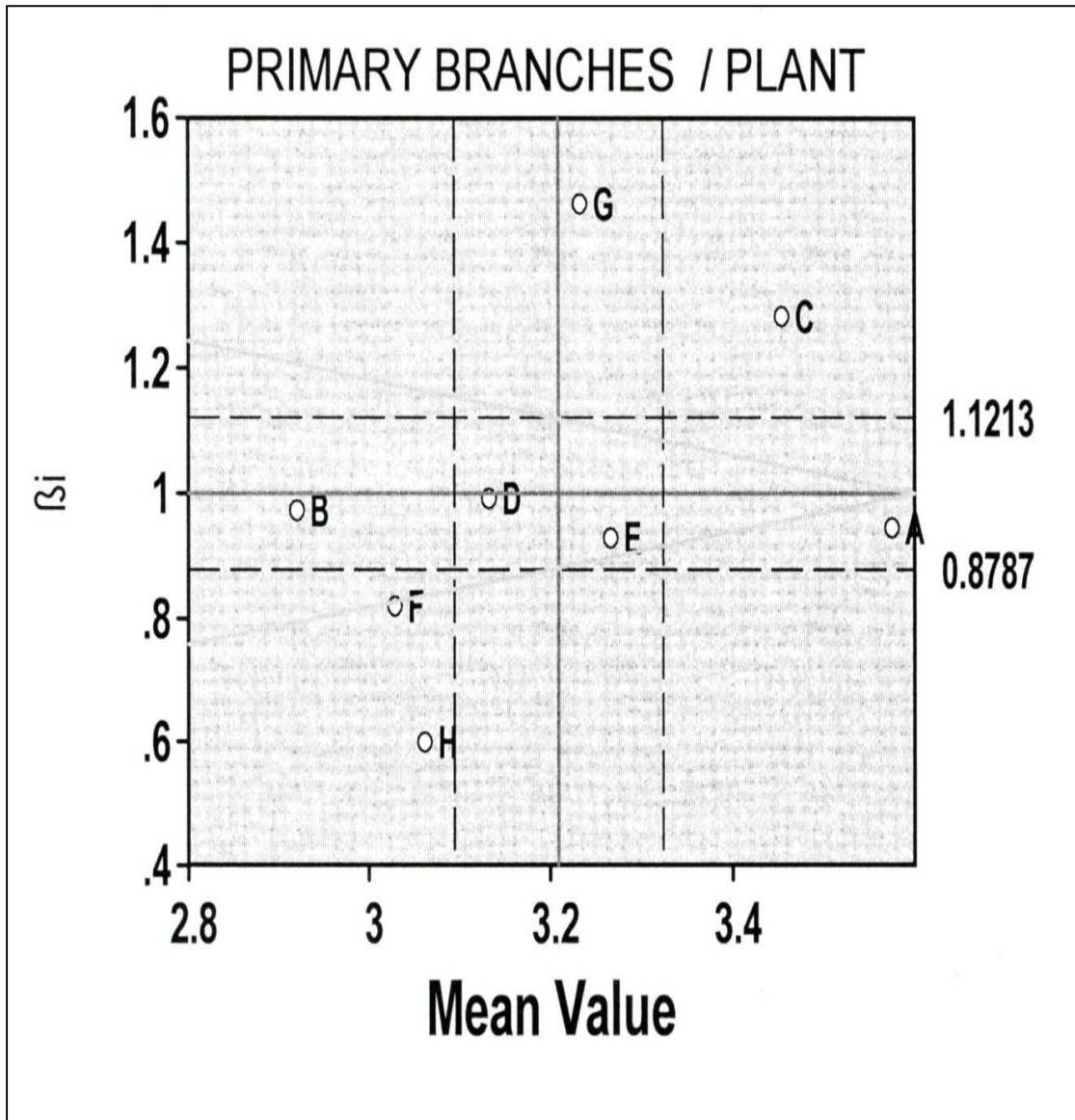
Fig 5 : Relation of days to maturity with stability



Legends of figures:

A	Phule G-07102	E	Phule G-06102
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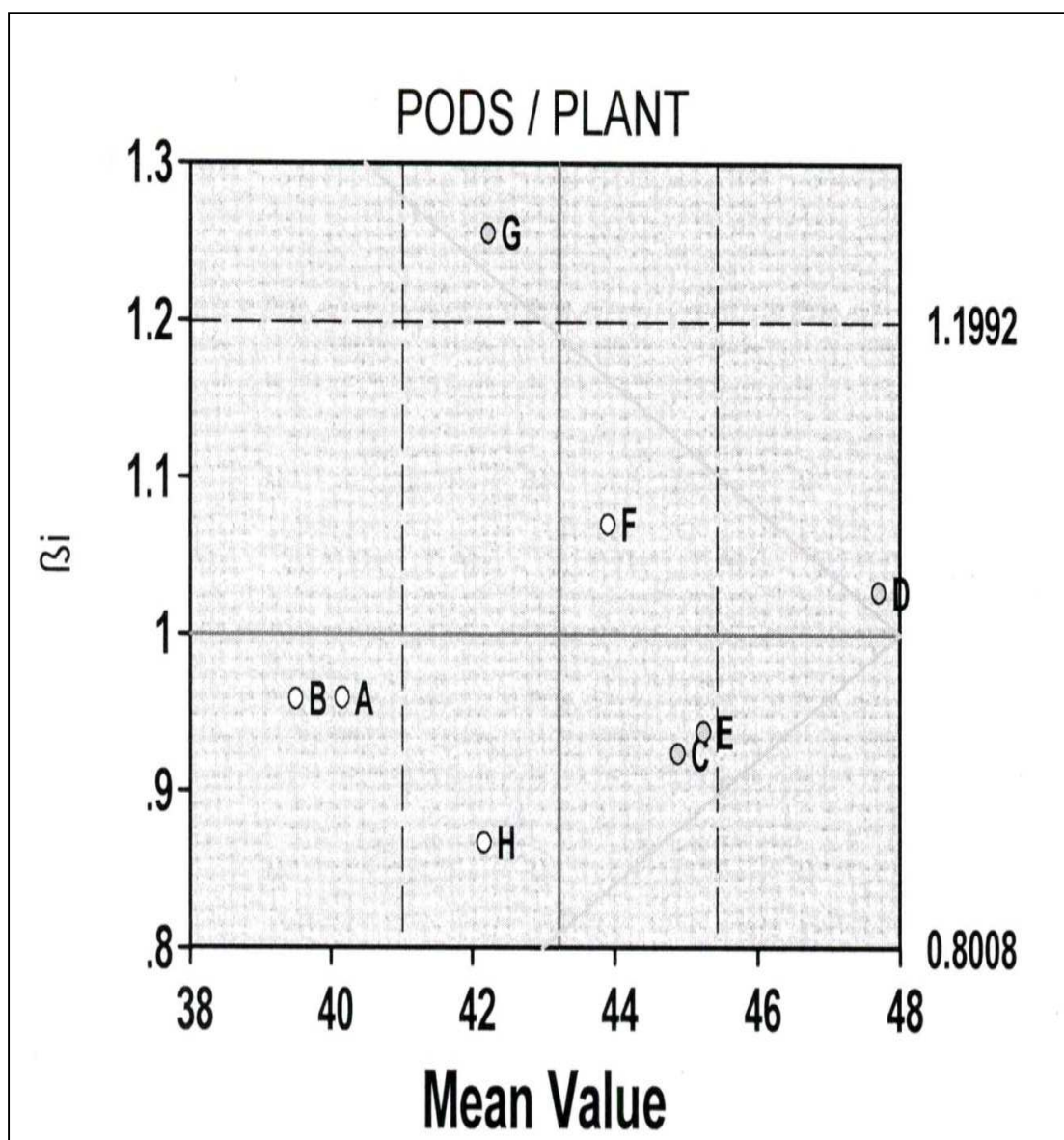
Fig 6 :Relation of plant height with stability



Legends of figures:

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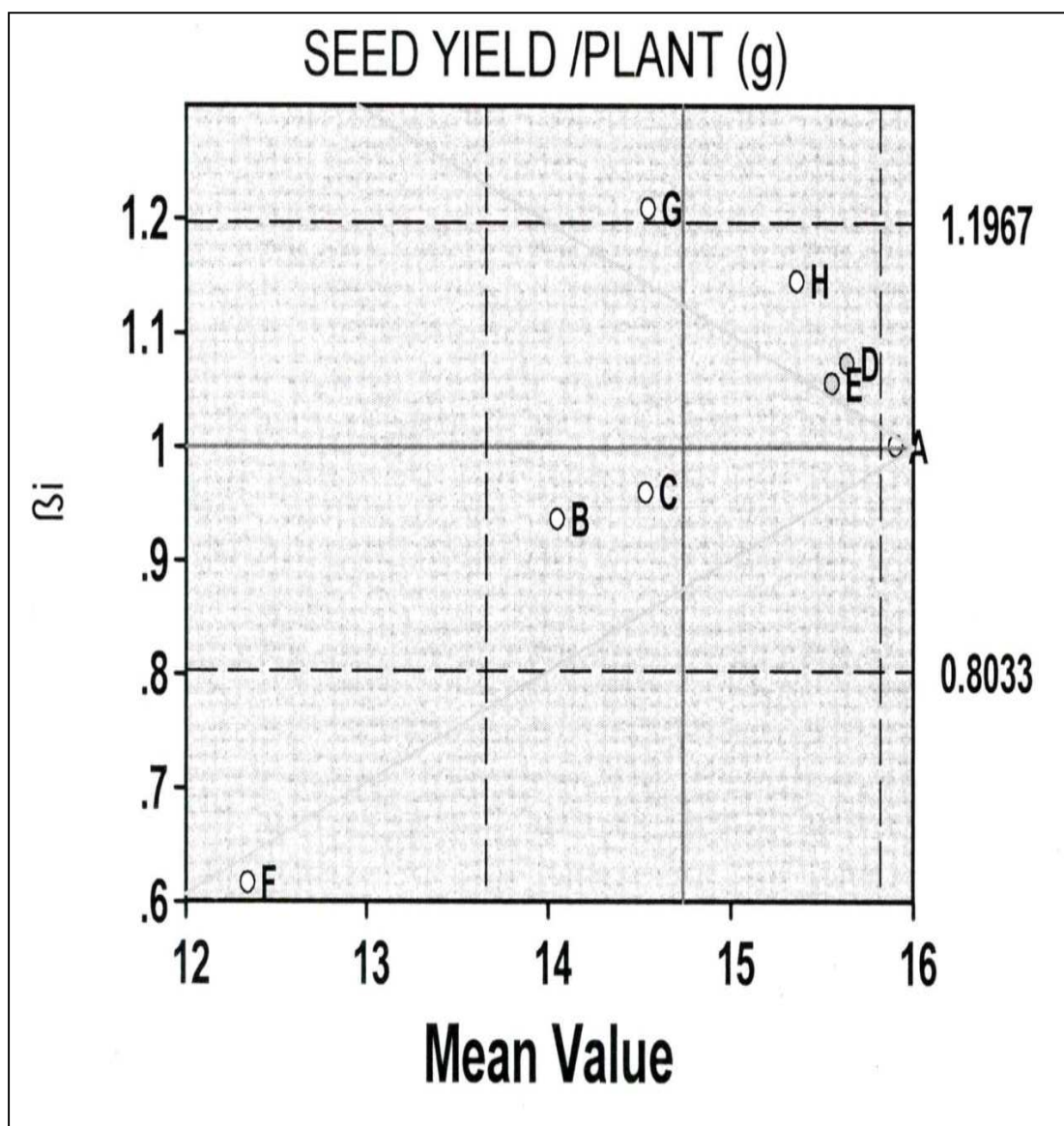
Fig 7: Relation of primary branches per plant with stability



Legends of figures:

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D	Phule G-09103	H	Digvijay(check)

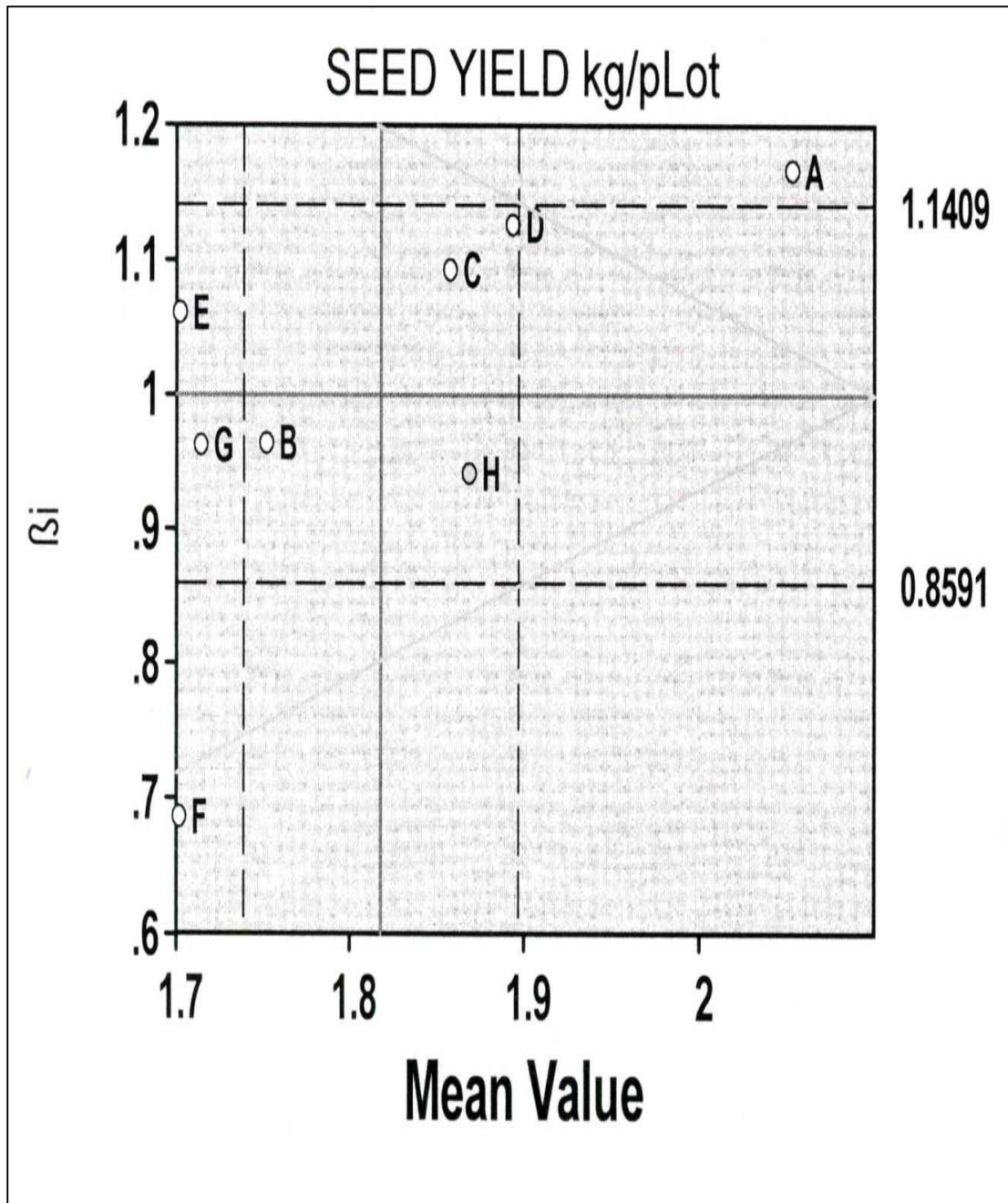
Fig 8 :Relation of pods per plant with stability



Legends of figures:

A	Phule G-07102	E	Phule G-06102
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C	Phule G-07101	G	Vishal(check)
D	Phule G-09103	H	Digvijay(check)

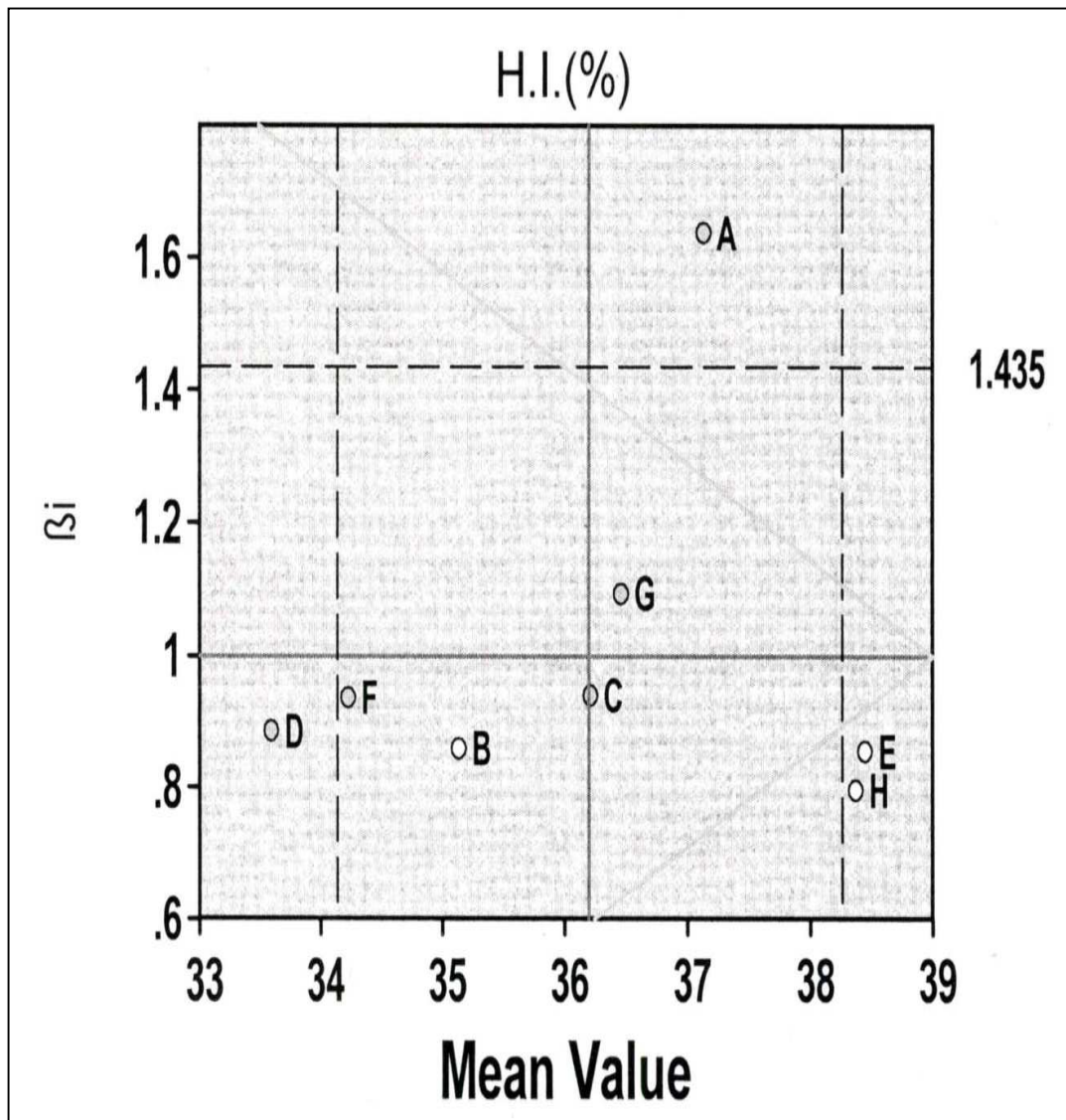
Fig 9 : Relation of seed yield per plant (g) with stability



Legends of figures:

A	Phule G-07102	E	Phule G-06102
B	Phule G-0204-4	F	Vijay(check)
C	Phule G-07101	G	Vishal(check)
D	Phule G-09103	H	Digvijay(check)

Fig 10 : Relation of seed yield per plot (kg) with stability



Legends of figures:

A	Phule G-07102	E	Phule G-06102
B	Phule G-0204-4	F	Vijay(check)
C	Phule G-07101	G	Vishal(check)
D	Phule G-09103	H	Digvijay(check)

Fig 11 : Relation of harvest index (%) with stability